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Simulation and Human–Systems Technologies ■

4 SIMULATION AND HUMAN–SYSTEMS TECHNOLOGIES

Advanced Distributed Simulation: Decade in Review and Future Challenges

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ABSTRACT

As networking technologies and computer hardware performance advanced in the late 1980s, distributed simulation became a feasible way to provide military training at distant, sometimes remote locations. Efforts were made to advance the technologies surrounding distributed simulation, from networking protocols to the representation of the battlespace and its entities. The following SSC San Diego efforts supported advances in distributed-simulation-related areas throughout the 1990s and continue to support the next generation of 21st century simulation systems.

INTRODUCTION

The 1990s saw SSC San Diego continue to be the leader in Advanced Distributed Simulation (ADS) technologies for the U.S. Navy. SSC San Diego simulations supported worldwide users in training, assessment, analysis, testing, experimentation, and technology research. SSC San Diego supported network-centric simulations and joint-service objectives. The Center defined and advanced two major simulation protocol threads: the Distributed Interactive Simulation (DIS) protocol and the Aggregate-Level Simulation Protocol (ALSP). These protocols were the genesis of the latest and current Defense Modeling and Simulation Office's (DMSO's) standard: the High-Level Architecture (HLA) Run-Time Infrastructure (RTI).

SSC San Diego's simulation efforts supported a variety of venues that tested and experimented with the protocols over large distributed networks, and developed capabilities that supported the trend from service-specific to joint-service exercises. The major advanced distributed simulation efforts during the decade were provided by the following SSC San Diego simulation systems: the Research, Evaluation, and System Analysis (RESA) Simulation; the Marine Corps' Marine Air Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS); the Synthetic Theater of War (STOW) Advanced Concepts Technology Demonstration (ACTD); and the Joint Simulation System–Maritime (JSIMS–M). These simulations supported venues that included the construction of Joint Federation training exercises supported by RESA and MTWS through their development of ALSP interfaces. The support included the advent of ACTDs, with STOW emerging as the first ACTD, and further support was provided to a variety of subsequent ACTDs (e.g., Joint Countermine Operational Simulation (JCOS), Extending the Littoral Battlespace (ELB), and Joint Medical Operations–Telemedicine (JMO–T)) using DIS and eventually RTI protocols. Additional support has continued through experimentation in Fleet Battle Experiments (FBEs) and Joint Experimentation (JE) events. SSC San Diego simulations will continue to support these venues by improving existing simulations and by developing next-generation advanced distributed simulation systems that support joint-service operations, such as JSIMS–M.

The following section will briefly describe support provided by these SSC San Diego simulations, including some specific events, followed by the final section on future potential.

ADVANCED DISTRIBUTED SIMULATION (1990s)

As networking technologies and computer hardware performance advanced in the late 1980s, distributed simulation became a feasible way to provide military training at distant, sometimes remote locations. Efforts were made to advance the technologies surrounding distributed simulation, from networking protocols to the representation of the battlespace and its entities. The following SSC San Diego efforts supported advances in distributed-simulation-related areas throughout the 1990s and continue to support the next generation of 21^{st} century simulation systems.

Research, Evaluation, and System Analysis (RESA)

The RESA simulation system has a 23-year history and has evolved to meet the Navy's ever-expanding needs for a constructive simulation system that focuses on theater-level naval operations. The capabilities of RESA to realistically simulate the naval warfare environment, generate streams of realistic scenario-driven data to C^4I support systems, and to interface with other models/analysis tools have led to its application in a wide variety of projects.

Throughout the 1990s and continuing today, the RESA system has provided the Navy with a stand-alone system to support a wide variety of applications, including systems analysis, concept of operations development, advanced technology assessment, and C^4I system simulation. In the early 1990s, the reliability of the system and its flexibility in adapting to the Navy's changing needs, led to its evolution into today's RESA system, fulfilling dual missions in the areas of joint-forces training and joint and naval research, development, test, and evaluation (RDT&E).

To fulfill the Navy's need for a naval training system within the U.S. Joint Forces Command (JFCOM) Joint Training Confederation (JTC), the RESA team aided in the design of the ALSP. Developed specifically for the JTC, the ALSP interface allowed the sharing of simulation information with other service constructive simulations including the Army's Corps Battle Simulation (CBS) and the Air Force's Air Warfare Simulation System (AWSIMS). Today, the ALSP JTC integrates a wide variety of models and simulations supporting joint forces and allied training at the command level, worldwide, in exercises such as Unified Endeavor at the U.S. Atlantic Command (USACOM) and Ulchi Focus Lens at the Combined Forces command in South Korea. In the mid-1990s, the Marine Corps MAGTF MTWS system, developed and supported by SSC San Diego, was integrated into the JTC, thus completing the inclusion of all joint-service warfare areas.

Concurrent with providing the Navy's system in the JTC, SSC San Diego was selected to participate in the design and development of the DIS protocols for the integration of joint-service constructive simulations, virtual models, and live-range entities. This task was accomplished in support of joint-service assessment, analysis, testing, experimentation, and technology research. The RESA system became one of the Navy's first DIS-compliant simulations, and it has been used in a variety of joint-service and allied studies sponsored by DMSO, the Defense Advanced Research Projects

Agency (DARPA), the Ballistic Missile Defense Office (BMDO), the Office of the Secretary of Defense (OSD), and the Office of the Chief of Naval Operations (OPNAV). As the naval component in joint-service distributed projects, the RESA system has contributed to developing and testing command and control structures, operational plans, concepts of operation, and analyses. Areas of study include analyses of the Cooperative Engagement Capability (CEC), the next-generation aircraft carrier (CVNX), the Zumwalt-class 21st century destroyer (DD 21), and Joint Theater Missile Defense Attack Operations.

The extensive simulation capabilities of RESA, coupled with its record of reliable operations and transportability, have not only resulted in its use at a number of facilities for a variety of applications but have also led to its use in providing the core simulation infrastructure for other simulation developments such as the CounterMeasures Analysis Simulator (CMAS), Space and Electronic Warfare Simulation (SEWSIM), the Air Warfare Simulation System (AWSIMS), and the Battleforce Electro-Magnetic Imagery (EMI) Evaluation System (BEES).

The history of the RESA system not only lends merit to SSC San Diego's current reputation as a prominent leader in the design and development of distributed simulation systems, but also attests to SSC San Diego's status as a true pioneer in the world of modeling and simulation (M&S).

Marine Air Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS)

The MAGTF MTWS system, developed and supported by SSC San Diego, is a constructive simulation that provides exercise control services and tactical combat simulation capabilities to support tactical training exercises. Development of MTWS began in 1989. In 1995, the system was formally accepted by the Marine Corps as the replacement for the Tactical Warfare Simulation, Evaluation, and Analysis System (TWSEAS). MTWS supports all aspects of MAGTF combat operations, including air, ground, maritime, and amphibious operations, in a multisided environment to permit creation of the widest possible range of tactical conditions to challenge staff decision-making. The MTWS Analysis Review System (MARS) component provides the training audience with exercise review, analysis, and replay capabilities.

In the mid-1990s, the MAGTF MTWS system was integrated into the JTC via an ALSP interface. The MTWS ALSP interface supports a wide variety of air, ground, and surface interactions with other ALSP confederates. In a confederation with multiple MTWS actors, the interface supports ground-to-ground interactions; this is unique within the ALSP confederation. Besides the ALSP interface for supporting interoperation with the JTC, a DIS interface was developed to support real-time simulation interoperability with other DIS simulations, such as the Joint Semi-Automated Forces (JSAF) simulation. MTWS was used in conjunction with JSAF to support modeling and simulation for the ELB ACTD in 1999. MTWS also interfaces to C4I systems such as the Global Command and Control System (GCCS), providing scenario-based track update information via over-the-horizon (OTH)-GOLD messages, and a variety of Intel-related U.S. Message Text Format (USMTF) messages.

In its original configuration, MTWS operated as a set of simulation applications distributed across a networked suite of TAC-4 HP processors, connected via a central hub to a second network of TAC-3/4 user stations.

The simulation applications—ground combat, air operations, ship-to-shore, logistics, etc.—can be distributed over as many as six host processors, or all can run on a single host processor, at the user's option, depending on the size, scope, and intensity of the scenario. The user stations provide a tactical map display supporting both vector and raster map images, as well as various exercise definition, control, and reporting functions. In early 2001, the TAC-3/4 user stations were replaced by PC/Win32 workstations, which provide enhanced functionality with increased performance.

As the TAC-4 hardware is phased out, and the functionality and capacity of the system continue to increase, MTWS is evaluating the benefits of migrating the remainder of the system to another platform(s). This includes migration to more platform-independent development tools (e.g., compiler, etc.). Also, MTWS expects to introduce a Web-based After-Action Review (AAR) system this year, which will significantly enhance the potential to support remote training.

Synthetic Theater of War (STOW)/Joint Semi-Automated Forces (JSAF)

STOW, developed in the mid-1990s, was based on the culmination of several advanced research projects sponsored by DARPA in the early 1990s. These projects spearheaded efforts to advance technologies for the next generation of computer-generated forces and distributed simulation; specifically in areas of aggregation/deaggregation, high vs. engineering fidelity, scalability (handling large numbers of distributed objects), and DIS protocols. STOW Europe (STOW-E) exploited these technologies by integrating constructive, virtual, and live simulation in a major joint exercise in 1994 called Unified Endeavor (Reforger). The exercise was held primarily in Germany but was distributed to sites in England and the U.S. In 1995, STOW transitioned to an ACTD.

STOW evolved from Simulation Networking (SIMNET) protocols to DIS protocols to DMSO's standard HLA RTI protocols. In 1997, STOW became the largest federation ever to use the newly mandated HLA RTI protocols. The main product that the STOW ACTD transitioned was a joint distributed simulation capability called Joint Semi-Automated Forces (JSAF).

Currently, JSAF primarily supports the JE events for JFCOM at the Joint Training and Analysis Simulation Center (JTASC) in Suffolk, VA. The JFCOM Experimentation Directorate, J9, is now the operational sponsor and makes extensive use of JSAF for Human-in-the-Loop (HITL), virtual experiments. The U.S. Navy's Maritime Battle Center uses JSAF as the core simulation for its Fleet Battle Experiments (FBEs). JSAF is also supporting the Joint Medical Operations–Telemedicine ACTD. A JSAF User's Group has recently been created to represent a broadening group of agencies making use of HLA-compliant JSAF technologies.

Joint Experimentation Using JSAF

Joint Experimentation 9901 (JE9901)

The JE9901 Experiment explored new approaches to JE in the context of investigating how future systems, especially sensor systems, can be used to defeat critical mobile targets in the form of theater ballistic missiles before they are fired. The Critical Mobile Target Cell (CMTC) was used to provide real-time tasking authority for the sensors, and then Automated Target Recognition was used to continuously track targets.

Attack Operations 2000 (AO 00)

The AO 00 Experiment used a war-game scenario with Sensor and Shooter Concept of Operations (CONOPS) for the 2007 timeframe. The experiment dealt with HITL acting as a black-box surrogate, deciding on which platforms and weapons systems/munitions were to be used in a synthetic environment. The AAR system logged the Experiment/Simulation in real-time for playback, thread analysis, and battle damage assessment. (See Figure 1 for sample synthetic environment.)

FIGURE 1. Realistic environments and dynamic terrain features have become a reality in simulation. A simulated vehicle crosses a bridge (left), and then the bridge is bombed and destroyed (right), making the bridge impassable by other vehicles. Bridging assets now exist that could build a simulated temporary bridge for forging the river.

ACTD Using JSAF

Joint Countermine Operational Simulation (JCOS)

The objective of the Joint Countermine (JCM) ACTD was to demonstrate the capability to conduct seamless mine countermeasure (MCM) operations from sea to land. The ultimate goal was to develop improved MCM equipment, operational concepts, and doctrine to support amphibious and other operations involving Operational Maneuver from the Sea (OMFTS), and to support the follow-on land operations.

Modeling and simulation played a key role in the JCM ACTD. JCOS was used to evaluate the operational use of countermine systems, to evaluate plans developed to accomplish exercise objectives, and to evaluate doctrine and tactics in a variety of scenarios and tactical situations.

The JCOS goal was to provide an end-to-end simulation capability for joint MCM operations. JCOS used and leveraged existing Advanced Distributed Simulation JSAF capabilities to meet this goal. With this approach, JCOS was able to simulate and rehearse joint warfighting operations in a mined environment across the operational continuum from deep water, through littoral, to inland objectives.

JCOS was used during the planning phases of two amphibious assault exercises that required extensive MCM operations. JCOS was also used during exercises to simulate a much more robust MCM component.

Joint Medical Semi-Automated Forces (JMedSAF)

The objective of the Joint Medical Operations–Telemedicine (JMO–T) ACTD was to provide a near-term capability to defeat time, distance, and organizational obstacles to effective Joint Health Service Support in austere and nonlinear operational environments.

The plan developed by SSC San Diego to provide M&S support for the ACTD was similar to that followed for the JCM ACTD, in which JSAF capabilities were enhanced in the specific domain area required. A comprehensive representation of Army, Air Force, Marine, and Navy medical treatment behaviors was developed to provide medical mission planning and rehearsal at a Joint Task Force/Commander in Chief (CINC) level that would be on a par with those employed by the combat branches. (See Figure 2.)

Specific capabilities developed include:

- Medical entities: hospital ships, medical treatment facilities, ambulances, helicopters, and individuals capable of being wounded or sick.
- Medical behaviors: combat injuries based on weapon/casualty type pairings and defined medical patient codes, disease and nonbattle injuries determined on percentage of population at risk, medical facilities with staff, equipment, holding capacities, and evacuation assets.
- Medical C^2 reporting: a medical C^2 message interface to the Medical Equipment Workstation (MEWS) that will provide Annex Q (medical reports section of an OP Order) reporting as well as information on individual patient encounters.

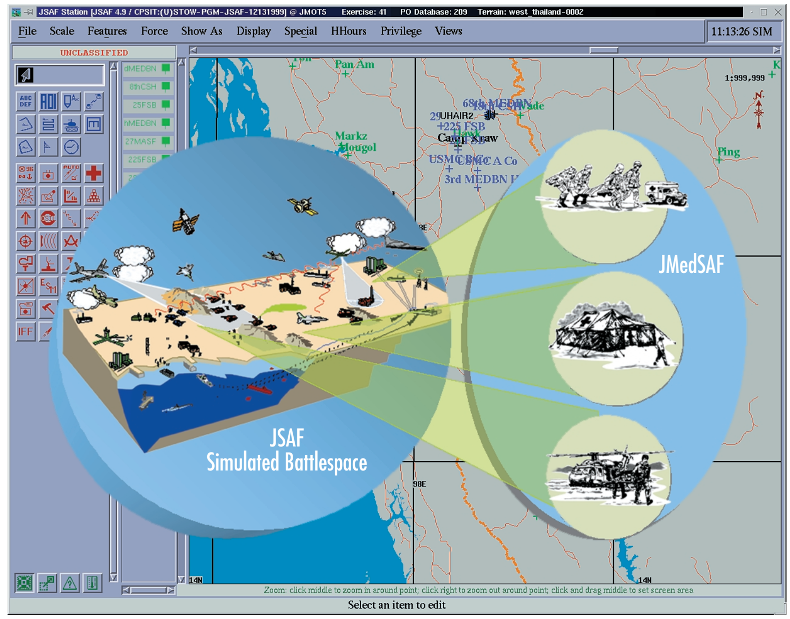

FIGURE 2. JMedSAF is a medical extension of JSAF, providing the ability to simulate medical play in the simulated tactical battlespace. Medical play includes combat injuries, disease-related illnesses, and nonbattle injuries; medical treatment facilities, their staffs, and supplies; the evacuation of injured or sick, or subsequent return-to-duty; and interfaces to medical C^2 workstations.

JMedSAF has been demonstrated at Kernel Blitz '99 in conjunction with ELB ACTD (April 1999), in the Pacific Warrior Exercise CPX (November 1999), and in Cobra Gold 2000 (May 2000). Participation in Cobra Gold 2001 is also planned. JMedSAF will also be used (in conjunction with a distributed simulation from the Army's Training and Doctrine Command) to assess the effects of varying levels of medical support for future Objective Forces.

Extending the Littoral Battlefield

The main objectives of the ELB ACTD were to (1) expand battlespace connectivity in the littoral regions by using wireless network technologies and hand-held computing devices, and (2) further flatten the command and control structure for executing missions in austere and nonlinear operational environments.

The plan developed by SSC San Diego provided M&S support to the ELB ACTD Major System Demonstration (MSD) #1 in order to (a) accomplish greater realism for the common tactical picture, (b) enhance situational awareness of the battlespace, (c) increase the density of message traffic to C^4I systems, and (d) provide a mechanism to support testing events when limited resources were available. The simulation objectives were to:

- "Round out the battlespace" by using simulated entities as required for testing and demonstration (e.g., Supplemental Blue and Opposing Force Units, Ships, End User Terminals [EUTs], P3C, etc.)
- Provide certain simulated sensor message feeds (e.g., Joint Surveillance Target Attack Radar System [JSTARS], Tactical Remote Sensor System [TRSS], Guardrail, and unmanned aerial vehicle [UAV])

- Stimulate the ELB Watch Officer Workstation with OTGold and USMTF messages
- Stimulate the RMTP network with simulated EUT message traffic (JUnit and SALUTE POSREPs)

ELB employed two war-gaming simulation systems to accomplish these objectives: MTWS and JSAF. The simulations used their specialized strengths to provide the required functionality. JSAF was primarily used for higher fidelity amphibious, mine, and special operations, while MTWS was primarily used for its higher echelon battlespace representation, including rear area force and other massed troops with fewer computing resources necessary.

Joint Simulation System–Maritime (JSIMS–M)

JSIMS–M began development in the late 1990s and promises to be the next generation of advanced distributed simulation. JSIMS–M is being developed as a state-of-the-art simulation system in conjunction with the overall JSIMS Alliance. The development environment is based on object-oriented principles that use automated-code generation tools for overall reduced costs in the development and maintenance phases. In 2000, JSIMS–M became responsible for developing the Simulation Engine for the JSIMS Alliance. The Simulation Engine is based on a Government off-the-Shelf (GOTS) parallel discrete event simulation called Synchronous Parallel Environment for Emulation and Discrete Event Simulation (SPEEDES). This high-tech simulation can support faster-than-real-time operations, multi-processor systems, and simulation repeatability. SPEEDES is a simulation framework that supports simulation interoperability across a variety of parallel and distributed platforms (see Figure 3.)

SPEEDES development was initiated in 1990 by the National Aeronautics and Space Administration (NASA) at the Jet Propulsion Laboratory and was one of a number of simulation infrastructure projects initiated in the early 1990s that explored simulation interoperability over different computing platforms. The primary goal of SPEEDES was to provide interoperability between objects distributed across large numbers of processors while using a common simulation engine. A key feature of SPEEDES is its ability to preserve causally correct event processing in a repeatable manner without sacrificing parallel performance or constraining object interaction.

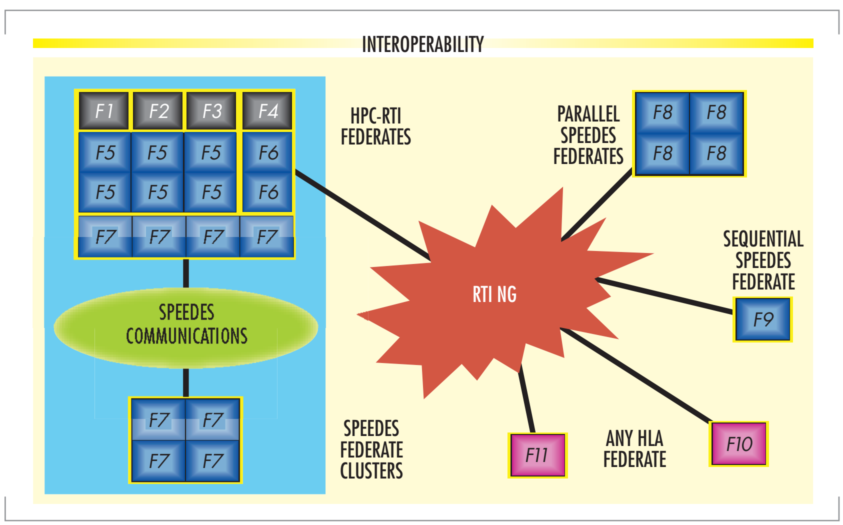

FIGURE 3. SPEEDES is a parallel discrete event simulation engine. The flexibility of the SPEEDES environment is depicted above and provides the capability of executing on one or many processors. The interoperability is maintained between SPEEDES nodes and any other HLA RTI federates.

Currently, several Department of Defense simulation projects use SPEEDES to provide all or part of their core infrastructure. Besides JSIMS, there is the Joint Modeling and Simulation System (JMASS), the Extended Air Defense Test Bed (EADTB), the Joint National Test

Facility's (JNTF's) Wargame 2000, the High Performance Computing and Modernization Office (HPCMO) infrastructure, and the Defense Modeling and Simulation Office (DMSO) project in support of a Human Behavioral Representation Test Bed.

The JSIMS program will provide a simulation environment capable of meeting a broad set of requirements for training and mission rehearsal. JSIMS is a single, distributed, seamlessly integrated modeling and simulation environment. The system provides the software and hardware infrastructure necessary to support multiple training, planning-and-analysis rehearsal, education, and doctrine development events in a variety of composable configurations. JSIMS–M is the component of JSIMS necessary to satisfy Navy training needs. JSIMS–M provides the capability to JSIMS to represent all aspects and elements of the maritime operational environment needed to support the execution of joint and service scenarios, and to train JTF and JTF component staffs. JSIMS–M will ultimately replace RESA and the Enhanced Naval Wargaming System (ENWGS) in joint and Navy training environments.

The overall development of JSIMS is the responsibility of an executive structure called the JSIMS Alliance, which relies on software development from multiple Domains. The Domain Agent (DA) for the maritime component of JSIMS is the Space and Naval Warfare Systems Command (SPAWAR) (PMW 153).

As a result of Alliance-wide reorganization occurring at the end of 1999, the Maritime domain has been identified as the development domain responsible for both Maritime objects in simulation (such as naval vessels, weapons), the ocean acoustic propagation loss data, and the development of certain common components that will provide data and software services to all components of the Joint Simulation. JSIMS Maritime common components' products include the Common Components Simulation Engine (CCSE), the Common Algorithms Support Services (CASS), and the Model Driver Database Diagnostic Interface (MDDI).

JSIMS is a multi-domain, cross-service military simulation system built on HLA. The HLA enables simulation objects modeled in multiple domains to be brought together into an application-specific joint simulation known as a federation. Within the HLA Architecture, multiple Simulation Object Models (SOMs) and supporting libraries can be accessed to provide various objects and services to compose a Federation Object Model (FOM). The coordination of object models is achieved through an RTI, which operates at the federate level. Services to the RTI are provided through the CCSE directly or provided through a specialized interface, depending on the architecture of the participating federate.

High Performance Computing (HPC)

High Performance Computing (HPC) initiatives were supported throughout the decade and have focused on the ability to use distributed, extremely high performance parallel-processing systems. SSC San Diego receives funding from the HPC Modernization Program (HPCMP) through its Common HPC Software Support Initiative (CHSSI). The CHSSI Force Modeling and Simulation (FMS)/C4I FMS Computational Technology Area supports the development of a simulation run-time infrastructure for HPC (HPC-RTI). Its immediate purpose is to greatly enhance computing capabilities for HLA distributed simulations. The HPC-RTI allows parallel computers to manage multiple HLA federates on a single machine while partaking in a distributed HLA simulation (Federation). The engine for the HPC-RTI is SPEEDES, which provides time management, data distribution management, object management, etc. SPEEDES, is currently the simulation engine for JSIMS and the BMDO Wargame 2000 system, and is currently being integrated into JMASS. The HPC-RTI then provides an HLA structure for SPEEDES.

ADVANCED DISTRIBUTED SIMULATION 2000+

As we move forward into the 21st century, JSAF and HPC will continue to support advanced distributed simulation efforts, and JSIMS–M will become part of the next generation of simulations.

JSAF will continue JE support with Unified Vision 2001 (UV01), Millennium Challenge 2002, and Olympic Challenge 2004. The mission of UV01 is to support the JFCOM Campaign Plan 2001. The Joint Experimentation Directorate (J9) is conducting a concept refinement experiment integrating Rapid Decisive Operations and its supporting functional concepts, as well as preparing for Millennium Challenge 2002 and Olympic Challenge 2004.

The HPC-RTI goal is to integrate into the GCCS as part of the Defense Information Infrastructure Common Operating Environment (DII COE) in order to provide a modeling and simulation capability to the Warrior in support of C^{4}I. HPC will also investigate further enhancements to SPEEDES, including an integration of a Common Reasoning Engine (CORE) along with other behavior-capture mechanisms and near-optimal decision-making mechanisms to provide commander objects in a distributed parallel environment through the HPC-RTI. The HPC-RTI will provide scalability of simulation size (large numbers of objects, large numbers of decision mechanisms, and large numbers of human-like behaviors) and reliable performance with real and faster-than-real time.

JSIMS–M will continue to investigate performance enhancements to SPEEDES and critical functionality improvements. The fundamental challenge for this parallel discrete-event simulation is to efficiently process events concurrently on multiple processors while preserving the overall causality of the system as it advances in simulated time. While JSIMS–M is currently being developed as the next generation of advanced distributed simulation based largely on the simulation engine (SPEEDES) and its future direction, the generation-after-next should also evolve with the advance of simulation technologies. Enhancements in performance and affordability of parallel systems, and automation of development and interface frameworks will lead to robust, high-speed, quickly reconfigured simulations to support a plethora of military and commercial uses. The simulations will cross domains from training, to analysis, to concept exploration, to test and evaluation and more. The simulation will simplify the support of training venues that include training at multiple echelons simultaneously. For example, the medic will be trained in triage or on a patient simulator by using virtual simulators, while another medic is in the field in a live exercise entering patient encounters using a Palm-top. The encounters are fed into the overall simulation and provide medical situational awareness to the medical commander and his staff. While using the same simulation, the staff will be able to take the "real" C^{4}I picture off-line, and run faster-than-real-time to evaluate and analyze various courses of action. These courses of action will be interactive and allow different inputs and constraints to be imposed. The ability to accomplish most of this exists, but the ability to do it with ease, and at reasonable cost, is still difficult.

Some challenges still facing future simulation include:

Scalability/Adaptability: Can a simulation be effectively tailored to support the task at hand both in size (footprint) and functionality? For instance, can the simulation be run on a laptop to train an individual or small group while in transit to an operational area? Can it be scaled to support large task forces over multiple operational areas, including coalition forces?

Network Capacities/Load Balancing: Can the simulation be distributed via various network capacities to the sites and/or platforms involved? For instance, can the simulation be used over limited bandwidth connections to a platform or perhaps limited because of security requirements? Do nodes on multiprocessing platforms have the approximate same work-load?

Multi-Echelon Training: Can modeling and simulation be cost-effective for supporting integrations of constructive, virtual, and live simulations? Can these integrated simulation solutions support multi-echelon training at the appropriate fidelity for each echelon? Can interface frameworks be developed that make interoperability between these domains affordable?

Multiple Domains: Can a single simulation architecture have the flexibility to extend through domain areas (training, analysis, research, experimentation, etc.)?

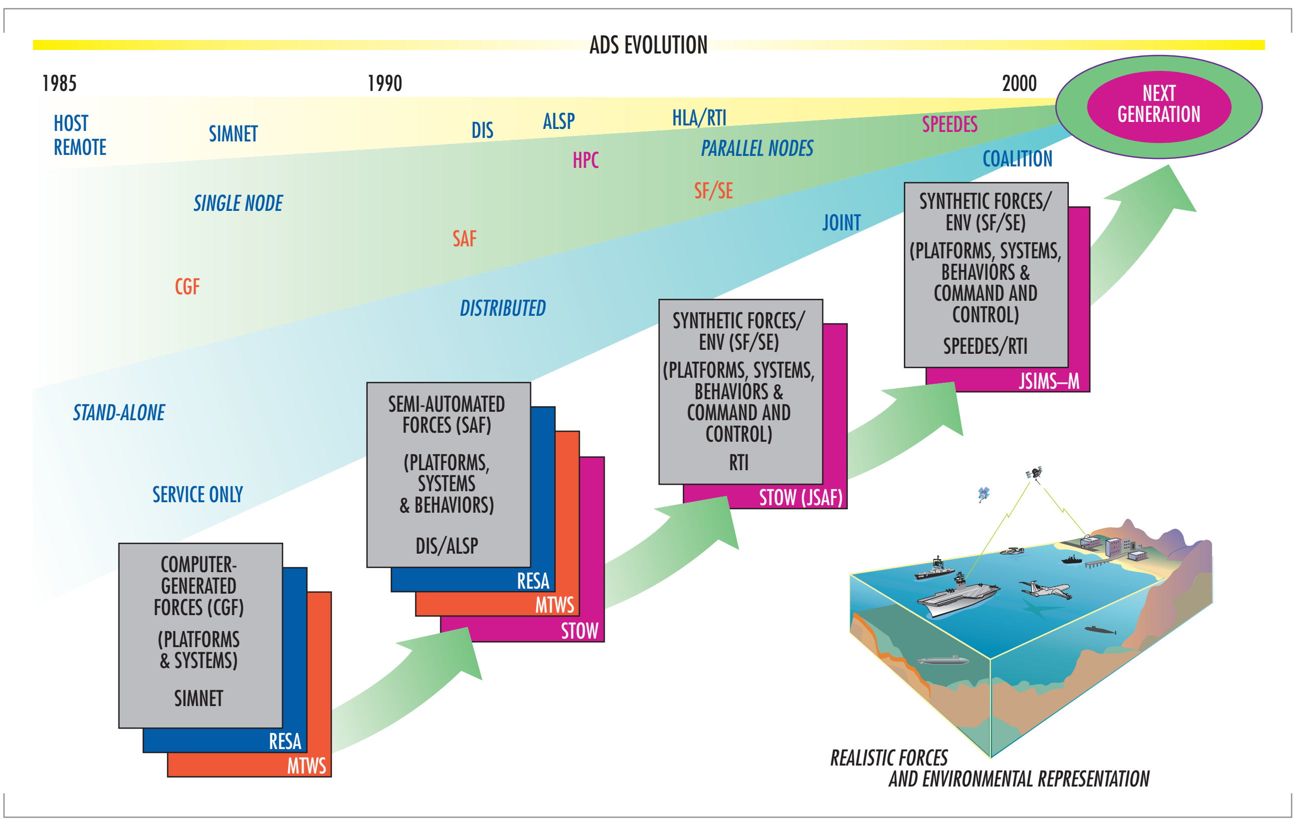

FIGURE 4. Advanced distributed simulation evolution through the 1990s and into the 21st century. Leading the way are advancements in network technologies and protocols, computer technologies, modeling representations of forces and environments, and the requirements of a more complex, diverse user community.

Modeling and simulation exposed and evolved these challenges in the 1990s. However, these are just a few of the challenges facing advanced distributed simulation in the 21st century. Next-generation and generation-after-next simulations need to address these questions, and SSC San Diego, with its simulation arsenal, will continue in the forefront of this investigation. (See Figure 4.)

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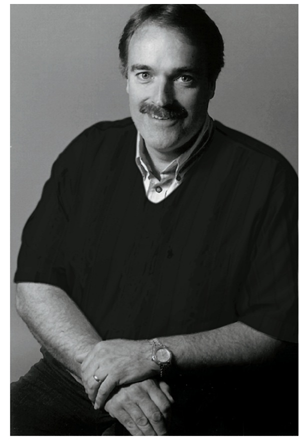

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"Task-Managed" Watchstanding: Providing Decision Support for Multi-Task Naval Operations

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

INTRODUCTION

Crew size and function allocation in future ships have been recognized as a significant cost factor and therefore have become a performance capability objective for a new class of ships planned for later in this decade [1]. Human performance, driven by a complex, multi-task littoral mission job environment, is the rate-limiting factor for crew optimization. Total task workload must be distributed among a trained crew and controlled in a manner that allows successful performance with minimum risk of mission failure or compromise. Current design practice calls for systematic assignment of tasks (workload) to crew members in a fairly rigid manner—creating periods of high workload or overload for some crew members while others may sit nearly idle with low workload. Crew-size optimization calls for much higher precision in task assignments and workload optimization, with minimum waste in workload capacity as tasks are assigned to the smaller crew.

In 1996, the Multi-Modal Watchstation (MMWS) project was initiated to investigate design concepts that would support crew optimization in command centers. An ergonomic, task-centered watchstation was developed (see Figure 1). The design approach first identified user requirements related to the total work environment and task workload drivers. For purposes of this design discussion, we define a "task" as a job activity with the following attributes:

1. A goal-oriented work activity that results in a defined product.
2. Varying in time from seconds to hours, or the entire watch period (6 hours or more).
3. Supportable by computer-based aids (i.e., not physical work or maintenance activities, although such tasks could benefit by using the principles of this design).
4. Supportable by various levels of automation, which are, in some cases, user-selectable and, in others, may be fixed. Thus, levels of task supervision and user/system task sharing are dynamic.
5. May vary from structured, rigid protocols to open-ended, user-defined sequences. Following Rasmussen's hierarchy [2], tasks may include skill-, rule-, or knowledge-based behaviors.

An important aspect of the task-centric approach is the focus on the "total" work environment, which is defined as mission + computer interface + work management tasks. Naval system designers typically focus on the narrow "mission-specific" requirements to derive the specifications of software functional design. They neglect workload derived from human–computer interface task activities such as computer interface control (e.g., graphical user-interface manipulations). Also neglected is the considerable cognitive workload for work planning, task selection, and time or resource management. The human operator must constantly strategize and allocate attention resources across multiple concurrent events. Current designs offer little or no user assistance to reduce this type of workload or to foster efficiency. The MMWS design focus on task management issues led to a definition of estimated task characteristics for a future naval system, such as listed in Table 1 [4]. (See [3] for discussion of the Task Characteristics approach.) These characteristics provided a starting point for watchstation design concepts based on these requirements. Since task requirements were only available at an abstract level for the future ship [5] and no concept of operations existed at this early design phase, several important assumptions were made about the future task environment such as (1) what degree of automation would be available; (2) multitasking would be required for crew optimization across multiple threats and multiple warfare areas: land attack, air defense, and area air defense; (3) cross-training across multiple tasks would be possible; and (4) system design would permit assignment of any task to any crew member at a watchstation, limited only by authority and planned operating procedures. These task and design requirements were then used as a basis to generate preliminary design concepts.

FIGURE 1. Ergonomic Multi-Modal Watchstation Pedestal. The MMWS console was designed to accommodate the 2.5% female through 97.5% male reach envelopes.

PRELIMINARY DESIGN

Each of the concept design requirements was matched with a variety of user-interface aids to support each task type. The design process employed was similar to that noted by Neerincx [6] in which tasks were defined according to their impact on cognitive performance. Specifically, tasks were good candidates for automation support that were judged to be skill- or rule-based. The allocation of task responsibility was considered to be dynamic and user controllable for most tasks. Certain mission tasks better fit the procedural aspects of skill-based behavior (e.g., when the air threat assessment process is completed and the procedural mechanics of issuing warnings or countermeasures become a primary task goal). Design concepts were created to address these projected requirements (Table 1), and examples are listed in Table 2.

The design concept of an "Information Set" was created to contain the "default" or typical information needed to support a task operator. The goal of the design approach was to automate much of the information-seeking task steps. An effective information set would filter pertinent information for the specific task from the visual "noise" or unimportant data. For example, a particular land-attack task in a given geographic sector would require the information set to filter the tactical display to show relevant threats and friendly forces icons. Information sets were defined to contain various graphical user-interface windows such as (1) tactical summary (situation awareness), communications (who to talk or listen to relevant to the task); (2) time and work management (task summary as shown in Figure 2); and (3) amplifying information specific to the task type (e.g., identification [ID] basis information for assessment when issuing a warning). Simple graphic-design rules were developed such as color-filled tactical symbol objects to represent tracks with a pending task and color-outlined symbols to represent no current work in progress.

To address requirements related to depiction of task progress, information formats related to task management were designed. Early concepts addressing air defense task progress were created in 1989 and reported in Osga [7]. Design concepts for the Response Planner Display from the Tactical Decision-Making Under Stress (TADMUS) project were also

TABLE 1. Key task characteristics related to task management requirements.

Task Characteristics Tasks:	**Design Requirement** System should:
May have definable start/stop schedules	Monitor concurrent loading and make schedules visible to user.
Have definable goals	Monitor progress toward goals—offer assistance if needed— report progress toward goals—allow user to modify or create new goals.
Are grouped as parts of overall job role	Provide visual indication of task assignments and task "health."
May be user and/or system invoked	Indicate who has task responsibility. Invoke and "offer" tasks when possible.
Have information and control requirements	Minimize workload to access information or controls.
Are mission- or computer-control focused	Provide full top-down task flow and status for mission tasks with consistent, short multi-modal procedures.
May involve varying levels of automation from full manual to partial to fully automated	Provide visual indication of automation state with supervisory indicators.
May require one or many databases	Do not require the user to know which database for any task. Direct queries automatically.
May require one or many software applications	Require user to know the tasks, not multiple applications—integrate information across the job vs. application.
Will require attention shift between multiple tasks in foreground and background (parallel)	Provide attention management and minimize workload to shift task focus.
Have definable cognitive, visual, and motor workload components	Use task estimates for workload distribution and monitoring among crew members.
Will likely be interrupted	Provide assistance to re-orient progress and resources to minimize working memory load.
Should be consistent from training to field	Provide consistent terms, content, and goals throughout.
Will evolve as missions, systems evolve over the life cycle of the ship	Support reconfiguration of task groupings and addition of new tasks as systems are upgraded.
May be individual or collaborative	Support close proximity and distant collaboration via visual and auditory tools.

TABLE 2. Key MMWS design concepts related to design requirements.

MMWS Design Concepts	**Design Requirement—**System should:
Response Planner/Manager—individual threat response summary. Task Manager Display—composite workload and tasks.	Monitor concurrent loading and make schedules visible to user.
Response Planner/Manager—range-based, single threat summary. Task Manager Display—task summary display.	Monitor progress toward goals—offer assistance if needed—report progress toward goals—allow user to modify or create new goals.
Task Manager Display—team overview and workload indicators.	Provide visual indication of task assignments and task "health."
Task Manager Display—task assignment summary. MMWS context and event monitoring to support task initiation.	Indicate who has task responsibility. Invoke and "offer" tasks when possible.
Multiple display surfaces—maximize visual workspace (within 5 to 95% reach envelope for touch).	Minimize workload to access information or controls.
Task manager task filters. Response Planner procedural list.	Provide full top-down task flow and status for mission tasks with consistent, short multi-modal procedures.
Visual coding of automtion state.	Provide visual indication of automation state with supervisory indicators.
Information sets automatically created.	Do not require the user to know which database for any task. Direct queries automatically.
"Information Sets" assigned to each task.	Require user to know the tasks, not multiple applications—integrate information across the job vs. application.
Multiple displays, task locator icons, intelligent task sorting and priority visual cues.	Provide attention management and minimize workload to shift between task focus.
Visual indication of team workload.	Use task estimates for workload distribution and monitoring among crew members.
Highlight changed information when task is "dormant." Reminders and notes tied to tasks.	Provide assistance to re-orient progress and resources to minimize working memory load.
Top-down task description carried through in display design as well as training curriculum.	Provide consistent terms, content, and goals throughout.
Design TBD	Support reconfiguration of task groupings and addition of new tasks as systems are upgraded.
3-D auditory support to spatialize multiple voice circuits, audio icons and visual/auditory linking of events (audio spatialized to match visual location.	Support close proximity and distant collaboration via visual and auditory tools.

reviewed [8 and 9]. The Response Planner display was used to depict planned response actions in air defense warfare showing task duration and deadlines related to individual air threats. For MMWS, an additional response manager was added for electronic warfare tasks related to uncorrelated electronic-signature reports. Figure 3 (lower part) shows the MMWS "Response Planner/ Manager (RPM)" display concept. This decision support window depicts the major steps in the detect-to-engage

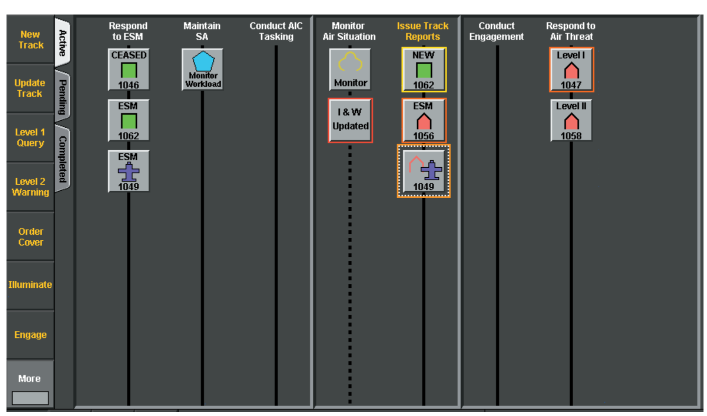

FIGURE 2. MMWS task management display with icons representing tasks awaiting user attention.

sequence that are possible and the ranges at which they might be completed and be in accordance with current response doctrine. Currently recommended task bars are filled white with an unfilled status circle. Previously completed tasks are represented by task bars that are filled black with a green status circle. Tasks that possibly could be triggered if the track maintains its current ID are gray with white letters. Tasks that will not be triggered if the track maintains its current ID are filled in with gray and with gray letters. The task bars are selectable, and the operator can launch a task manually by clicking on them. The RPM window is paired with the Track Profile Window, shown as the upper window in Figure 3. Both windows share a common range-scale from ownship. The track profile window provides a graphical representation of the hooked track's altitude and speed as a function of range from ownship. The altitude trail is color-coded to display the ID history of the track. The speed trail is shown in white. Commercial air transport (COMAIR) ranges are shown colored in purple along both the altitude and speed axis of the graph. Black boxes with white letters displayed along the altitude trail show the tasks performed for that track.

For air defense warfare, the following codes are used on the track profile to display which task was performed:

N = New Track Report issued
U = Update Track Report issued
Q = Level I Query issued
W = Level II Warning issued
V = Visual Identification (VID) ordered
C = Cover ordered
I = Illuminated
E = Engaged

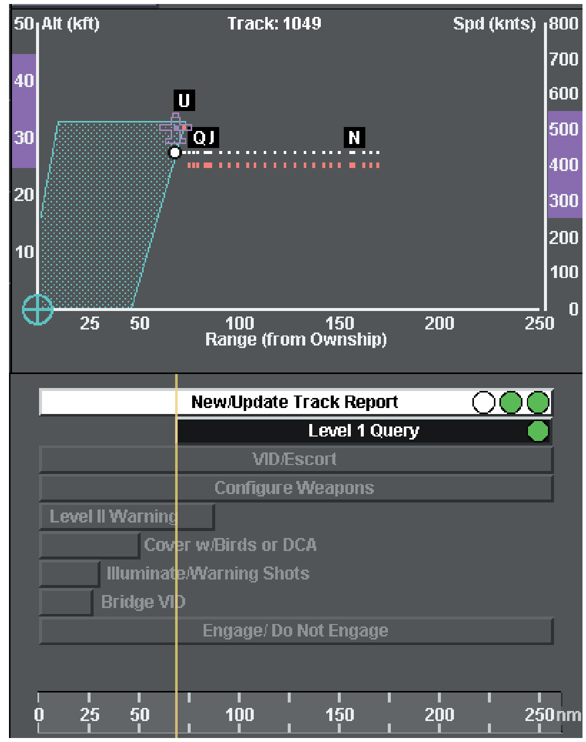

FIGURE 3. Track Profile (upper window) and Response Planner (lower window) displays. This example shows that a New Track report, two Update reports, and a Level 1 Query were previously completed. The track is progressing at a steady altitude (25 kft) and speed (450 knts). The tactical graphics show the weapons envelopes of ownship in teal, and, if applicable, unknown or suspect track possible weapon envelopes are shown in red.

Attention Management

The MMWS design considers the requirement to guide user attention through all phases of the task life cycle. These phases are (1) initiation, (2) orientation, (3) decision, (4) execution, (5) confirmation, and (6) transition. User attention must be directed across and within task activities. Figure 4 illustrates the benefits of consistent color-coding across windows, within a task type. Color-coding for ID illustrates

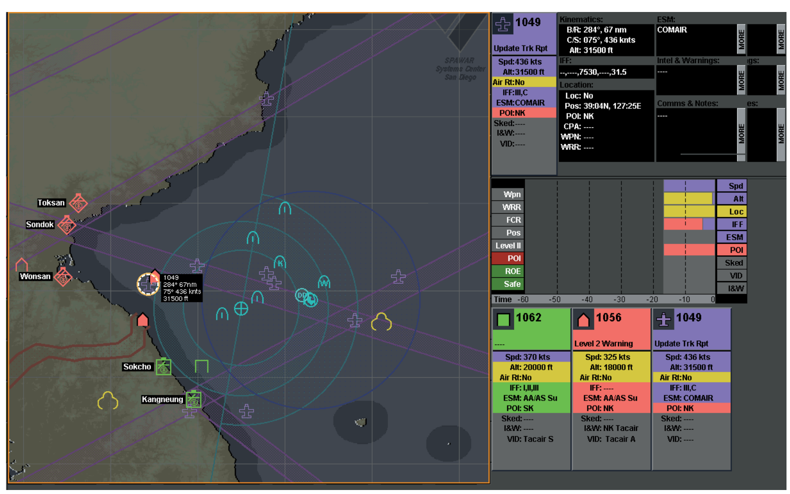

FIGURE 4. Consistent color-coding for ID and improved tactical graphics help to guide user attention and speed visual search tasks. Consistent color-coding across displays aids in information scanning and interpretation. The Track Profile (Figure 3), Amplifying Info, Basis of Assessment, Mini-Amp-Info, and Tactical Displays shown in this figure illustrate the common coding used throughout all windows.

evidence both for and against a given ID assessment. Uniform color represents higher ID certainty while a "rainbow" of color represents less certainty. At a glance, the user can see in each display if there is consistent or conflicting ID evidence, and can quickly assess where the conflicts exist. The Basis of Assessment display provides a history of the changes in ID basis; thus, the user can tell if the data elements are consistent over time or changing. This coding supports efficient visual scanning and task dwell-time optimization. Experts dwell on problem areas such as a "suspect" track with an inconsistent ID basis, and spend less time visually sampling tasks or tracks with consistent information.

Another requirement exists to guide user attention in an efficient manner through multiple tasks. Task detection may be unreliable when the system relies on human vigilance during multi-tasking, and often users are reluctant to drop a non-critical task when a higher priority task appears. There can be a reluctance to leave work unfinished. The MMWS task management system monitors for task-event triggers in the environment. Relative to today's systems, user workload to monitor and trigger tasks should be significantly reduced, allowing attention resources to be allocated for task execution, not task detection. Also, tasks may be categorized with respect to both time and mission urgency. Task management displays have been found to improve judgments about the effect of delays for subtasks and global tasks when problems were introduced into task progress [10]. Results indicated significant performance gains for task management assistance in selecting appropriate response strategies for mission- and time-critical tasks. Automation to support task prioritization of the highest level task improved user efficiency.

Recent usability testing results for the MMWS [11] indicate that visual depiction of time and display scrolling on the task manager were not beneficial during high workload periods. This result led to a revision of the MMWS design concept to allow more tasks to be depicted without scrolling, using visual separation of completed, current, and pending tasks.

Design Testing and Analysis

A critical part of the design and engineering process involves usability testing with fleet participants. Testing involves user hands-on interaction with design items to obtain measures and observations of user training and acceptance, and to identify design items that invoke confusion, error, or slow performance. The goal is to test a few subjects to identify repetitive or common problems across all participants. Significant usability testing has been used to mature the designs in this capability to their current status. Over 75 military and civilian participants were tested from 1997 to 2000 as part of the MMWS development program. Metrics vary in usability testing depending on the focus for the test. During MMWS development, versions 1.x through 5.x were subjected to quantitative measurement. Figure 5 shows the successive changes in question accuracy as scored by accuracy points over four Version 3.x design iterations. Such measures provide an indication of design improvement. Design

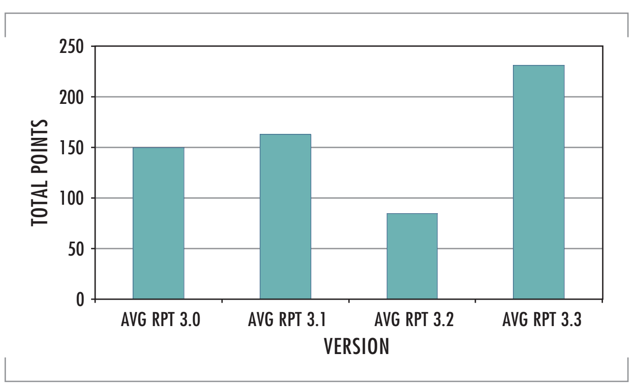

FIGURE 5. Points scored in testing over multiple design versions of MMWS.

comments and workload ratings provide indications of user preference and workload induced by the design and task scenario.

Team performance measurement is a critical design success criterion resulting in quantitative measures of the improvement of the MMWS capability in comparison to existing air defense decision support tools. A realistic air defense problem scenario was used for team performance assessment. The use of the scenario allowed specific comparison of teams using the MMWS Decision Support System (DSS) capability with Aegis teams tested with various Aegis software configurations. This allows a direct assessment of the MMWS DSS capability improvement vs. today's systems. The test was also designed to demonstrate a 50% crew reduction using eight operators in the Aegis team vs. four in the MMWS team. A test goal was to determine if workload and performance could be sustained with reduced crew sizes, such as those proposed for future ship teams. The scenario design was coordinated with Aegis Training and Readiness Command in Dahlgren, VA; subject experts at BCI, Dahlgren, VA; and scientists and engineers at SSC San Diego and Naval Air Warfare Center Training Systems Division (NAWCTSD), Orlando, FL. The scenario was engineered and set in a restrictive warfare environment to foster cognitive workload and decision-making under ambiguous circumstances. Fleet comments at the conclusion of test sessions indicated the scenario was as realistic as other operational test scenarios used in fleet training.

The test scenario contained low and high workload periods and a "coast period" was used in the middle portion of the scenario to allow for further data collection. In the second period, there were more tracks, increased ambiguity of information, and a higher threat situation. The operational parameters for the scenario were defined including:

1. Political Summary
2. Ownship Mission and Tasking
3. Air Tasking Order (ATO) and Carrier (CV) Flight Plan
4. Rules of Engagement (ROE) and Warning/Weapon Status
5. Operational Tasks (OPTASK) Link-ID
6. South Korean Military Tactical Air (TACAIR)
7. OPTASK Air Warfare Plan
8. Call-Signs
9. Operations Order (OPORDER), Warfighting Doctrine and Policy Guidance
10. Communications Assumptions and Plans
11. Location of Air Routes, Return-to-Force Routes, Air Fields and Stations

The scenario was conducted in Condition III steaming, with restrictive ROE and weapons posture for the battlegroup ranging from white/safe to red/tight. Measures included in this study were speed, timeliness, and accuracy (errors of omission or commission). As shown in Figure 6, multiple types of data were collected, including the following:

Timeliness and Accuracy. Collected by viewing video and audiotapes of team actions. Task times were also logged for the enhanced capability version of MMWS.

Efficiency and Workload Capacity. Workload ratings obtained by online scales. Proportion of low criticality tracks addressed by both teams.

Expert Opinion. Subject experts in a review team were assigned to an individual operator. They recorded subject responses to critical track events (25 identified) using the Shipboard Mobile Aid for Training and Evaluation (SHIPMATE) hand-held device.

Situation Awareness. Three probes were conducted during the low and high workload periods. A post-events questionnaire was used during the middle and final coast periods. Questions asked included the following: (1) What are your current tracks of interest? (2) What is your assessment of the intent of Track X? (3) What is your intent with respect to Track Y?

A post-events questionnaire addressed the top tracks of interest and an explanation of the interest. Performance-based inferences also were derived based on tactical response to events in the scenario. Subject-matter experts rated planning, prediction, and critical thinking. The same measures and probes were used for previous Aegis tests [12] and will allow for comparison and measurement of success in this project.

Test Result Highlights

Table 3 shows results indicative of the situation awareness improvement in teams tested using MMWS vs. Aegis crews using legacy equipment. The critical scenario event included a track that appears to be a COMAIR initially, but demonstrates several important kinematic (course, altitude, speed) and other ESM information changes that would warrant increased suspicion. Note in Table 3 that fewer Aegis crews queried or warned the track prior to it attacking the battlegroup, while all MMWS crews did so. The MMWS teams exhibited confidence and awareness in their response actions. With apparently less situation awareness and decision support, Aegis crews used last-second response methods when the air threat launched missiles, while MMWS crews were fully prepared and forewarned. Figure 7 shows that even with a reduced crew size of 50% for the MMWS teams vs. Aegis, the MMWS estimated workload was lower throughout the entire scenario periods tested. Thus, the benefits of the MMWS design included increased situation awareness and performance, with less workload induced on the operating team: a clear win-win situation with respect to performance and workload, therefore reducing mission performance risk.

FIGURE 6. MMWS designs were subjected to individual and team testing in realistic tactical operations.

TABLE 3. Responses of Aegis and MMWS to kinematic changes and ESM events with a critical scenario threat.

	Kinematics	Query/Warning	Engage ASM
Aegis Teams	1 of 8	2 of 8	7 of 8
MMWS V1	6 of 6	6 of 6	6 of 6
MMWS V2	2 of 2	2 of 2	2 of 2

CONCLUSIONS

The MMWS project investigated the design concept of explicitly creating and embedding mission tasks and their associated goals within the visual user interface, using visual priority cues and task progress summaries. The user was assisted throughout the entire task life cycle. Draft task products were prepared for user review, in contrast to the manual workload in visual search, discovery, and task product creation in today's systems. Test results for usability and team performance indicate that the design concepts in MMWS could be a key enabler for crew performance, enabling improved situation awareness and workload reduction. This may be particularly true in multi-tasking missions where workload is externally paced and attention must be distributed across multiple simultaneous tactical events. Task management appears to support work in command and control environments that involve a mixture of rule-, skill-, and knowledge-based tasks. Task management greatly facilitates real-time workload assessment, useful for adaptive automation and re-allocation of functions between team members [13]. Further team-performance research is needed in these complex naval task environments to determine best methods for task distribution and automation monitoring by humans working cooperatively with intelligent task management aids.

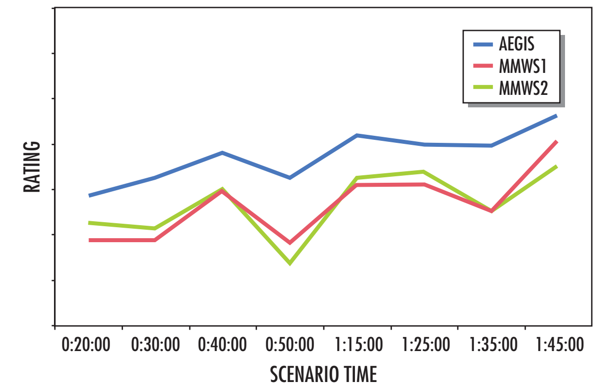

FIGURE 7. Workload levels across scenario periods for Aegis and MMWS as determined by subject-matter-expert ratings.

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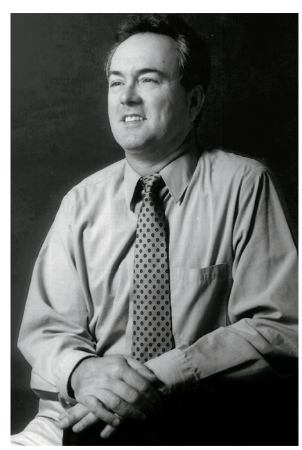

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Perspective View Displays and User Performance

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ABSTRACT

Consoles that use three-dimensional (3-D) perspective views on flat screens to display data seem to provide a natural, increasingly affordable solution for situational awareness tasks. However, the empirical evidence supporting the use of 3-D displays is decidedly mixed. Across an array of tasks, a number of studies have found benefits for 3-D perspective over two-dimensional (2-D) views, while other studies have found rough parity, and still other studies have found 2-D superior to 3-D. Interestingly, many realistic military tasks have complex demands that require both types of views at different points in time. This paper investigates an interface concept called "orient and operate," which employs the advantages of both 2-D and 3-D displays.

INTRODUCTION

Objects and scenes displayed on a flat screen from a 30- to 60-degree perspective viewing angle can convey three-dimensional (3-D) structure and shape. They are increasingly being used in military and civilian occupations such as air warfare, command and control, air traffic control, piloting, and meteorological forecasting. However, they have not been shown to be effective for all tasks. Comparisons between two-dimensional (2-D) (top-down, side) and 3-D (perspective) displays in the literature on a variety of tasks have found mixed results.* Several factors have been proposed to account for the differences (see, e.g., [9, 12, and 19]). In an attempt to identify and evaluate the factors important to the effectiveness of the viewing angle, we developed a series of experimental tasks using simple block stimuli (see Figure 1, left) viewed on a non-stereo display. We found that 3-D views were superior for tasks that required understanding the shapes of the blocks, but that 2-D views were superior for tasks that required judging the precise relative position between the blocks and another object (a ball) in the scene [20]. In these experiments, the 3-D view was from 30 degrees with shading, and the 2-D views were from the top, the front, and the side.

We then extended these findings to more complex and naturalistic terrain stimuli. Participants were shown a 7- by 9-mile piece of terrain in either 2-D or 3-D (see Figure 1, right) and asked to perform tasks that required either shape understanding or judging relative position. We again found that 3-D views were superior for the shape understanding tasks, and 2-D views were superior for relative position judgment tasks [21 and 22]. In these experiments, the 3-D view was from 45 degrees with shading, and the 2-D view was a topographic map with color-coded contour lines.

Interestingly, many realistic military tasks have complex demands that require both types of views at different points in time. For these tasks, we propose an interface concept called "orient and operate," which employs the advantages of both 2-D and perspective view displays. A 3-D view can be used initially to orient or obtain an understanding of the layout of

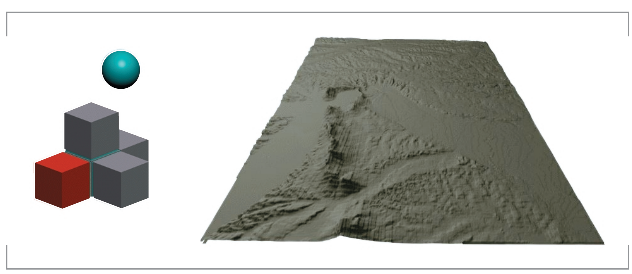


FIGURE 1. Simple block stimuli and terrain stimuli shown in 3-D perspective views.

*A number of studies have found benefits for 3-D perspective over 2-D [1, 2, 3, 4, and 5]. Other studies have found rough parity or different results on different measures or tasks [6, 7, 8, 9, 10, 11, and 12] and still other studies have found 2-D superior to 3-D [13, 14, 15, 16, 17, and 18].

background topography and the shape of objects in a scene. Then, a 2-D view can be used to operate on the objects, such as moving them around on the background.

THE GEOMETRY OF 2-D AND 3-D VIEWS

Before continuing, it is useful to understand the basic geometric and functional differences between 2-D views and 3-D views.* One reason 3-D views are good for understanding the general shape of objects and the layout of a scene is that all three spatial dimensions of an object can be seen within a single, integrated view [23]. With a single, integrated view, the user does not need to switch among and integrate information from separate 2-D views to obtain an understanding of the three-dimensional shape of an object or scene. Another reason why 3-D views are good for understanding shape is that natural cues to depth, such as shading, relative size, and texture, can be readily added to an image. Adding these cues can increase the salience of depth in the scene and thereby enhance the sense of a three-dimensional shape. Stereo and motion can also be used to aid the perception of depth,† though these are less commonly used.

One problem for 2-D and 3-D views is that information along the line of sight from the observer into the scene cannot be represented. The reason is that all of the information along a line of sight between the object in the displayed world and the viewer must be represented by the same pixel in a display. In a 2-D top-down or "plan" view, the x and y dimensions are represented faithfully, while the z dimension is lost entirely (see Figure 2). Actually, the x and y dimensions are scaled down in the plan view. "Represented faithfully" means that this scaling is a linear transformation that preserves angles and relative distances in the x-y ground plane so that, for example, parallel lines remain parallel. In the 3-D view, all three spatial dimensions are represented, but the line-of-sight ambiguity remains. Instead of losing one dimension entirely, all three dimensions are foreshortened. The effect of this ambiguity can be seen in Figure 1 (left) where the location of the ball cannot be determined: Is it floating in back of the figure, or is it floating toward the front of the figure?

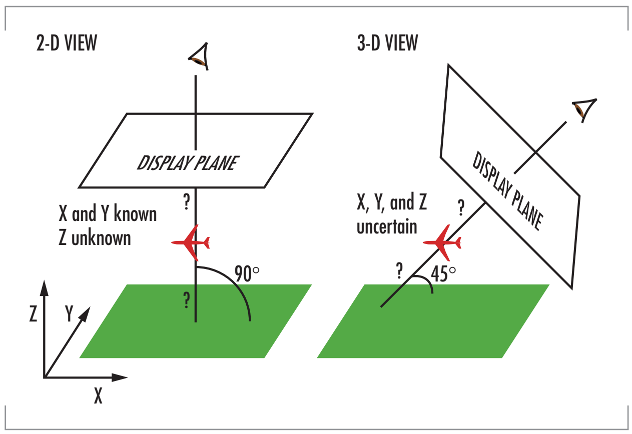


FIGURE 2. Line-of-sight ambiguity makes the location of the aircraft uncertain in different ways, depending on the viewing angle.

A further problem for 3-D views is distortion in the representation of distances and angles. Some distortions result from foreshortening, which increases as the viewing angle drops from directly top-down to ground level. This distortion can cause the sides of a square to appear shortened and the right angles to appear acute or obtuse, as seen in Figure 2. Other distortions result from perspective projection, which causes distances in the x and z dimensions to scale linearly (i.e., a linear perspective), but distances in the y dimension to scale nonlinearly. Due to this distortion, parallel lines appear to converge toward the vanishing point, as can be seen in Figure 1 (right). Perspective projection is, in fact, a cue to depth, but it works by distorting distances and angles. It can make depth more salient in an image, but at the price of making precise measurements more difficult.

* Sedgwick [24] provides a thorough description of 3-D views and perceptions of space.

† See our report [25] for a description of depth cues.

Antenna Placement Experiment

Here, we will discuss an experiment that evaluates our interface concept of "orient and operate" using a relatively detailed operational military task. In this experiment, participants were shown a terrain map that contained two fixed antennas (a source and terminal), several enemy unit locations, and a set of antennas to be placed on the map to establish line-of-sight communications. The task was to create a chain of antennas across the map to connect the source and terminal antennas. The antennas had to be within line of sight of each other while remaining concealed from the enemy units. Participants positioned antennas simultaneously out of sight of the enemy, but in line of sight and range of other antennas, thereby creating a chain of antennas across the map. One group of participants viewed only the 2-D topographic map. Another group received only the 3-D view, and a third group received both views, side by side. In the side-by-side condition, the two views were visible to the participant on separate monitors: a 3-D "orient" view and a 2-D "operate" view (see Figure 3). The antennas were constantly visible on both views, even as they moved, so participants could look at either view at their discretion. Participants were timed to complete a series of nine problems.

FIGURE 3. Side-by-side condition from antenna experiment: 3-D perspective view map (left) and 2-D top-down topographic view map (right).

It was not entirely clear which type of view would prove better for making these precision judgments. In previous work [21], we used line-of-sight judgments as a shape understanding task and found that 3-D views were superior. Participants viewed a terrain segment in either a 2-D top-down topographic view or a 3-D perspective view and judged whether or not there was a line of sight between two points on the terrain. This task appeared to require only a very general gestalt understanding of the terrain—whether a large mountain or range of hills was obstructing the line-of-sight view. In contrast, placing antennas on a map to create an unbroken chain of line-of-sight communications while keeping them out of sight of enemy units may require judgments that are far more precise.

We found that performance with 2-D maps was, in fact, much better than performance with 3-D maps. Our interpretation is that routing of antennas requires placements of units just in or out of lines of sight, and these precise judgments are facilitated by the 2-D view with its faithful representation of space. Interestingly, performance in the side-by-side condition proved to be even better than performance in the 2-D condition. Our interpretation is that some aspects of the antenna task, namely, orientation aspects, were still better performed in 3-D.

We investigated this interpretation in a follow-on experiment. From observations of participants, we found that the 3-D views appeared to be useful at various points throughout the task to help interpret the 2-D topographic views, and that the 3-D views were especially important toward the beginning of the task for determining a basic route. We believe that the ability of the 3-D views to naturally and easily convey shape makes them useful for finding canyons and hills that could be used to build a route through the terrain. This idea fits with our concept of "orient and operate," wherein the user first orients to a scene using a 3-D view and then switches to a 2-D view to perform fine-tuned operations on the scene.

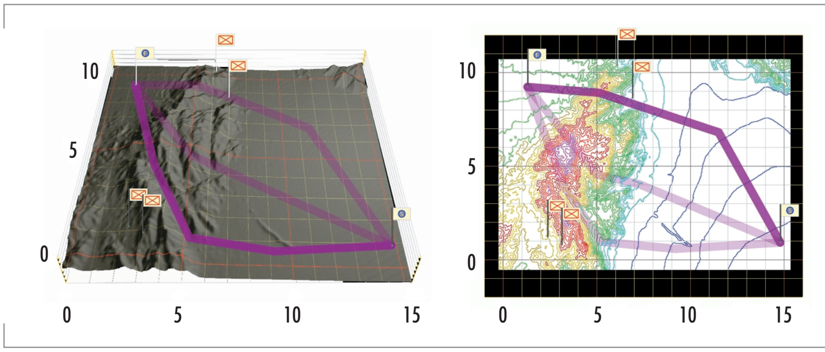


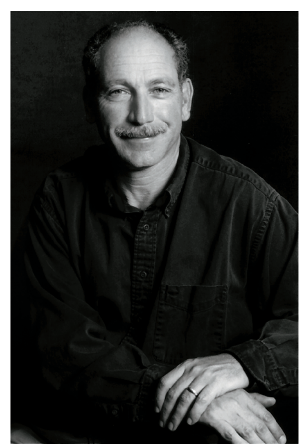
FIGURE 4. An example 3-D map and the equivalent 2-D map from "pick-a-path."

In the follow-on experiment, called "pick-a-path," participants were shown three potential routes across the terrain for constructing their chain of antennas (see Figure 4). One of the three routes was much more promising than the other two, in that it followed canyons and skirted hilltops to remain out of enemy lines of sight. Participants were shown the terrain and routes in either 3-D perspective views or 2-D topographic views. "Pick-a-path" performance was found to be much faster for the 3-D perspective views than for the 2-D views.

We concluded that the ability to select a path on a terrain map depends not only on the viewing perspective (e.g., 2-D, 3-D), but also on how precise the route needs to be. Initial path planning benefited from a 3-D view while the actual routing of the antennas benefited from a 2-D view. The 3-D view was better able to convey terrain shapes, and the 2-D view was better able to convey where two objects needed to be placed to solve the tactical problem. We recommend using 3-D for initial path planning and 2-D for object placement, supporting our "orient and operate" display design paradigm: Users should orient to a scene using a 3-D perspective view and then operate on the objects in the scene using a 2-D view.

Further supporting "orient and operate," we found that participants performed the best when provided with both 2-D and 3-D views. However, the effect was of small magnitude, and we believe that more improvement is possible. Placing views side by side may not be sufficient for creating an effective suite of displays. Moving from one view to the other requires considerable re-orientation to the scene by the user. Methods are needed for improving the correspondences between objects in the views that alleviate the effects of re-orientation. The concept of visual momentum [26] may offer ideas, such as the use of natural and artificial landmarks, for improving the correspondence. Investigation of these and other concepts is currently underway.

Our antenna placement experiments extended our program of research on how to improve perception of object shape, position, and location to a more complex and applied operational domain. In this domain, we found considerable support for our basic distinction for using 3-D perspective views for shape understanding and for using 2-D views to judge relative position of objects. Applying this framework, we are currently building several "orient and operate" prototypes for use in real-world military display systems.



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Decision Support Displays for Military Command Centers

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ABSTRACT

This paper summarizes work on interface design requirements for decision support tools and for command centers at the Commander, Joint Task Force (CJTF) level. These tools include a "knowledge wall" for decision-makers and multi-modal work-stations for the liaison officers who maintain the summary situation displays for each functional area, enabling a new concept of operations based on enhanced situation awareness throughout the command team.

INTRODUCTION

For over 10 years, SSC San Diego, with sponsorship from the Office of Naval Research (ONR), has been striving to develop improved displays based on decision support technology for military decision-making. At the center of this effort has been the Tactical Decision-Making Under Stress (TADMUS) project and its successors. The TADMUS project was spawned by the 1988 USS *Vincennes* (CG 49) incident, in which an Aegis cruiser, engaged in a littoral peacekeeping mission, shot down an Iranian Airbus after mistaking it to be a tactical threat. Investigations following the incident suggested that stress may have affected decision-making and that the effects of stress were not well understood. The TADMUS project was established to address these concerns and to develop improved decision support tools for use by command decision-makers.

TADMUS developed a series of prototype decision support tools that came to be embodied as the integrated Decision Support System (DSS), (Figure 1). The DSS research showed that when tactical decision-makers had the prototype DSS available, significantly fewer communications were needed to clarify the tactical situation, significantly more critical contacts were identified earlier, and a significantly greater number of defensive actions were taken against imminent threats. Furthermore, false alarms were reduced by 44%, and correct detection of threat tracks

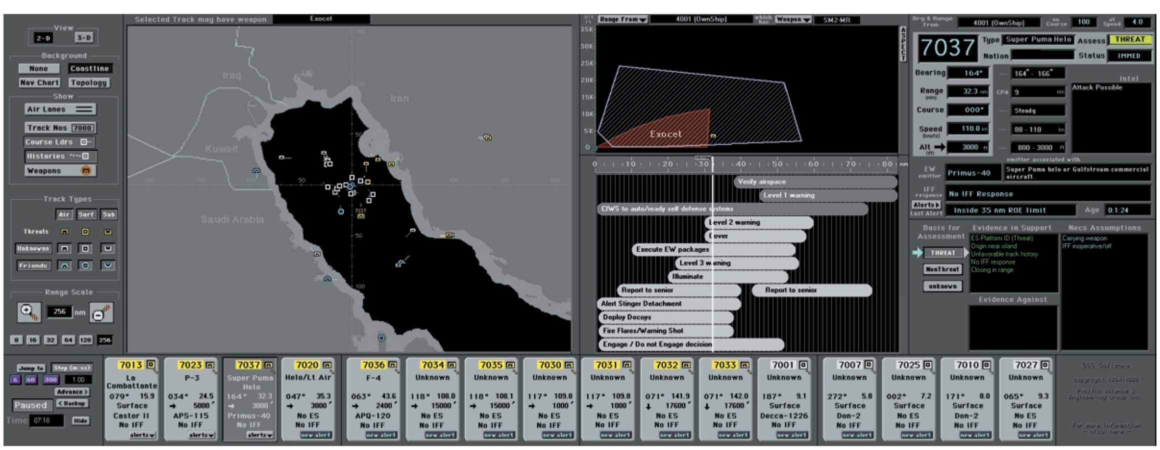

FIGURE 1. The TADMUS Decision Support System.

increased by 22%. These findings suggest that the prototype DSS enhanced the commanders' awareness of the tactical situation, which in turn contributed to greater confidence, lower workload, reduced errors in adherence to rules of engagement, and more effective performance.

The Chief of Naval Operation's Strategic Studies Group XVI report "Command 21—Speed of Command" recognized the significance of the TADMUS work and stated that its results were more broadly applicable. The Group concluded that

- Fleet decision-makers are faced with too much data and not enough information.
- Fleet information systems are often not designed to support the decision-makers.
- Reduced manning requirements and complex mission requirements will further exacerbate the problem.

One of the key recommendations to come out of the Command 21 report was that decision support technology developed in the TADMUS project should be extended from single ship combatants to higher echelons of command. The Command 21—Decision Support for Operational Command Centers (Command 21) project is addressing this recommendation by conducting research into the unique requirements of decision-making within military operational command centers.

The initial Command 21 work with Second and Third Fleet command ships has suggested that (1) collaboration is problematic in these command centers, and (2) commercial off-the-shelf (COTS) collaboration tools often are not as useful as might be expected. Military decision-makers were found to engage in "asynchronous collaboration," where each was working on different parts of a common problem in their own space and their own time, and as a result, each having their own decision cycle. This situation is different from traditional "synchronous" collaboration, such as the "brainstorming" or group problem solving found in the business world. Staff-wide synchronization is largely achieved when briefings are given to the assembled staff at watch-turnover. A central premise for Command 21 is that "Speed of Command" can only be achieved when it is not necessary to stop and brief command decision-makers so that they can be fully informed as a basis for deciding what actions to take. The Command 21 project has developed a concept of operations for sharing information that incorporates unique, Web-enabled collaboration "push" tools to provide all decision-makers ready access to the best available data at all times.

One Command 21 tool is the "knowledge wall," shown in Figure 2. The wall features a series of windows incorporating decision support tools tailored to the Commander Joint Task Force (CJTF), as well as windows with "summary status" information being "pushed" from the anchor desks used by liaison officers (LNOs) representing the various

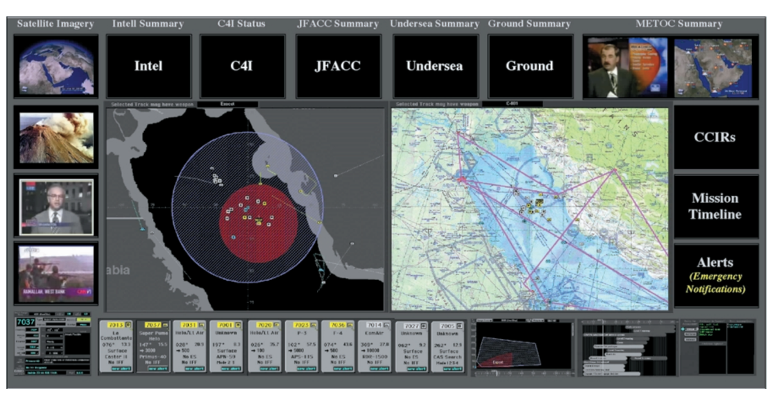

FIGURE 2. Command 21 knowledge-wall vision.

CJTF departments. The battle watch captain in charge of the command center can choose which aspects of the situation to focus on by moving relevant content to the center of the wall and drilling down into deeper levels or related information.

A watchstation being developed for the DD 21 (21st Century Destroyer) as part of the ONR Manning Affordability Advanced Technology Demonstration could be adapted as a "knowledge desk" to allow LNO collaboration. The knowledge desk uses software tools (COTS and information-push Web applications) together with computer display hardware to enable the operator to create and publish value-added information to the Web. Figure 3 shows a conceptual version of the knowledge-desk operator console. It consists of an integrated "desktop" spread across four different display surfaces. The top-right display is dedicated to routine office tasks such as preparing briefs, processing e-mail, writing memos, etc. The top-center display is dedicated to providing the tactical situation "big picture" tailored to the user's decision-making needs. The bottom-center display is a dedicated place for monitoring the execution of an operational plan. The top-left display is a tool explicitly designed to facilitate sharing information. The concept uses templates to "push" information from the operator to a Web site viewable by the rest of the command staff. The information "pushed" consists of worksheets, forms, and prompts to others on the command staff that would facilitate their understanding information relevant to their decision-making tasks. The software tools cause the information pushed to be formatted in a manner that others would recognize and understand, and published to a shared database in the Web environment.

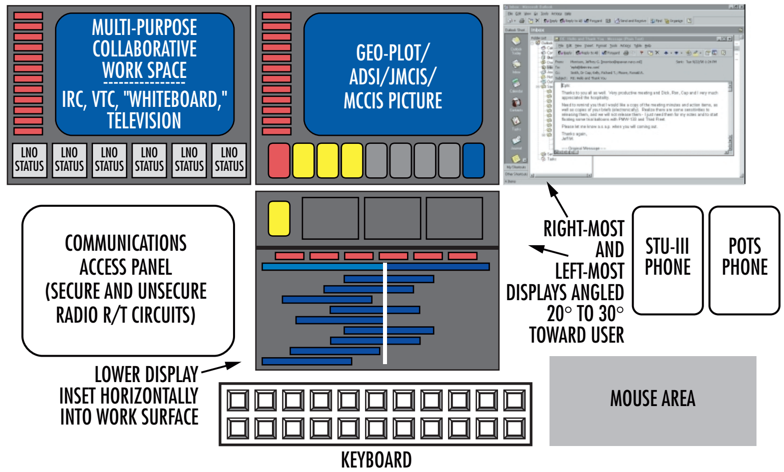

FIGURE 3. Knowledge-desk concept.

The development of the knowledge wall was greatly accelerated through its use as part of the Global 2000 wargame. The objective of this game was to explore how the elimination of "stove pipe" command and control systems (i.e., "network-centric warfare") might change the way we perform military missions. The wall was designed using COTS hardware and software capabilities that exist today so as to minimize development costs, and therefore differs from the original Command 21 knowledge-wall vision. Figure 4 shows the knowledge wall as installed in the Joint Command Center at the Naval War College.

FIGURE 4. Global 2000 wargame knowledge wall.

The knowledge-wall hardware consists of a dual-processor Information Technology for the 21st Century (IT-21)-compliant workstation using three 4-port Appian Jeronimo Pro COTS video boards. The knowledge-wall display is made up of ten 21-inch CRTs and two SmartBoard rear-projection large-screen displays with internal liquid-crystal display (LCD) projectors. The displays operate as a single, integrated digital desktop, where each physical display has a resolution of 1024 by 768 pixels. This creates a digital desktop of 6144 by 1536 pixels. An additional CRT is dedicated to video and video teleconferencing requirements.

The peripheral displays are intended to provide summary information for each of 14 functional areas of the CJTF command identified through knowledge engineering with the staffs of the U.S. Navy Third Fleet, Carrier Group One, and Carrier Group Three. Each summary display is formatted consistently by using a template-authoring tool that facilitates the creation of, and linking to, a variety of Web content without the operator responsible for producing content having to know hypertext mark-up language (HTML). Additional authoring tools were provided to facilitate the creation and publishing of map-based tactical data. All pages are implemented as HTML pages on a common server, with numerous links to more detailed pages for supplemental information.

Figure 5 shows how the information might look in a representative summary display. The title line indicates the functional area described by the display. The "stop lights" in the top-left quadrant are intended to be viewable from 15 to 20 feet away, and indicate the status of activities in various time frames. Light colors indicate the severity of the alerts in terms of their deviation from the plan. The bottom-left quadrant provides space for a summary graphic or multimedia object. The right side of the screen provides space for amplifying links/headlines. The "Alerts" section describes specific problems within this domain/functional area that might be of interest to others. The "Impacts" links describe the impacts of alerts in terms of effects on other functional areas. The "Links" area allows access to reference and supplemental material. Any text or graphic in the page may be linked to a more detailed Web page.

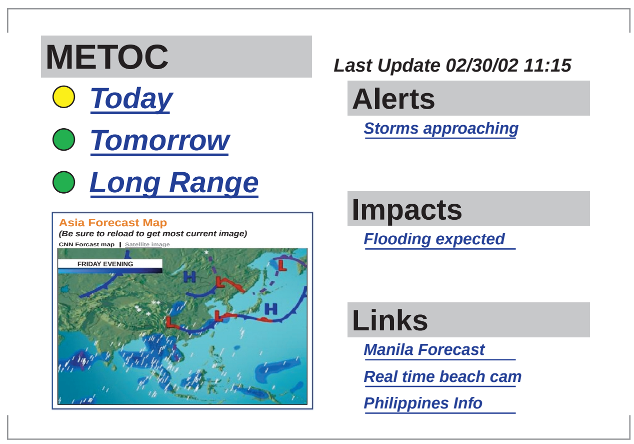

FIGURE 5. Representative summary display.

The Global 2000 wargame substantially validated the case for the use of Web-enabled decision support and collaboration tools as a means to "Speed of Command" and network-centric warfare. At the start of the game, it was argued that speed of command meant not having to stop to have a situation briefing to figure out what was known across the staff. By using the knowledge wall and a number of information technology collaboration tools, not one staff briefing was required through 8 days of game play. The wall was used extensively, with 30 to 70 unique summary pages being accessed each hour.

Both the TADMUS and Command 21 projects have empirically demonstrated how the application of decision support technology and effective human factors can improve military decision-making by turning data into meaningful information presented where, when, and the way it is needed. The Global 2000 wargame showed how network-centric warfare, in combination with decision support and a Web-enabled command and control architecture can move tomorrow's military to "knowledge-centric warfare."

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Development of Wearable Computing, Advanced Visualization, and Distributed Data Tools for Mobile Task Support

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ABSTRACT

This paper presents an overview of SSC San Diego projects to develop novel information systems based on wearable computing, advanced visualization, and wireless technologies. User-centered design of these devices, to include proper principles of human perception and cognition, enables individuals to interact seamlessly with information and with other personnel regardless of their physical location. The results are better decision-making and shortened timelines for task completion.

INTRODUCTION

New approaches to on-the-job information support are being made possible by advances in wearable computing, hand-held information devices, and wireless communications technologies. Expanded data-storage capacity, innovative visual displays, and small lightweight packaging provide many choices for the design of systems that enhance information access, decision-making, and communication among sailors or Marines regardless of their location.

While commercial products can be assembled to accommodate a variety of purposes, an enterprise-level perspective is still required to realize their full potential. SSC San Diego has supported this need by integrating diverse commercial technologies, mapping them to user applications, adding design or functional improvements as appropriate, and conducting impartial performance testing of the resulting systems. SSC San Diego's goal is to ensure the smooth integration of commercial products into capable and robust military systems that support new operational capabilities.

ENABLING TECHNOLOGIES

Mobile information tools continue to emerge from industry at an accelerating rate. Critical technologies for enabling mobile support include improved computing resources, innovative information displays, interaction tools optimized for portability, a range of small imaging sensors, and a wireless communications infrastructure. These technologies can provide the user with responsive, easily accessible task and decision support at virtually any work location. The quantity and variety of these new products, however, only highlight the essential engineering tasks of system integration and testing to ensure that technology investments are ultimately realized as practical enhancements to naval capabilities. Although such tools may work well independently, it is their combined interaction that provides major advances in mission effectiveness.

Computing Resources

Computing and storage power for wearable or hand-held computers expands at roughly the same rate as desktop units, owing to the increased interest in these portable devices for an ever-widening range of industrial jobs. Typical commercial systems feature Pentium II CPUs in the 233-MHz class, with random access memory (RAM) resources of 160 MB and integrated hard-drive storage of 8 GB. Many vendors have already announced systems with greater power.

Information Displays

High-resolution color displays (e.g., 640 x 480 pixels), readable in both bright and dim light, are now available in hand-held and head-worn variants. While hand-held systems are most common, head-mounted displays (HMDs) support task performance in unique ways. In particular, HMD information is always available in the field of view so the user does not need to look away from the workspace. Some systems feature "see through" capability, where information is presented on a semitransparent surface or on the lenses of eyeglasses. If additional sensors are added to the system to track head position, displayed information can be synchronized, or registered, with the real-world scene, much like a pilot's head-up display (HUD). This approach is known as "augmented reality," and current applications include labeling and explanations of equipment parts, visualization of subassemblies that cannot be directly seen, animations of component operation, and sequential cueing of procedures as they are performed. SSC San Diego researchers have developed new display metaphors for effectively presenting information on HMDs—with special emphasis on augmented reality—and have conducted systematic user testing to establish the most appropriate allocation of information between hand-held and head-worn displays. In addition, SSC San Diego has generated inexpensive concepts for head tracking required to support practical augmented reality displays.

Interaction Tools

Miniaturized keyboards, keypads, and mouse tools are already familiar to users of portable computers, although stylus tools and speech recognition are becoming more common due to personal digital assistant (PDA) popularity and the growing need for hands-free computer interaction in offices. SSC San Diego has tested each of these technologies and has, additionally, developed gesture control methods (i.e., computer interaction using hand and finger movements with specially instrumented gloves) for interacting with information on HMDs.

Sensors and Imaging Tools

The utility of mobile information devices is clearly enhanced when they are equipped with sensors that capture data about the work environment (to document a task or to share visualization with others) or when they are equipped with sensors that extend human senses in hazardous situations. Video and still cameras are commonly used in industrial settings to support maintenance collaborations with remote technicians, and both military and civilian communities have employed thermal and low-light sensors during firefighting and surveillance tasks. SSC San Diego engineers are exploring the roles of such sensors in a variety of field, ship, and shore settings through user interviews and job analysis.

Information Sharing

Whether recording data on site, transmitting data to another site, or accessing remote data resources, essentially all naval jobs involve information sharing. Portable information tools on the commercial market typically offer some form of sharing through physical transfer (e.g., computer docking), or through radio, infrared, modem, or cell phone connectivity. Most recently, wireless local-area network (LAN) technologies—and Internet-based communications methods—have become a primary focus of fleet interest for distributed information exchange aboard ship. Internet-based communications are useful for linking networks of people and data sources with each other. SSC San Diego is actively involved with ship- and shore-based wireless LAN systems, and has designed innovative extensions to Internet communications protocols that support the unique demands of mobile, intermittent connectivity (such as lost or unreliable communications nodes, retransmission of unacknowledged data, etc.).

SSC SAN DIEGO DEVELOPMENT ROLE

There is no shortage of portable, yet potent information technologies to support mobile Marines and sailors. Operational effectiveness of new systems, however, must be preceded by a development process that starts with examination of user task and information needs, moves through informed selection and integration of component technologies, and concludes with field validation testing. Given that most technologies now originate from the commercial sector, execution of this process represents the essential "value added" contribution of SSC San Diego engineering. Two projects that illustrate this SSC San Diego development role in wearable computing technologies are the Advanced Interface for Tactical Security (AITS) and the Virtual Technical Data System (VRTDS).

Advanced Interface for Tactical Security (AITS)

The AITS project—an initial SSC San Diego effort in mobile computing and visualization—was intended to support field soldiers. Specifically, the Defense Threat Reduction Agency (DTRA) charged SSC San Diego with developing an intuitive information interface for U.S. Army security system operators (although units of all the military services perform similar missions). These personnel monitor sensors of diverse types are placed around the perimeter of a protected area. When sensors detect an intrusion, security operators must quickly orient themselves and interpret the nature of any threat. The AITS design effort began with observations and interviews of several security units, and proceeded based on documented user information needs.

AITS is based on a commercial wearable computer with both HMD and backup hand-held displays (Figure 1). SSC San Diego engineers extended this foundation with a commercial global positioning system (GPS) unit for location tracking, a compass and tilt sensor for head tracking, a wireless communication subsystem, and an instrumented glove for gesture control of display features. Head tracking permitted the development

FIGURE 1. Based on a commercial wearable computing system and augmented with SSC San Diego-developed software and display concepts, AITS is used for field surveillance and monitoring. With use of see-through display components and head-tracking technology, symbology can appear superimposed over the environment.

of three distinct display modes based on the operator's gaze:

1. When the operator looks up—a raw information display from whichever sensor initiated an alert.
2. When the operator looks down—a geo-referenced map presentation, synchronized to the user's location.
3. When the operator scans the horizon—discrete target cues and supporting information about the detected intrusion.

AITS provides a practical augmented reality interface for field use and permits security operators to monitor their sensor suite while on the move. Internet protocol extensions, described above, support data sharing by multiple security operators in real time, using the continuously updated map display. The AITS interface introduces a range of new display, interaction, and tracking capabilities at relatively low cost; SSC San Diego developers are currently testing user response to these design features.

Virtual Reality Technical Data System (VRTDS)

VRTDS was initiated as a component of the Network-centric Q-70 program under the sponsorship of the Space and Naval Warfare Systems Command (SPAWAR). VRTDS built upon a technical foundation established by AITS and is intended to support a variety of mobile shipboard tasks. The VRTDS design approach involves a selectable range of sensors, displays, computing resources, and interaction tools, all placed on a foundation of wireless communications technologies (Figure 2). VRTDS can present information in a variety of formats and incorporates augmented reality concepts for selected applications. Because VRTDS relies on proper selection and configuration of commercial components, the interface can be tailored in cost and capability, and can grow with new technologies. VRTDS emphasizes situation awareness and ease of operation for faster response and reduced training requirements.

FIGURE 2. The VRTDS employs a see-through display concept, with graphics and text superimposed over the environment, which can provide maintenance and troubleshooting information directly in the user's field of vision. VRTDS displays can be controlled with gestures, using a specially instrumented glove.

The VRTDS development process is characterized by early and frequent involvement of operational communities (e.g., tactical decision-makers, maintenance personnel, and technical experts) concerning design features and functions. VRTDS has given explicit priority to information display and decision support issues, with technology selection and integration used only to realize a required information need. Shipboard functions targeted for VRTDS support include maintenance, emergency response, telemedicine, and command and control.

Maintenance

The visualization tools for maintenance support typically provide for the electronic display of equipment diagrams and text material. More sophisticated methods, however, can furnish the technician with views of the inner assemblies of equipment before maintenance begins. Such tools can also present amplifying information about equipment without making a person stop and consult manuals. Portable computing systems with flexible commercial software can even be employed in place of current test equipment, i.e., "virtual test instruments," providing both the computer processing and the visual interface for a variety of troubleshooting functions now supported by special-purpose devices. When maintenance tasks are completed, these same portable tools can be used to document the actions performed, the parts used or ordered, and the results of the repair effort—information that can then be uploaded to remote databases to support quality-assurance measures, trend analyses, material resupply, and scheduling of future tasks. Finally, advanced visualization and computing tools can be used to deliver maintenance training and procedures practice in order to keep seldom-used or complex skills sharp while deployed.

Emergency Response

Current damage-control activities are still coordinated almost exclusively with verbal communications. Data visualization using portable sensors, personnel tracking, and wireless communications tools can, however, disseminate a large volume of status information accurately and quickly to team leaders and to the ship captain in order to enable more rapid selection and efficient deployment of response resources. Expanded use of such tracking technologies can support real-time location of all personnel deployed in ship spaces, as well as report on their condition and welfare (e.g., through physiological and environmental sensors), thus greatly reducing the time required to locate and account for ship crew members during emergencies.

Telemedicine

It is a relatively straightforward matter to extend the application of maintenance and emergency response features, described above, to the needs of telemedicine. A combination of special sensors (e.g., physiological monitors, thermal and conventional imaging cameras), virtual test equipment concepts (to process sensor signals), on-site data stores, and wireless data sharing provide a complete foundation for mobile medical personnel to gather and transmit casualty data from the encounter site, to confer with remote experts, and to record care procedures for patient processing.

Command and Control

Finally, VRTDS components are being examined as interfaces for Navy command and control applications. Such interfaces could provide tactical information to the warfare commander without the space and power requirements of current workstation displays. Furthermore, this information would be available regardless of where the commander was physically situated in the ship. Such a distributed computing and visualization capability could, for example, permit personnel to monitor and control ship systems, evaluate tactical displays, and control weapons entirely from a variety of locations. Control authority is, however, a central issue beyond the realm of technology support; this application is, therefore, only exploratory.

SUMMARY

Wearable computing, portable visualization tools, and distributed communications tools have already proven their value for many shipboard activities; mobile information support, wearable computing systems, and wireless communications have all been successfully tested both ashore and aboard ship with the help of SSC San Diego engineers. Current SSC San Diego efforts are focused on incorporating additional government and commercial technologies into these mobile information systems, developing a stable testing facility, and coordinating efforts with other agencies.

Military and engineering leaders should be prepared to expect powerful new tools from these technologies and should also be prepared to think boldly when formulating management schemes to use such capabilities. In whatever form such systems evolve, however, SSC San Diego will have an important role to play to ensure that the Fleet obtains maximum benefit from its investment.

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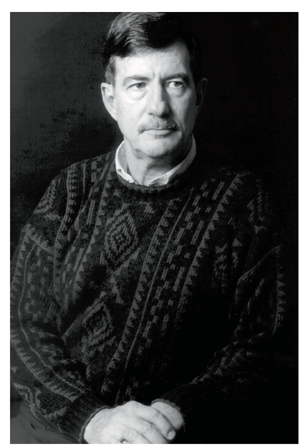

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Adaptive Intelligent Agents: Human–Computer Collaboration in Command and Control Application Environments

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ABSTRACT

In the past decade, intelligent agents have proven to be of interest in many important application areas, such as electronic commerce on the Internet, the control of space probes on missions to the outer planets, the design of user interfaces, and military mission planning and execution operations involving decision-making and coordination functions—collectively known as command and control (C^2). C^2 application environments are dynamic and non-deterministic; thus, there are unique challenges involved in incorporating intelligent-agent technology within them. Decision-makers are required to assess and solve a variety of problems as quickly as possible, at times without adequate resources. The incorporation of agent technology into C^2 applications offers great benefit in the form of human–computer collaboration and provides decision-makers with assistance in carrying out their mission-related activities. This paper presents some suggestions on the types of tasks best suited to agents used in C^2 application environments and discusses the challenges involved in using agent technology within C^2 application environments.

INTRODUCTION

Command and control (C^2) application environments are characterized by their uncertainty and dynamism. This presents several challenges in implementing agent technology into them. Agents must be able to adapt to the changing circumstances and events of a military contingency, which means they must remain somewhat autonomous if they are to effectively assist human decision-makers in accomplishing their C^2 mission-related activities. Agents must possess enough autonomy to behave proactively in order to be of maximum benefit in a human–computer partnership. While this is true, the abilities of human decision-makers in the areas of conceptualization, abstraction, and creativity [1] far surpass their agent counterparts, whose strengths lie in computational speed, parallelism, accuracy, and data assimilation and management. Given these facts, this paper attempts to answer the following questions: (1) How can we effectively use agents to assist military decision-makers? (2) To what level can agents remain truly autonomous when humans must be kept in the loop? (3) Are there certain tasks that are better suited for agents to perform in C^2 application domains?

DEFINITIONS

This section defines some of the terms that will be used throughout this paper.

Autonomous Agents: Software and robotic entities capable of independent action in open, unpredictable environments. Autonomy has most often been defined as freedom from human intervention, oversight, or control [2].

Software Agents: Autonomous software entities that perform tasks on behalf of a user or another agent. Autonomous entities can assist users when performing their operations, collaborate with each other to jointly solve different problems, and answer users' needs [3].

Adaptive Agents: Webster's dictionary [4] defines "adapt" as the capability "to adjust (oneself) to new or changed circumstances." An adaptive agent can acquire knowledge (learn) and adapt (adjust) its behavior accordingly.

Multi-agent Systems: Multi-agent systems may be regarded as a group of intelligent entities called agents, interacting with one another to collectively achieve their goals [5]. Multi-agent systems implement distributed problem-solving, which provides many advantages including fast, parallel computing and increased fault tolerance [6].

Command and Control: Decision-making and coordination activities performed by military decision-makers during a contingency.

Human–Computer Collaboration: The ability of humans and computers to work together to solve problems. Specifically, while engaged in problem-solving and decision-making, humans contribute the ability to draw upon personal experience and intuition, and autonomous agents assist humans by providing superior speed, accuracy, and computational power.

AUTONOMOUS AGENTS IN C^2 APPLICATION ENVIRONMENTS

This section is divided into two parts. The first part gives an overview of current C^2 operations. The second part presents a domain example describing possible tasks that could be assigned to agents acting autonomously to assist decision-makers in accomplishing their mission-related activities.

C^2 Overview

The need for automating methods of accomplishing military C^2 activities is of utmost importance in today's military mission planning and execution operations. As previously defined, C^2 activities are those decision-making and coordination activities performed by military decision-makers. In combat, effective C^2 and success in battle requires commanders to develop associations and thought patterns. During a contingency, military commanders and their staffs must make timely and effective decisions under pressure. They often spend too much time manipulating information systems to filter data into meaningful information and performing routine tasks to assess the situation. It takes years of training and experience to develop the required skills to manage the pre-planning and subsequent engagement during a tactical encounter. Thus, even with advances in the area of intelligent systems, in C^2 environments humans must be kept in the "loop." Currently, most military C^2 activities performed by decision-makers are accomplished via paper and voice circuits. Toward this end, technology based on intelligent agents acting autonomously to perform user-specified tasks offers potential for automating and speeding up many of these time-critical activities. The next section focuses on human–computer collaboration within the context of a specific C^2 application domain example.

Domain Example

Air Warfare Operational Overview

Air warfare is defined in Joint Department of Defense publications as "the detection, tracking, destruction, or neutralization of enemy air platforms and airborne weapons, whether launched by the enemy from air, surface, subsurface, or land platforms." In an air warfare mission, the Air Warfare Commander (AWC), also known as the Area Air Defense Commander (AADC) for joint operations, is responsible for the development and distribution of an Area Air Defense Plan (AADP). The AADP, which contains the campaign plan and pre-planned responses used in dealing with the enemy air threat, is sent via teletype as a standard formatted military message called the Operational Tasks (OPTASK) Air Defense (AD), to all of the commanders in the battle group and subordinate air defense units, both afloat and ashore. The other significant report promulgated throughout the battle group is the OPTASK Link, which specifies the data link (communication) procedures within the battle group. Upon receipt, the individual commanders analyze the OPTASK AD and Link and generate plans for their respective region/sector of concern within the area of operations. Air defense planning also involves the coordination of air, surface, and mobile air defense assets. Decision-makers coordinate the allocation of scarce resources (airplanes, pilots, missiles, etc.) and work to minimize conflicts between competing engagements. This process is known as maintaining situational awareness. One of the main objectives of the AWC/AADC and his subordinates during the contingency is to maintain situational awareness. Table 1 lists the information they must keep track of in order to accomplish this objective.

The report generated in conjunction with maintaining situational awareness is called a situation report (SITREP). Currently, this is a voice report that is required once an hour from all warfare commanders in the battle group.

The next section presents suggestions about opportunities for human–computer collaboration in a Littoral Air Defense mission. Some ways that autonomous agents can assist decision-makers in carrying out C^2 activities, such as formulating pre-planned responses and maintaining situational awareness, are discussed.

TABLE 1. Situational awareness description.

Enemy
Locations (latitude-longitude, grid position, etc.)
Resources (troops, aircraft, tanks, artillery, etc.)
Status (in garrison, deployed, etc.)
Possible actions (attack, defend, reinforce, withdraw)
Friendly
Locations
Resources (platforms)
Status (combat ready, deployed, inside the continental U.S. [INCONUS], etc.)
Control measures (fire support coordination lines, restricted fire areas, phase lines, etc.)
Planned actions (e.g., OPTASK AD, pre-planned responses, etc.)
Logistics (Friendly and Enemy)
Locations
Resources (fuel, ammunition, food)

Agents in a Littoral Air Defense Environment

Picture a littoral air defense environment (operating close to the shore), where the Joint Forces Air Component Commander (JFACC) is responsible for coordinating theatre air defense among Joint and Allied forces. U.S. forces are involved in a major regional contingency located off the coast of California. The commander responsible for air defense is the Area Air Defense Commander, and is located ashore in an underground command center collocated with the Combined Forces/Joint Task Force Commander. Now we consider some of the specific tasks that agents could be assigned to assist decision-makers in the context of a littoral air defense mission. The AADC's first task will be the formulation of the pre-planned responses contained in the OPTASK AD. To accomplish this, the geographical constraints of the battle space and the evaluation of the enemy and assessment of its capabilities must be considered. The constraints of geography in the battle space must be considered because the contingency is located in confined waters. The battle space may be defined as a conceptual bubble around a friendly force in which a commander feels comfortable in detecting, tracking, and engaging threats before they can pose a significant danger to his vital units/defended asset list. Assume the commander is also constrained by physical "borders," such as reefs or shallows, or territorial borders such as the 12-mile limit, in the positioning of surface-to-air missile picket ships or screening platforms. These factors further reduce the reaction time allotted to any threat that does materialize. Agents with expert knowledge of the specifics of the topology of this region could take the initiative, generate potential plans for attack/defense, and present them to human decision-makers for acceptance or rejection. Another task that must be accomplished is the generation of the OPTASK Link message. Currently, the OPTASK Link report is prepared manually, using a chart and cross-referencing the communication protocols for each asset in the battle group to come up with the list of who can talk to whom. Clearly, this is a cumbersome task that could be automatically handled by an agent that could simply retrieve the necessary information, cross-reference it, and produce a report in a fraction of the time. Upon completion, the agent could present the OPTASK Link to the user for transmission.

Some tasks that agents could perform to help decision-makers maintain situational awareness include keeping track of both friendly and enemy logistics (see Table 1) and monitoring weather conditions. For example, an agent might be assigned the task of keeping track of how many missiles the enemy has. Agents that have access to knowledge about enemy order of battle, (the list of enemy assets) could recommend the optimum shot and determine vulnerabilities. Weather data should be updated periodically, a task that could be performed by a monitoring agent assigned to that particular type of information. For example, if an agent detects an approaching storm, it would then know to advise the decision-maker to suspend air operations temporarily. The agent would also check to ensure that the ship's fuel level was not less than 50%. If the fuel level was less than 50%, action would need to be taken. Fuel level seems like a small detail, but the consequences of a ship running out of fuel and not being able to refuel could be disastrous. Consider that decision-makers are already under a large amount of stress in a contingency, and that declarative memory power is reduced in such a situation. The commander has already been advised to know the enemy capabilities, which involves the analysis of all the ships, aircraft, and submarines that could be encountered. Clearly, this is not a trivial task because it involves the ability to commit a large amount of information to memory. Agents with expert knowledge can provide platform-specific guidance when the need arises, thereby reducing the chances of error in decision-making. There is no reason why a decision-maker should have to keep track of and remember these kinds of details when agents, which are independent of reactions to stress, can assist.

CONCLUSION

The need for automating methods of accomplishing military C^2 activities is critical in today's military mission planning and execution operations. This paper presented some suggestions on the types of tasks autonomous agents operating within C^2 application environments could best perform. These tasks could best be performed in a littoral air defense environment and include assisting decision-makers in maintaining situational awareness, keeping track of both friendly and enemy logistics, monitoring weather conditions, providing information about the geographical constraints of the battle space, and gathering data on the communication protocols for each asset in the battle space and producing a report. Agents need to maintain a minimal degree of autonomy to be of maximum use to decision-makers involved in performing their mission-related C^2 activities. For example, agents, unlike human decision-makers, can keep track of vast amounts of information and do not experience stress in crisis situations. Thus, agents with expert knowledge of enemy capabilities and enough autonomy to determine a need for action could provide platform-specific guidance, thereby reducing the chances of errors in decision-making.

Future research is required to establish the degree to which agents should remain autonomous when acting as planning and decision aids for military decision-makers. Additional research is also needed to prove that the tasks identified in this paper are the types of tasks best suited to agents operating in C^2 application environments.

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