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PERFORMANCE MEASUREMENT METHODOLOGY FOR ENHANCED SUBMARINE COMBAT

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This presentation outlines the development of a methodology for objective man-in-the-loop performance measurement of combat system features based on experimentation in a simulated tactical environment. A history of submarine tactical performance measurement is discussed. First, a top-down functional analysis for experimental design was conducted yielding a descriptive decision model. Considerations involving experimental repeatability and the validity of results in a part-task, medium-fidelity environment are discussed as well as measures of performance. A data-specified approach to decision analysis is described which distinguishes this effort from other scenario building efforts. Implications of this approach for decision aiding and training efforts are discussed. In conjunction with analytical efforts, the development of a simulation facility incorporating rapid prototyping is presented.

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NOSC

ANALYSIS BY-PRODUCTS

Guidelines for display prototyping

Training implications

Decision aiding design

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PART TASK FIDELITY vs. REPEATABILITY

Relatively less dynamic and complex submarine environment

Focus on Commanding Officer

Limit interaction to slice of time around a specific decision point

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MEASURES OF PERFORMANCE

Time

Accuracy

Adequacy

NOSC

Submarine as microcosm of command and control environment

Slower speeds

Fewer contacts

Less stringent communications

Decision makers not distributed

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ANALYSIS

Review of tactical documentation

Observation of combat teams

Interviews and workshops

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User centered top-down analysis

Medium fidelity part task simulation

Man in the loop experimentation

NOSC

OBJECTIVES

Realistic front-end evaluation process-
"Try before you buy"

Facility for measuring combat system operability

Effective displays/controls and decision aids

REFERENCES

Callan, J. R., Kelly, R. T., & Nicotra, A. (January 1978). *Measuring submarine approach officer performance on the 21A40 Trainer: Instrumentation and preliminary results* (NPRDC Tech. Rep. 78-9). San Diego, CA: Navy Personnel Research and Development Center.

Foley, J. D., & Wallace, V. L. (April 1974). The art of natural graphic man-machine conversation. *Proceedings of the IEEE*, *62*(4), 462-471.

Funk II, K. H., Kaiwi, J. L., & Fernandes, K. (February 1988). *Development of a facility for evaluating the interface design of submarine combat systems: A progress report* (NPRDC Tech. Note 88-19). San Diego, CA: Navy Personnel Research and Development Center.

Rau, J. G. (August 1974). *Measures of effectiveness handbook*. Irvine, CA: Ultrasystems. (AD-A021 461)

Sage, A. P. (September 1981). Behavioral and organizational considerations in the design of information systems and processes for planning and decision support. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-11*(9), 640-678.

Ship Analytics, Inc. (June 1983). *Plan for the use of SMARTTS to evaluate SUBACS operability*. Manassas, VA: IBM.

To summarize, the methodology for objective performance measurement of combat system effectiveness depends on human factors experimentation in a simulated tactical environment based on decision analysis. It features a rapid prototyping capability and performance assessment system. In the short term, these methods will help designers avoid system-induced human errors and inefficiencies. Eventual application should provide system capabilities for mitigating human information handling limitations and biases. The overall result should be submarine combat systems that enhance platform tactical effectiveness through the full range of operations in a more affordable manner.

Simulation Facility Development

The development of a simulation environment to support the experimental design has been undertaken. It consists of a simulation manager that creates and maintains a medium-fidelity tactical environment, making scenario data available to other components. The experimenter controls vignette interaction from this station. The second component is the command workstation, which provides the means for interaction of the subject with proposed displays. A large screen display has also been installed for additional capability. An integral decision-aid station has been provided to investigate advanced decision-aiding concepts within the tactical simulation environment.

A key component in the system is the display authoring system, currently under development. It provides a rapid display prototyping capability that allows display building by non-programmers and, potentially, subject matter experts. Candidate displays are configured here for immediate insertion into the command workstation where they can immediately interact with the scenario running in the simulation manager. A performance assessment system is also being developed to support the defined MOE/MOPs and to offer as much of an automated data collection system for experimental purposes as desired. Future improvements include incorporation of a 3-D graphics system. A detailed description of the facility appears in a previous report (Funk, Kaiwi, & Fernandes, 1988).

SUMMARY

The scope of our initial effort has broadened to include much more than objective performance measurement of submarine combat system features. A byproduct of the top-down analysis of the CO's tasks includes potential knowledge-based guidelines for the use of the display authoring system and system design. Guidelines distilled from specific task analysis form the basis for using the rapid prototyping capability by focusing on explicit user-centered issues.

The decision analysis conducted at the data-specific level can also benefit training. A great deal of time and effort is expended in generating exercise controller guides for tactical team training. These guides consist primarily of the target geometries to be used during the training scenarios. As noted earlier, given how long the CO has to interact with the initial target geometry, the final problem configuration bears little resemblance to that provided in the exercise controller guide. It is the instructor who creates and maintains tactical geometries in this interactive environment, actions which are by and large not specified or documented. Examining the tactical data and its use by the CO may lead to more efficient training. This has been discussed with the Tactical Training Department of the Submarine Training Facility, San Diego, California.

The level of abstraction in tactical data presentation may also hold insights for decision-aiding capabilities. For instance, it might be argued that a pictorial situation assessment display should be favored over an alphanumeric display for ease of interpretation. Consider, however, that the sensitivity of recognition to a parameter such as bearing rate is enhanced by the abstraction of alphanumeric presentation.

The analysis of tactical data also brought to light the generic nature of contact data from completely different sensor types. Aggregation of tactical data into spatial or object categories also holds promise for further work in decision-aiding concepts. A report addressing specific decision aids has already been published, with another in preparation. The next report in this effort will be a compilation of all the specific vignettes and the methodology in their development.

Vignette Development

The evolution of the target engagement vignettes has progressed from our initial analysis. The generic steps in each of the final vignettes have already been defined. Further definition, presently underway, will concern the CO decision sequence within each step of the vignette, and will take the form of a script. The intent is to "decompose" the overall decision sequence into its component parts in order to specify the core considerations from the CO's perspective. The purpose is not to model CO behavior, but to provide a framework for vignette development. By using man-in-the-loop experimentation, the CO brings his experience and knowledge regarding target and weapon capabilities to the experimental environment without the experimenters having to model it.

Specific information sources and types of data required by the CO to complete each portion of the vignette decision sequence will then be identified. Specific decision rules and evaluation criteria used by the CO to relate information input to decision output in each sequence can also be identified, as well as the data set used for each decision sequence, including logical linkages to prior and succeeding vignettes (see Figure 2). It is this data-specific approach to scenario development that distinguishes these vignettes from previous scenario-building efforts.

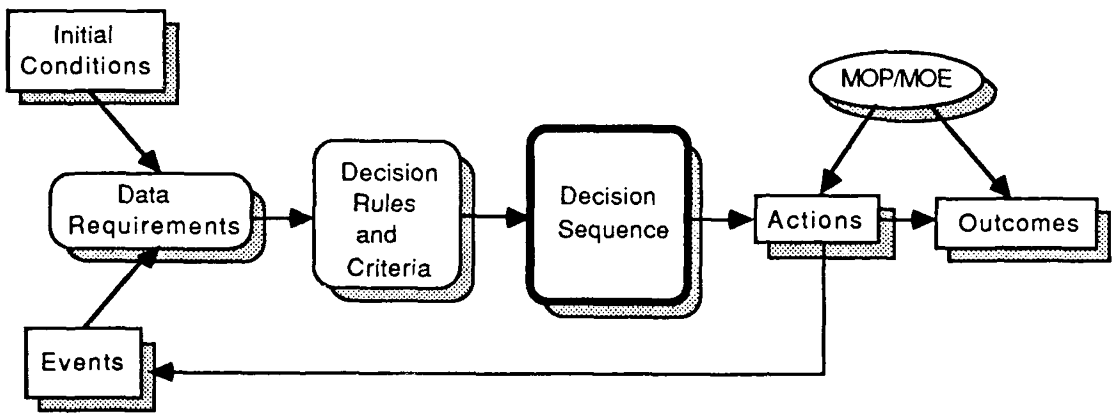

Figure 2. Tactical vignette development.

A tactical vignette is a set of operational events (including CO decisions and actions) that occur in chronological sequence. A set of initial conditions sets the stage for the vignette. We will use sets of initial conditions to define tactical situations that examine variations of the decision sequences involved and yield the most useful measures of performance. Sets of initial conditions and events for each specific vignette will then be categorized. The completed vignettes will form a cohesive package of initial conditions, events, outcomes, and MOE/MOPs. These vignettes, then, are not experiments but the experimental tactical environment for use in objective performance measurement.

Only portions of the overall decision-making process exhibited by the CO are amenable to decision path analysis. This is due to the modular nature of decisions in a data-driven, real-time environment. Certain decisions must be deferred until enough data is available for their consideration. Additionally, certain decisions may have to be made more than once depending on tactical considerations. Recent experiments indicate that the segmenting of decisions on the part of the CO may be a common decision-making strategy.

The two major parallel processes engaging the CO with respect to sonar target prosecution are localization and classification. These are continuous processes, characterized by "state" updates with respect to target parameters. For instance, while the ship is localizing a sonar contact, the range to that contact will change in a continuous manner, passing through certain "gates" for applicable sensor and weapon employment. As those gates are passed, the state is incrementally updated by the CO and held until another gate is passed. These gates are easily employed as specific initial conditions or events during the tactical vignettes.

By segmenting the CO decision process into decision vignettes, it might be argued that a lack of process continuity would adversely impact experimental results. Consider, however, that each separate decision sequence has its own initial conditions and categories of outcomes. The outcome of one decision sequence becomes the initial condition for the following decision vignette, linking the separate vignettes in terms of context, if not time. An error by a CO resulting in an adverse outcome in one vignette is represented by unfavorable initial conditions in one or more following vignettes.

Measures of Performance

The measures of performance and measures of effectiveness (MOPs/MOEs) developed to evaluate quality and timeliness of selected command decisions focus on three areas: time, accuracy, and adequacy. Elapsed time for specific decision events is quite a valuable measure, particularly in a vignette restricted to several minutes in length. Accuracy pertains to the number and types of mistakes made in a given scenario. Finally, since there may be multiple adequate solutions in a dynamic tactical environment, our effort will be directed at identifying those combat system features that allow the CO to pick the best one.

The MOE/MOPs identified are intermediate rather than ultimate performance criteria. The intent was to focus on observable events. The MOEs for given tactical scenarios tend to evolve into a hierarchy, as detailed by another researcher (Rau, 1974). In addition to the MOP/MOEs currently identified, others that are display- or experiment-specific will undoubtedly develop. Again, the purpose is not to propose why mistakes are made, but to determine which displays tend to give better performance. In a sense we are developing relative MOPs vice absolute MOPs owing to the part-task approach to this effort. We are evaluating displays, not COs.

As stated above, additional MOPs will develop through refinement of the experimental methodology. For instance, the two modes of FCP failure can be characterized in two ways. First, there are those situations that are too dynamic for the FCP architecture, with its overriding communications requirements. Secondly, failures can occur due to unexpected conditions or target actions that do not fit into the CO's pre-programmed responses. The observation of different types of coping behavior exhibited by COs in a tactical environment might also produce some additional MOPs (Foley & Wallace, 1974; Sage, 1981).

APPROACH

The development of techniques to objectively evaluate combat system displays has proceeded along two parallel paths at NOSC. First, a progressive functional analysis for experimental design was conducted, yielding the methodology of investigation. Secondly, and concurrently, the development of an experimental tactical environment for implementing performance measurement was undertaken.

We spent considerable time in our early efforts on problem definition and experimental design. A functional analysis of the approach and attack scenario led to an outline of technical steps required to improve information integration in the submarine combat system. A technical analysis was undertaken to investigate current combat control procedures. This consisted of document review, combat team observation, and interviews and workshops with experts.

Document review resulted in a collation of current tactical doctrine and practices from a diverse selection of publications. Observation of combat teams in the training environment allowed investigators to confer with instructional staff familiar with tactical evaluation and to question COs during the performance of their duties. All these efforts led to a comprehensive understanding of the problem environment.

In order to identify key decisions and actions performed by the CO during target encounters, a formal descriptive model was developed. This model identified significant decisions and actions, events, and informational inputs that impact these decisions and actions, and general sequencing of them during tactical evolutions. The resulting descriptive decision model was scenario-independent so that it would not simply be a time-based narrative chain of events. It was, however, reflective of the dynamic real-world environment, with multiple parallel activities rather than idealized sequential phases.

The Experimental Environment

A target encounter scenario in submarine warfare can vary from .5 to 4 hours in length. There are roughly 25 people in the FCP. This kind of real-time interactive environment is difficult to analyze from an operability standpoint because it tends not to be repeatable. In order to provide an element of experimental repeatability, several things were considered. First, as noted earlier, the submarine environment is less dynamic and less complex than other warfare areas and made a good starting point for initial analysis. Next, by restricting the experimental environment to the CO exclusively, we eliminated the confusion of having many people to keep track of during an experiment. Finally, we restricted the time available for interaction to a slice of time only several minutes in length around a specific decision that the CO must make. These three considerations formed the basis of the part-task, medium-fidelity simulation environment to be used for experimentation.

The validity of a part-task experimental environment is crucial to the applicability of our experimental results. It must be emphasized that the purpose of this effort is to determine display utility for a given task or range of tasks, since no single display or decision aid will support all CO decision-making requirements. It made sense, therefore, to segment the overall target engagement scenario into the slices of time, or vignettes, about critical decisions for which a particular display or decision aid was targeted.

BACKGROUND

The submarine platform represents a microcosm of the larger command and control environment. It is felt that initial analysis undertaken in this area will be manageable due to the nature of the tactical environment. This environment is characterized by relatively slow speeds and fewer contacts due to the types of organic sensors. Additionally, the communications requirements for submarines are much less stringent than those for other platform types, and the functional command structure is not distributed among several people. It is more or less a pure platform-level environment. The tactical environment is getting much more demanding due to the erosion of the technological advantage enjoyed for so long by the submarine force. Detection ranges have fundamentally changed system and operator requirements. This makes for a critical opportunity to improve combat system interface utility.

The incorporation of a specific command interface in a submarine combat system introduces a new and powerful capability. No other single person on the submarine contributes more to the tactical effectiveness of the platform than the Commanding Officer (CO). Historically, the CO has been isolated from tactical data by a large number of operators and supervisors comprising the Fire Control Party (FCP). These intermediate personnel serve as selective filters and buffers. In previous systems the designated command displays were, by and large, underutilized by the CO because they were either inaccessible or cumbersome. The use of an effective command interface and decision aids may be able to bridge the gap in the approach and attack architecture, giving the CO timely access to the relevant tactical data he needs to do his job. Additionally, the combat system should provide better spatial orientation and correlation of data to everyone in the FCP.

Initial efforts at measuring tactical performance of submarines were aimed at recording tactical parameters in a training environment (Callan, Kelly, & Nicotra, 1978). These procedures were expanded and formalized with incorporation of the Submarine Advanced Reactive Tactical Training System (SMARTTS) in the design evaluation of digital combat systems (Ship Analytics, 1983). This approach designated certain tactical parameters as "performance indicators," though justification of these designations was never fully specified or developed. The SMARTTS capability was not meant to be comprehensive. It was recognized at that time by the researchers that interpretation of recorded tactical parameters still required the subjective assessments of instructors or subject matter experts to be useful. Their approach was never improved to a sufficient level of detail or completeness to support NOSC's efforts in performance measurement.

A decision-oriented approach to defining combat system data requirements in support of design efforts for the next-generation combat system was conducted a few years later at the Naval Underwater Systems Center (NUSC). While comprehensive, this decision analysis was still at a level of detail insufficient to support experimental design and evaluation of combat system interfaces. A series of "concept of operations experiments" (COOPEXs) was initiated by NUSC to augment the information management analysis. These, however, were severely restricted by hardware capabilities that could not support real-time tactical scenarios and took the form of seminars and questionnaires rather than experiments.

Unfortunately, measures of performance historically used for systems evaluation or wargaming have taken the form of complex products of probabilities with little direct application to individual decision-making performance (Rau, 1974). These were also not usable in an experimental environment aimed at display evaluation.

INTRODUCTION

This project investigates man-machine interface issues and operability enhancements for use in the design of combat systems for future attack submarines. The Naval Ocean Systems Center (NOSC) will design and conduct experiments concerned with submarine combat control and decision making. A top-down decision analysis forms the basis of experimental design within a part-task, medium-fidelity simulated tactical environment. Rapid prototyping of proposed displays and decision aids that can be immediately linked with this simulation will provide a timely and cost-effective vehicle for objectively evaluating display utility from the user's perspective.

The objective of these experiments will be to evaluate system design and procedural factors, such as display formats, operational routines, and decision aids. The methods, procedures, and facilities for designing an operable combat system resulting from this effort will be incorporated into combat system acquisition programs as a transportable product available for use by government and contractor personnel involved in specification, design, and evaluation of new combat systems.

The ability of a performance-based evaluation system to provide a try-before-you-buy capability for complex combat system-human interfaces can yield several other important benefits. The identification of system software shortfalls early in the design process should save on expensive software revisions. This identification may also drive some hardware design considerations. The overall utility of the final system should also decrease training requirements that are costly, time-consuming, and difficult by reducing operator hands-on time required for proficiency.

The ultimate goal of this effort is to replace subjective preference with objective man-in-the-loop performance measurement for evaluating interface utility. Experimental results will provide the character and quantification of benefits to be achieved in improved designs. Finally, objective examination of potential, sophisticated combat system features will ultimately yield a more capable platform. Figure 1 is included here to guide the reader through the report.

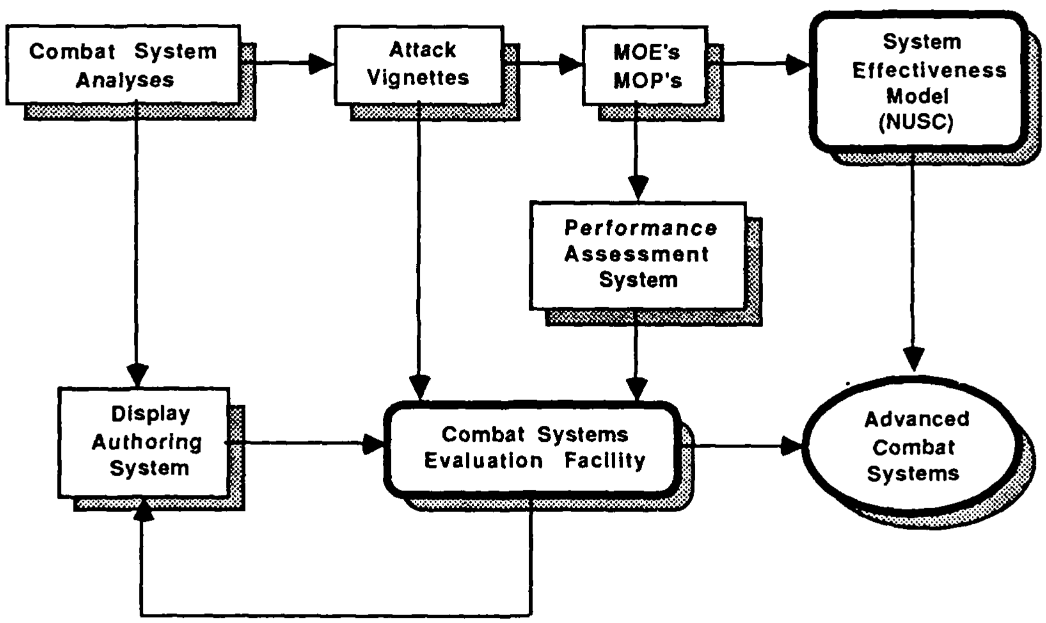

Figure 1. Development of performance measurement methodology for combat system operability.

Performance Measurement Methodology for Enhanced Submarine Combat System Effectiveness

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ABSTRACT

This presentation outlines the development of a methodology for objective man-in-the-loop performance measurement of combat system features based on experimentation in a simulated tactical environment. A history of submarine tactical performance measurement is discussed. First, a top-down functional analysis for experimental design was conducted yielding a descriptive decision model. Considerations involving experimental repeatability and the validity of results in a part-task, medium-fidelity environment are discussed as well as measures of performance. A data-specific approach to decision analysis is described which distinguishes this effort from other scenario building efforts. Implications of this approach for decision aiding and training efforts are discussed. In conjunction with analytical efforts, the development of a simulation facility incorporating rapid prototyping is presented.