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Modeling of Cognitive Loading aboard Naval Surface Combatants

Modeling efforts to support Optimization of Human/Machine teaming to support tactical decision makers afloat

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NIWC Pacific

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EXECUTIVE SUMMARY

Naval Surface platforms rely on human operators to interpret data from shipboard sensors and the Global Information Grid (GIG) in order to initiate actions that safeguard the ship and prosecute threats. The human must respond to information flows by taking appropriate actions. Currently the information flow overwhelms the operator's cognitive processing capabilities and the result is suboptimal decision making that can threaten the ship and crew. The goal of the Battle Management Aids and Decision Support (BMASED) project is to provide a modeling environment that quantifies mission performance as a function of threat lethality. The model identifies bottlenecks and inefficiencies that impede mission performance. The model indicates where artificial intelligence algorithms and machine learning should be introduced in order to increase the efficiency of the kill chain and reduce threat lethality.

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ACRONYMS

Acronym	Full Text	Meaning
ACT-R Models	Adaptive Control of Thought-Rational	A human performance modeling technique
AW	Alpha Whiskey	Battle group Air Control Authority for Integrated Air and Missile Defense
AWC	Air Warfare Coordinator	Shipboard Air Warfare Coordinator
CIC	Combat Information Center	Nerve center of surface combatants where situational awareness necessary to enable combat operations resides.
CO	Commanding Officer	self-explanatory
CSC	Combat Systems Coordinator	Responsible to keep the TAO informed of Combat System Equipment Status.
CSOOW	Combat Systems Officer of the Watch	The Officer or Chief Petty Officer that Manages the Ships Combat Systems.
DARPA	Defense Advanced Research Projects Agency	DOD agency for advanced research and capability prototyping
EOOW	Engineering Officer of the Watch	The Officer or Chief Petty Officer in charge of the Ships Propulsion and auxiliary systems such as steering gear and electrical plant equipment.
EWCO	Electronic Warfare Control Officer	Officer or senior enlisted watch stander that monitors the electromagnetic spectrum for threats and can electronically engage them.
HFE	Human Factors and Ergonomic Systems	A methodology and employs and "onion" model that describes how physical work environments effect knowledge elicitation and work efficiency.
IDS	Identification Data System Technician	Petty officer that attempts to Identify sensor contacts.
JFCOM	Joint Forces Command	The military organization tasked with analyzing and improving Joint Operation processes and lethality through manning and training.
MRT	Mean Residence Time	Task duration and human performance modeling technique
MSS	Missile System Supervisor	The Petty Officer that manages the ships two Vertical Launch Systems
OOD	Officer of the Deck	The officer in charge of maneuvering the ship safely and effectively.

Acronym	Full Text	Meaning
OPNAV	Chief of Naval Operations Staff	Staff that supports the Chief of Naval Operations at the Pentagon
RED CROWN	RED CROWN	Force Air Control Authority for check in/check out and return to force Air control
RSC	Radar System Coordinator	Responsible to effectively employ the ships AEGIS/SPY1B/C/D system
SAG	Surface Action Group	A tactical element of 2 or more ships tasked to perform a common mission
SESS	Signal Exploitation Surveillance System	Classified
SuWC	Surface Warfare Commander	Shipboard Surface Warfare Coordinator
TAO	Tactical Action Officer	Officer in charge of "fighting the ship"
TIC	Track Intercept Coordinator	The Petty officer that works with the TAO to determine track intentions
VACP	Visual Auditory, Cognitive, psychomotor	Human Performance research methodology
Whiskey	Alpha Whiskey	Battle Group Air Warfare Commander
Zulu	Alpha Zulu	Battle group Sea Combat Commander

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APPENDICES

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1. INTRODUCTION AND BACKGROUND

There are significant challenges ahead for the US Navy with regard to potential peer-adversary naval combat capabilities. Although many individual US Navy warship system components have improved over time (e.g., signal processing within radars, electronic warfare systems, and intelligence systems), the integration of these systems has been slow to improve. Efforts to improve human operator interaction with complex combat systems remain encumbered and outdated. In part, this is the result of disparate programmatic acquisition pipelines (i.e., OPNAV N9, Combatant Platforms, versus OPNAV N2/N6, C4I Systems). A lack of focus on surface ship combat system human interfaces has resulted in a myriad of confusing displays for CIC watch standers. The current class of human-machine interfaces (HMI) was considered well after the hardware and software engineering efforts produced required system functionality. The production of these interfaces was rushed, cursory and suboptimal.

Consider a scenario depicting current system performance versus desired performance during a ship self-defense exercise against air and missile threats. In Figure 1, lethality/survivability is plotted as a function of the threat lethality (e.g., number, heterogeneity, and dynamic behavior of threats). Figure 1 is a conceptual representation of system performance. Collecting data in order to create the plots depicted in Figure 1 is a challenge. Fleet exercises do not accurately reflect near-peer threats other than one or two threats at a time, as opposed to salvos of five or six aircraft or missile threats. Fleet exercises also do not use threats that mimic the true airspeed and behavior of the threat system seen in a combat scenario. Worst of all, these exercises do not allow for rapid manipulation of these types of variables, and there is no infrastructure for recording human performance. The number of data points required to characterize the curve depicted in in Figure 1 is large. Tens to hundreds of points are required versus the low 1 to 2 points that existing exercises may provide per year. Since the goal of any enhancement for Threat Lethality / Survivability is to move the inflection point of the curve to the right, and decrease the slope of any performance decline, the creation of enough data samples is of high importance. Further, this is desired for a large variety of conditions, thereby increasing the demand for data. It is unlikely that such data collection efforts can be done outside of lightweight, rapid, human-in-the-loop experiments.

The critical factors determining mission performance and hence the shape of the curve in Figure 1, are system capabilities and human decision-making capabilities. Human information processing and decision-making aboard naval surface platforms is currently extremely task intensive. This presents serious rate-limiting problems to the execution of an effective kill chain. As a consequence, in Figure 1, current mission performance deteriorates rapidly when confronted with higher degrees of threat lethality. In the future, threat lethality will increase as our adversaries augment their combat capabilities.

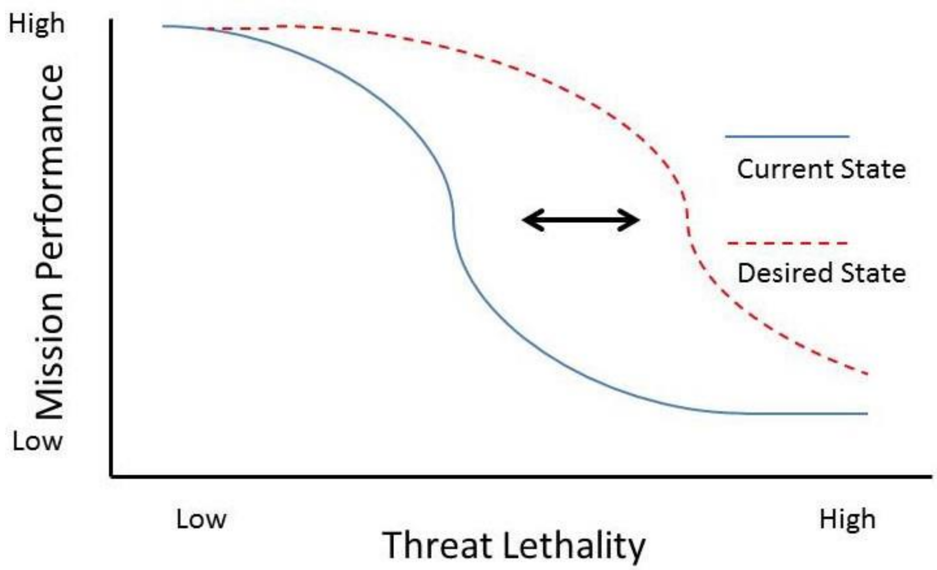

Figure 1. Mission effectiveness or performance (ME) as a function of Threat Lethality (TL); (TL is determined and varied by manipulating the number, heterogeneity, and behaviors of threats).

As an example of the intensity of the tasks combat decision makers must face, consider the role of the Tactical Action Officer (TAO). The decision-making capabilities of the TAO on a US Navy warship greatly affects mission performance in response to ballistic missile threats. The TAO is expected to monitor and interpret an immense amount of data. Figure 2 depicts the information input the TAO must process in order to obtain situational awareness. Each data set is independent and is presented over a separate device. There are many things the TAO must keep track of at once: Aegis over a proprietary terminal; IVCS over an audio handset; Internal Battle Group communications over Chat client; C4I Data over various HTTPS sessions. As if these were not enough the TAO also is required to keep track of Additional Battle Group communications over an RF channel. In combat [1], the TAO can be overwhelmed by the resulting data flow. None of the sources of information are integrated with other complimentary data sources. Thus the presentation of information creates a “Data Dump” instead of a Data repository that feeds a well-designed Human Interface tailored to decision-making.

Perceptibly well integrated information sets and data flow, based upon specific mission critical tasks, would enable faster and better decision-making. Good system design based on human/machine teaming would greatly facilitate overall system performance. For example, repeatable and effective combat engagements would occur and more stable and effective kill chains would be possible. These improvements would create second order effects by facilitating ease of use and lowering training requirements. An example how design can impact CIC air defense crew performance can be found in [2].

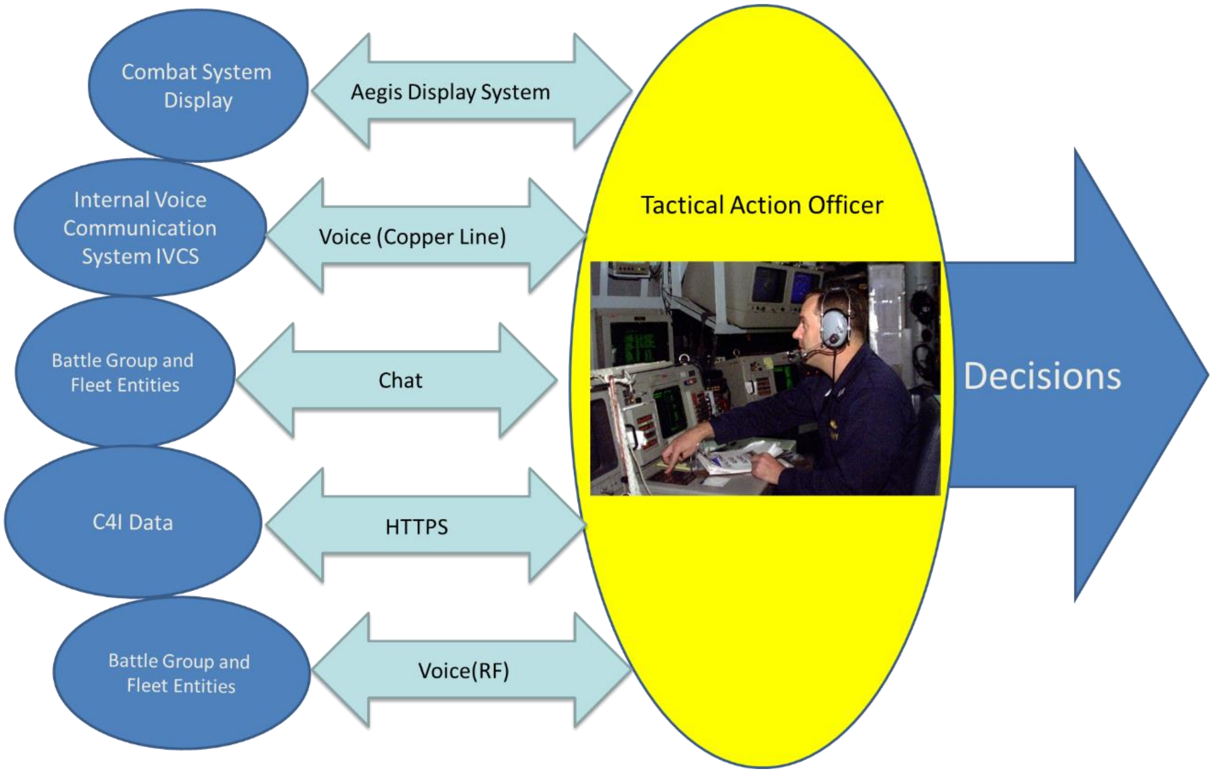

Figure 2. TAO network of information and communications a TAO must deal with simultaneously.

The purpose of this research is to quantify mission performance and demonstrate how it may be improved. The goal of improving the kill chain process and mission effectiveness raises the question: Where should funding and research efforts be directed in order to achieve these improvements? *Which* processes should be the focus of research and engineering? Can the problem of directing research efforts in order to improve system performance be scientifically addressed?

Perhaps the most critical problem is analyzing the complexity of human behavior found in Combat Information Center (CIC) decision-making. In the past, the Navy has relied on anecdotal accounts of human performance. For example, subject matter experts provide “guesstimates,” regarding task levels of difficulty and time demanding tasks. This creates problems for selecting which processes to improve. Guesstimates are not readily verifiable and may be misleading. SME estimation alone does not allow the exploration of the solution space necessary to predict mission effectiveness across a wide range of threat lethality.

The solution proposed in this research is to model human operators performing CIC tasks and decision-making. These models enable repeatable representations of complex relationships between human watch standers in order to quantitatively identify stressors and impediments to timely decision-making. This research entails cognitive modeling, systems modeling, and human in the loop experimentation.

The BMASED project focuses on the key decision makers and operator roles found in surface action groups (SAGs) and Strike Groups. These roles include the Tactical Action Officer (TAO), and the roles onboard surface combatants that support the TAO’s situational awareness, such as the Tactical Information Coordinator (TIC), and the Air Warfare and Surface Weapons Coordinators (AWC). To provide a clearer picture, Figure 3 depicts the watch stations in an Air

Warfare threat scenario where aircraft and anti-ship cruise missiles are threating own ship. Each of these watch stations must be modeled. (There is a list of all acronyms at the end of this paper that helps to understand the various roles of the watch stations below.) The heavily bolded circle represents the TAO, lightly bolded circles represent roles of high interest, and circles that are grayed represent auxiliary roles that may not be essential to the missile defense mission. In Figure 3, the TAO is communicating via both voice and via chat with various watch positions to develop his/her awareness of the battle space and also to formulate offensive and defensive decisions. Additionally, the TAO is reporting to higher-level authorities as well as answering queries from watch stations below him/her. The amount of communications and information processing required is immense.

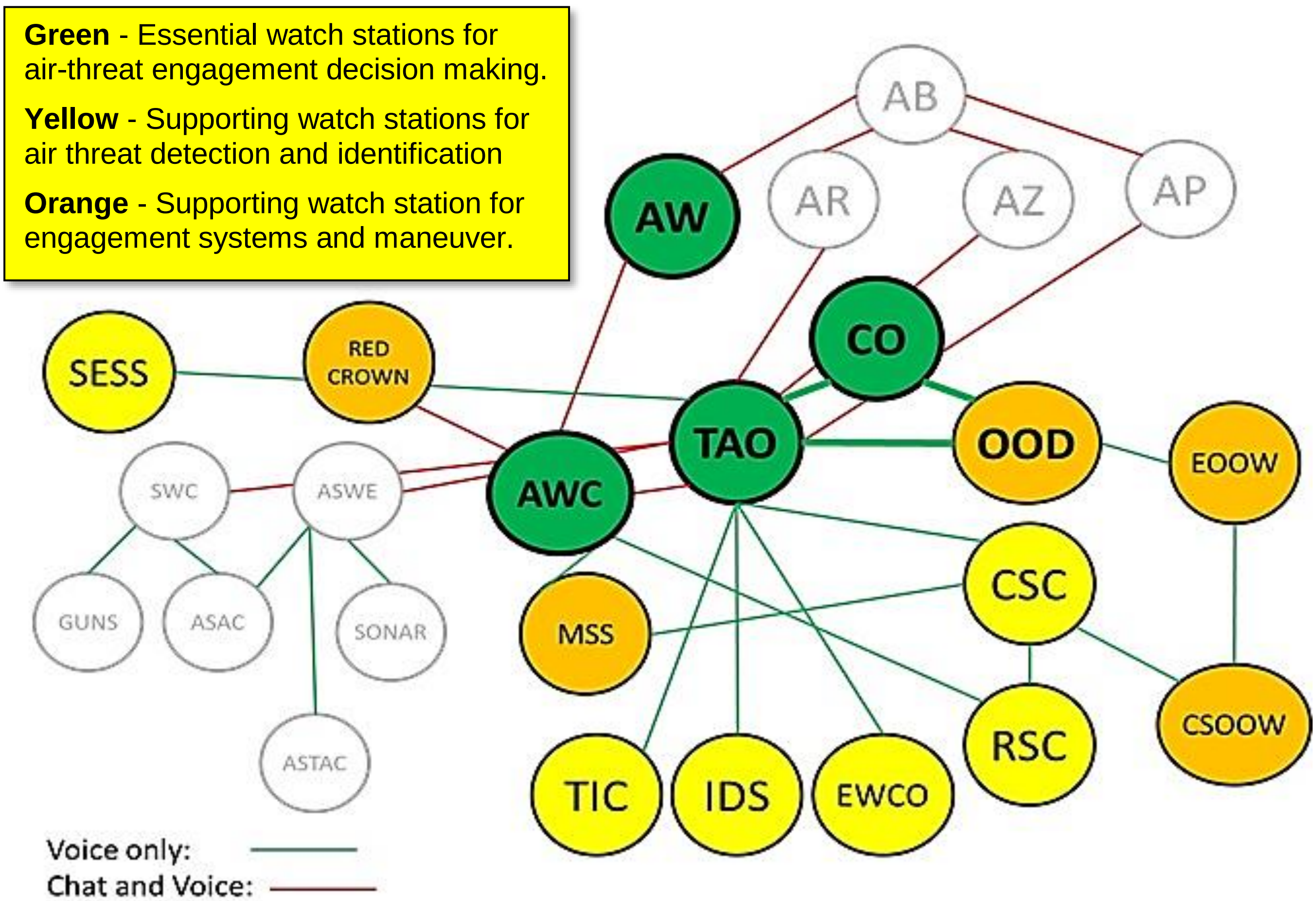

Figure 3. Air Warfare Watch stations.

2. MODELING MISSION PERFORMANCE

The BMASED project focuses on creating a model that optimizes human interactions with shipboard systems. The end goal is to demonstrate a model that informs choices the Navy makes among proposed improvements to the ship's system-of-systems.

Our effort includes both modeling and simulation capabilities. These components interact to provide precise estimation of proposed system enhancements to mission effectiveness and the kill chain. These models may be validated by testing predictions of how quickly or accurately a given mission element can be completed in experimental settings with real-world users in the loop (see Figure 4).

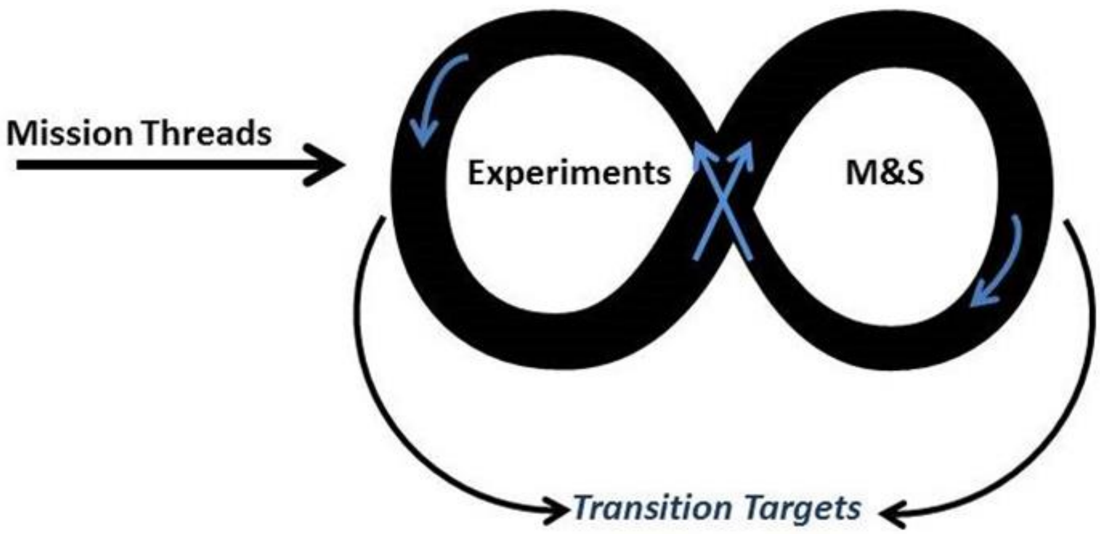

Figure 4. Human Machine Teaming Experimentation Methodology.

C3TRACE - Command, Control, and Communications - Techniques for Reliable Assessment of Concept Execution — is a modeling tool for evaluating different organizational concepts of Command and Control (C2) that can predict the impact of information flow on decision quality. The purpose of C3TRACE is to provide a modeling environment that can be used to evaluate the effects of different personnel architectures and information technology on system and human performance. Within C3TRACE, any organization, the people and technology assigned to that organization, and the tasks and functions performed by the organization, can be represented. Communications within and outside of the organization represented as information (voice, face-to-face, emails, chat, sensor, updates, haptic, radio, intercom, etc.) that will be considered in information processing and decision-making can also be represented.

Organizations, their personnel, and technology can be evaluated quickly and inexpensively with scenarios that test the impact of the different personnel or technology configurations, without the need for a live exercise or experiment. C3TRACE captures and evaluates important performance considerations for each organization that include task durations, information quality on which tactical decisions can be based, human Situational Awareness (SA) at the time of a decision, and workload levels [3].

This project uses C3TRACE to model the human-machine components of air defense warfare. In Figure 5, various combat scenarios are input to the model and trigger simulated operator responses. The model represents the "Systems" and human "Operators" that comprise the Air Defense Warfare team. Each operator in the air defense warfare team is represented by performing an Observe, Orient, Decide, Act (OODA) loop (see Figure 6). Each operator's OODA loop is a simulation designed to respond by performing tasks triggered by the scenario events that an operator would perceive on the combat system they are monitoring. These are the tasks that would be performed by actual human operators monitoring sensors and warfare information systems in combat. The model simulates human-machine interaction and human-human interaction necessary to respond to scenario events that unfold over time. In addition to an OODA loop, each operator has a communications loop that represents voice communications among the team of operators.

The C3TRACE model will be used to evaluate mission performance as it relates to threat lethality. To accomplish this, BMASED generates scenarios of increasing complexity resulting in increasing demands on the air defense warfare team. Each scenario is based on air platform trajectories generated by our MATLAB trajectory simulator. The scenario is represented as a dataset for input into C3TRACE.

Mission performance will be expressed as a function of threat lethality. The C3TRACE model evaluation consists of human time-on-task measures and System detection characteristics and response times. These measures allow the model to pinpoint bottlenecks and choke points that impede Mission performance. Thus the C3TRACE model will indicate where automation should be introduced in order to increase the efficiency of the kill chain and reduce threat lethality.

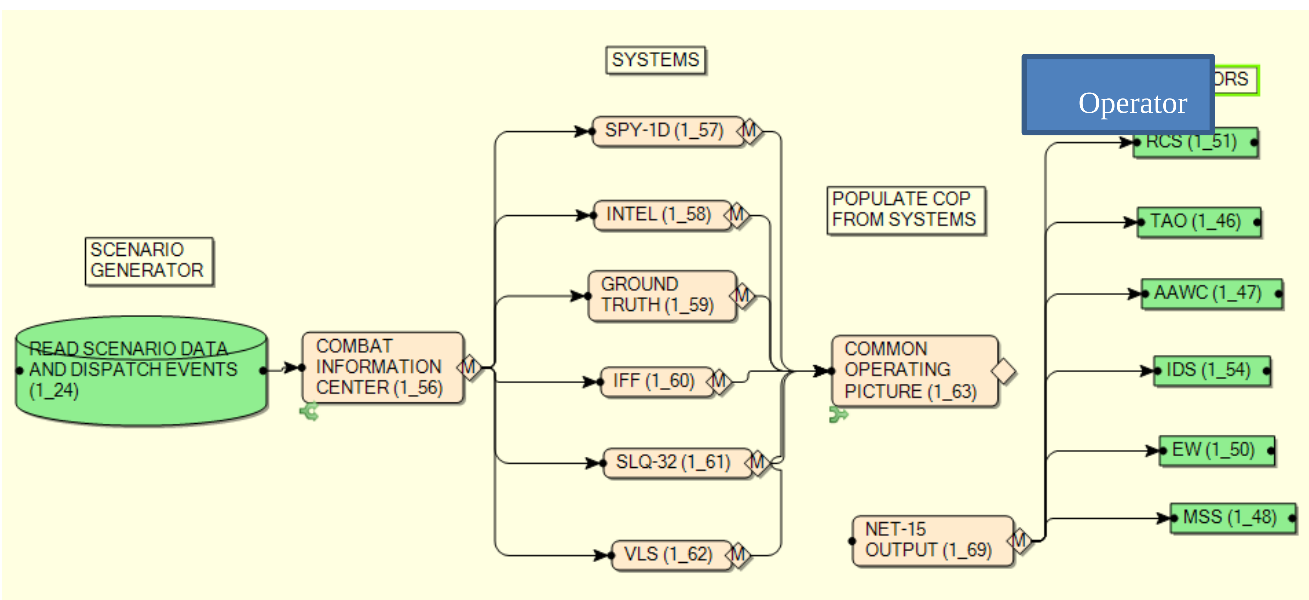

Figure 5. Air Defense Warfare C3TRACE model is comprised of 3 major components: the input scenario, the combat systems, and the air warfare human operators.

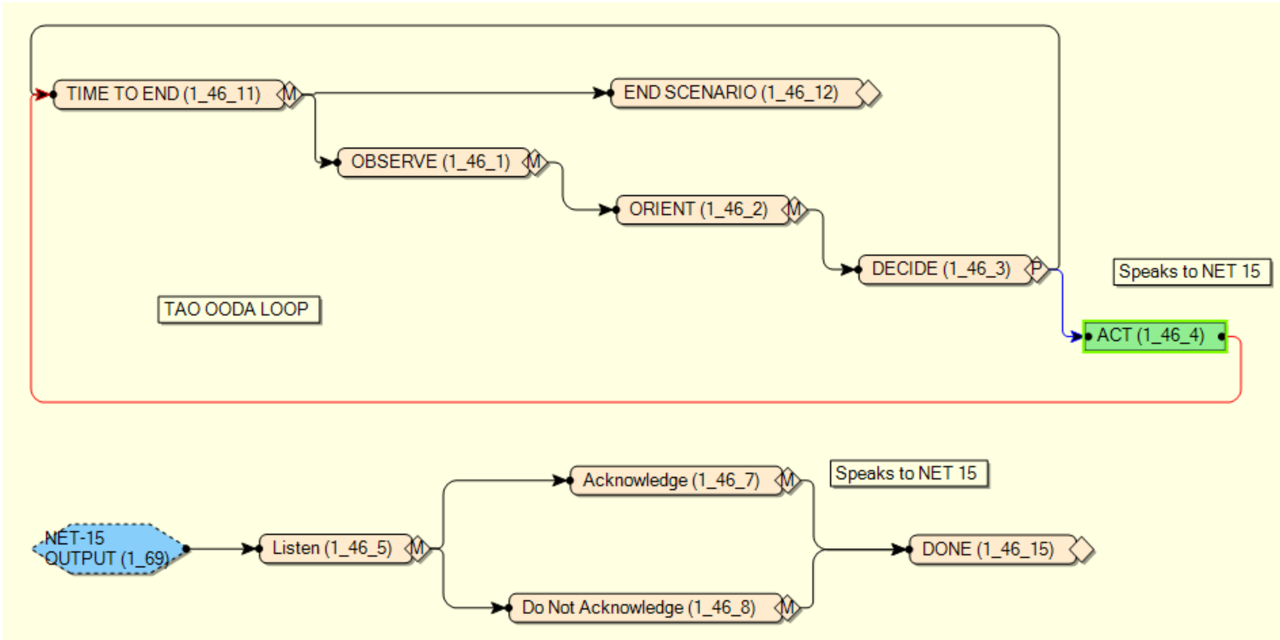

Figure 6. OODA loop (top) and communications loop (bottom) for the Tactical Action Officer. Each operator has similar loops.

In the future, in order to increase the predictive capability, we will introduce components of shipboard systems into the BMASED Performance Simulator. In Figure 7 are the following:

- The tactical simulator (TacSim 7.3) for the SEWIP/SLQ-32 electronic warfare suite generates realistic message traffic for scenarios represented by the trajectory files generated by our MATLAB® trajectory simulator.
- The DDG Display (EWBM) combining data flows to produce an insightful display for the TAO.
- NGTS, which produces real-time, own ship position data.
- NSS, which collects statistical data on threats, encountered versus threats defeated.

Currently, the emulation of human performance and computation of performance metrics will be performed; in C3TRACE. Future versions may incorporate additional shipboard components and human subjects.

Test Bed Data Flow:

1) The Next Generation Threat System (NGTS) is use to provide the experiment scenario with geo sit display and enemy force generation using user defined behaviors.
2) The Naval Simulation System (NSS) records statistics from experimental runs
3) BMASED Threat Model Stimulates the Anti Ship Cruise Missile (ASCM) threats.
4) The TacSim 7.3 detects the threat and provides line of bearing.

5) The Electronic Warfare Battle Manager (EWBM) determines the necessary defensive countermeasures to be launched.
6) The C3 Trace model generates the human response based on the tasks defined in the model and based on the EWBM recommendations.
7) The Human Performance Data Capture occurs via a laptop connected to the C3Trace Model

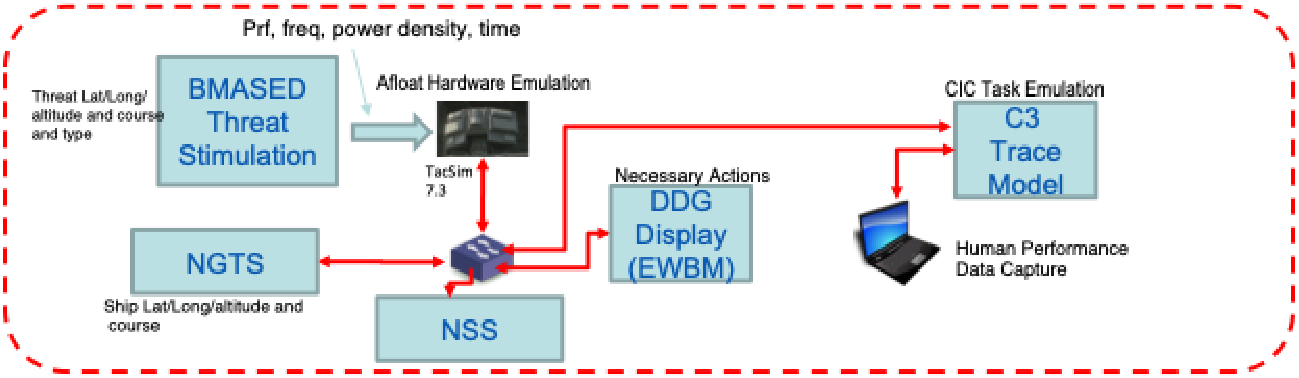

Figure 7. Human performance test bed (Planned).

3. SUMMARY AND CONCLUSION

In the future, modeling and verification of missions that incorporate human roles could lead directly, to the creation of virtual “agents.” Machine learning and other artificial intelligence applications routinely struggle to interface with human operators. In part, the difficulty in human/machine teaming is because man and machine do not have a common, task-based, language to share workload. Modern research done at NIWC Pacific focuses on developing interfacing methods for man-machine teaming. This; will be accelerated, by applying our modeling efforts [4–6]. Moving forward, the research team is utilizing the Army Research Lab ARL tool known as Command Control and Communications- Techniques for Reliable Assessment of Concept Execution (C3TRACE). After we have developed a validated model for mission thread execution, we will be able to predict mission effectiveness and our validation efforts will ensure these models are reasonably accurate. We will be able to represent mission effectiveness utilizing various metrics, including ship survivability/raid annihilation, time for raid annihilation, etc. Various needs for performance improvements; will be identified. The model, will be modified to represent any human-machine teaming improvements, and the data generated from the model may then be analyzed to validate those improvements. This will allow convergence on desired alternative human-system engineering plans that can improve overall Navy mission effectiveness.

In addition, within the next year (2019–2020) the BMASED team plans to build a human performance test bed as depicted above. The team will employ the human performance modeling techniques outlined in this paper and model results obtained through stimulation of the model with representative Navy Tactical data flows using stimulators and stimulators. This include such systems and models as the NAVSEA funded TacSIM which emulates a SLQ-32 (V6) and also a Next Generation Threat System (NGTS) that can stimulate a threat scenario as well as stimulate voice and information flows that align to the threat scenario. Additionally, BMASED will employ a flexible MATLAB kinematic model for inbound threats to “own ship” and these threats will include Anti-Ship Cruise Missiles and Maritime fighters.

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APPENDIX A
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13. SUPPLEMENTARY NOTES

14. ABSTRACT

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