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A brief description is given of the (1) research objectives (including some of the psychological and engineering principles guiding the research); (2) general methodological approach; (3) hardware and software used; and (4) some development issues related to operationalization of such a research testbed.

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Decision-Making Evaluation Facility for Tactical Teams

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ABSTRACT

The Decision-Making Evaluation Facility for Tactical Teams, or DEFTT, is a portable testbed system designed to provide a simulation environment for conducting tactical decision-making research. Teams engage in nine vignettes which provide the context for studying "naturalistic" decision making in a realistic environment. A primary concern was to maintain the fidelity of the Navy combat information center (aboard ships) for six-member tactical teams under relatively stressful conditions. Six consoles and an experimenter control station are electronically linked, and actions taken by each team member are recorded as they respond to highly complex decision events.

A brief description is given of the (1) research objectives (including some of the psychological and engineering principles guiding the research); (2) general methodological approach; (3) hardware and software used; and (4) some development issues related to operationalization of such a research testbed.

INTRODUCTION

This paper covers a brief overview of the Tactical Decision Making Under Stress (TADMUS) program, sponsored by the Office of Naval Technology, being conducted as a joint laboratory effort at Naval Command, Control and Ocean Surveillance Center (NCCOSC), San Diego, and Navy Training Systems Center (NTSC), Orlando; then describe the Decision-Making Evaluation Facility for Tactical Teams, or DEFTT, and some of the related development efforts and issues related to conducting this research program.

BACKGROUND

Complex information gathering and processing systems have been designed to aid the decision maker. However, these systems often increase the decision maker's burden due to the inherent system complexity and the failure to use basic principles of human information processing in system design. Moreover, these systems require operators to perform difficult cognitive tasks under heavy workloads. In engagements involving crisis and limited objective warfare situations (CALOW), which may represent the majority of future anticipated naval conflicts, the decisions to be made are even more complex than they would be in full-scale warfare. Civilian and neutral

nation resources are often in the conflict area. Incoming information thus carries an added element of uncertainty. In these situations, interpretation of the rules of engagement, contact identification, inferring intent from identification and behavior, and the shoot/no-shoot decision often pose extremely difficult decision problems. In extreme cases there is no clear cut right or wrong answer about a decision. Rapidly unfolding events result in severe time pressure and severe (often catastrophic) consequences for errors. Current battle management systems are not optimized for use in CALOW situations where human intervention in decision making is required.

The objective of the TADMUS program is to apply recent developments in decision theory and information display technology to the problem of enhancing tactical decision quality under stressful conditions. The products of this research will be demonstrated in the context of antiair warfare scenarios, however, general principles will be developed that will be applicable to other warfare areas. A long-term objective is to produce an experimental decision-support system with sufficient robustness to permit examination of tactical decision making under different stressful conditions. Prototype system components and tools will be evaluated in simulated tactical environments, initially in a laboratory setting, and later, during at-sea exercises. Development of the prototype software support tools will be based on decision-process models developed by Klein (1991), situation assessment tools developed by Noble (in press), and explanation-based reasoning tools developed by Hair and Pickslay (1992). Klein's models are based on decision making in "naturalistic" settings which are characterized by: high time pressure; ambiguous, incomplete and erroneous data; action-feedback loops; ill-defined goals; and frequent shifts in goals. According to this recent approach, expert decision makers may rely on well-developed memory representations to guide decision making in new (but similar) situations. From this point of view, the decision-making process is considered to be intuitive rather than analytical.

A second product of this task will be a set of general principles and prototype displays for advanced decision support systems to mitigate human information processing biases and to enhance tactical decision quality under stress (Barnett, Perrin, & Walrath, 1992). A substantial body of research has demonstrated that humans apply a limited set of heuristics to simplify decision making in complex and ambiguous situations, and that these heuristics can result in errors, or judgment bias, when compared to normative theory. Research will be conducted to assess whether naval personnel, trained and experienced in antiair warfare (AAW) operations, exhibit these biases when performing their duties during AAW scenarios. For example, the confirmation bias may have been operating when, as was indicated in the official investigation of the Vincennes incident, console operators "distorted data flow in an unconscious attempt to make available evidence fit a preconceived scenario" (Parks, 1989). Research will also be conducted to examine human-machine interface concepts which maximize both the effectiveness of tactical decision aids under stressful conditions and the efficiency with which the use of decision support systems can be trained. Display concepts will be evaluated for their ability to aid the decision-maker(s) in acquiring and maintaining the ability to extract and integrate information rapidly and accurately from decision support systems under high stress loads. Products of this task will include display principles for: predictive displays, situation assessment, option generation, resolution of conflicting or ambiguous information, and cognitive consistency among team members.

DECISION-MAKING EVALUATION FACILITY for TACTICAL TEAMS (DEFTT) LABORATORY

The ambitious timelines proposed for TADMUS technical development mandated use of an off-the-shelf tactical simulator for the experimental phases of the research. A survey was conducted of the

existing simulation systems for their potential applicability to TADMUS. Essential technical capabilities included the following features: (1) capability to run complex antiair warfare scenarios; (2) multiple, networked stations to enable configuration of a Navy combat information center (CIC) suite; (3) capability to measure operator performance at all consoles, including console keystrokes and timestamping of operator actions for later synchronization to simulation events; and (4) ease of scenario authoring and simulation control. Additional logistical capabilities included: (1) modest cost; (2) demonstrated system performance and reliability; (3) transportability; (4) an unclassified database; and (5) minimal support requirements.

The Navy's tactical antisubmarine warfare (ASW) interim trainer (TASWIT) was selected with modifications required. TASWIT is a personal computer-(PC) based system, developed in 1984, for tactical ASW team training which has been well received by the fleet and has considerable current support with planned upgrades. Software is written in UNIX/C and is transportable. Additional features include the ability to: (1) present complete "ground truth" or only what the given operator would normally see; (2) simulate input from a variety of sensors and selectively downgrade them; (3) support monochrome or color displays and accommodate large-screen projections; and (4) rapid manipulation of task features from an instructor console. The required modifications included converting the ASW database to an AAW database and adding performance measurement capabilities. This modified TASWIT system is called the Decision-Making Evaluation Facility for Tactical Teams, or DEFTT, Laboratory.

In support of the TADMUS experiments, DEFTT provides: (a) a multithreat, multiplatform environment, (b) a broad range of sensor inputs and tactical information that replicates the type of information available to tactical decision makers, (c) a scenario generation capability, and (d) a data collection and playback capability. To gather the controlled, experimental data needed to develop decision performance models and solutions to identified problems, the DEFTT laboratory was developed to mimic critical features of an Aegis combat information center. The emphasis on Aegis combat teams and systems was predicated on the increasing presence of these systems in Fleet operations.

The DEFTT system is comprised of six computer workstations and an experimenter control station where the scenario is interactively controlled in response to behaviors by the team members. The six workstations simulate the following positions which are found aboard a Navy Aegis cruiser: commanding officer and tactical action officer, both of whom use the Aegis display system; the antiair warfare coordinator, tactical information coordinator, and the identification supervisor, all of whom use the command and display (C&D) system; and the electronic warfare supervisor who uses the AN/SLQ-32 system (a passive receiver/analysis system for radar signals).

DEFTT SYSTEM DESCRIPTION

DEFTT integrates hardware stations and software modules. The major hardware stations are a Hewlett-Packard (HP) 345 workstation (referred to as the experiment control station [ECS]) with an experiment control software module and six Gateway 2000 386 personal computers with Aegis display system (ADS), command and decision (C&D), and electronic warfare (EW) software modules. The DEFTT components are interconnected through a local area network (LAN) as illustrated in figure 1. (LAN is hardware and software used to interconnect a wide variety of normally incompatible processors, operating systems, and network interfaces.)

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│                    │      HP 345           │                 │
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│   Note: Each station can utilize any of the following       │
│   display formats: C&D, ADS, or EW.                         │
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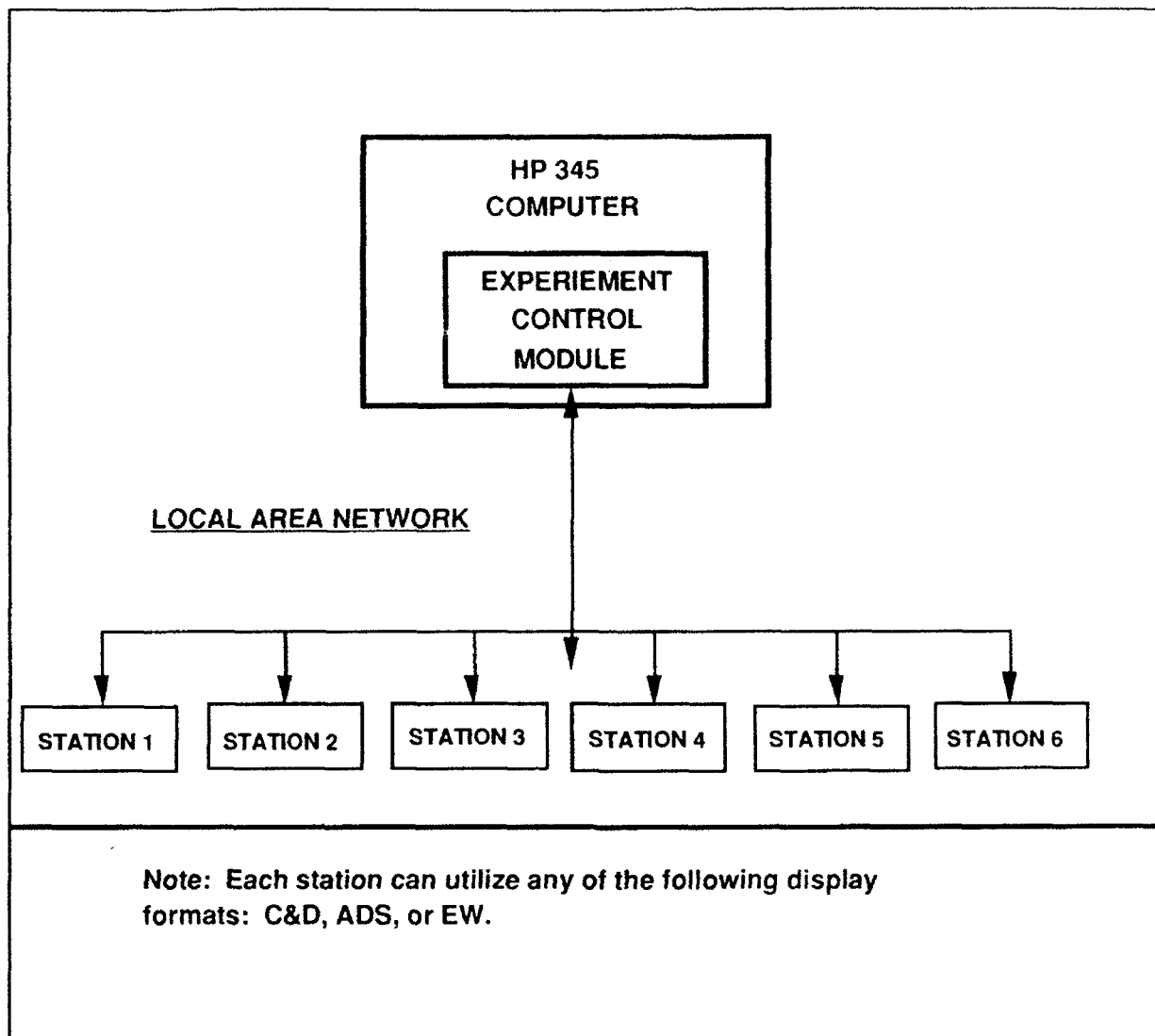
Figure 1. DEFTT System.

Hardware Architecture. DEFTT consists of the following three major components: HP 9000-series Model 345CH (HP 345) computer (1); IBM-AT type 386 personal computers (6); and a high resolution 19-inch monitor (1). Figure 2 illustrates the DEFTT laboratory configuration.

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Note: The experimenter control station (HP 345) and the 19-inch monitor are co-located in a separate game control room. This depiction shows five of the six workstations and the large screen display.

Figure 2. DEFTT Laboratory.

The PCs are networked together with the ECS, which is used to control the simulation programs in the PCs. Platform position and status data are calculated in the ECS and sent to the PCs every six seconds. All experiment setup functions are performed at the ECS with specific data downloaded as appropriate to the PCs. The PCs serve as selected AEGIS operator stations, allowing operators to perform AEGIS display system (ADS), command and decision (C&D), and EW functions.

Software Architecture. DEFTT consists of the following software components: Experiment Control Module, Aegis Display System (ADS) Module, Command and Decision (C&D) Module, and EW Module. The Experiment Control Module, installed in the ECS, provides for generation and control of scripted TADMUS scenarios and control of ADS, C&D, and EW module functions.

Each PC can be configured as separate platforms or grouped together as different displays on the same platform. Each station is configured for a particular display at the ECS during scenario setup. The platform and display configurations, along with appropriate data sets, are transmitted to the operator stations from the ECS during the startup routine.

Command and control support includes the two main computer systems in the Aegis combat information center: C&D and ADS. The C&D tactical display provides simulated C&D geographic situation (GEOSIT) summary displays, selected C&D track data control functions, and

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platform control functions (dynamics, sensor control, and weapons). The ADS tactical display provides simulated ADS displays and associated control functions. The EW module provides simulated AN/SLQ-32(V)3 countermeasures set electronic support measures (ESM) detection and display formats.

DEFTT SYSTEM CAPABILITIES

Experiment Control Capabilities. The experiment director controls the overall operation of DEFTT through the use of the DEFTT ECS (HP 345 computer, function keypad, trackball, and high resolution monitor). The experiment director performs all experiment setup and experiment control functions. When configured in the experiment mode, the experiment director has the capability to generate scenarios, control the exercise by responding to subjects' actions, and play back a specified exercise.

Scenario Generation. TADMUS scenarios establish the time-ordered platform events for each experiment run. The experiment director has the option to use an existing scenario, modify an existing scenario, or develop a new scenario. DEFTT supports 150 dynamic platforms per scenario. These dynamic platforms include: own ship; surface vessels (friendly, neutral, and/or hostile types); own ship-assigned aircraft; and independent aircraft (friendly, neutral, and/or hostile types). In addition, up to 150 tracks per scenario can be entered by the station operators and/or experiment director through the C&D track manager function.

Own ship is a CG 47-Class cruiser and is configured with the CG 47-Class antiair warfare (AAW) sensor suite. The experiment director can specify aircraft platforms assigned to own ship including light airborne multipurpose system (LAMPS) type and combat air patrol (CAP) aircraft. The experiment director specifies other dynamic platforms to be used in the scenario including associated platform emitters. A DEFTT scenario contains the following initial settings for all scenario parameters: data link reference point (DLRP) position, platform type and/or name, platform course, platform speed, platform initial X/Y position, platform bearing/range to DLRP, platform altitude, platform classification, platform track number, platform identification friend or foe (IFF) codes and transponder status, platform emitter types, and platform modes and status.

Playback. Prior to running another exercise, the experiment director can save the scenario track history for playback. The playback display is available at the ECS and at all C&D stations. Playback replays an exercise by displaying geographic track history data, including NTDS symbols, for all platforms activated at any time in a scenario. The playback can run in real time or at an accelerated time rate (2X or 6X real time).

Command and Decision Geographic Situation (GEOSIT) Display Capabilities.
The C&D is a 360° geographic situation display that presents appropriate navy tactical data system (NTDS) symbology to the experiment director and the station operators. The experiment director and the station operators have the capability to: alter display radius (range scale), change display center, enable/disable range rings, enable/disable display of friendly tracks, enable/disable display of sonobuoy positions, enable/disable display of track history dots, and enable/disable display of course/speed vectors. In addition, the experiment director can display reported positions of contacts and actual positions of hostile contacts.

Station operators are provided with a ball tab capability. The ball tab, which is controlled by a trackball, can be used by the operators to hook and sequence tracks. When a track is hooked, the following data is displayed in the tabular readout area (referred to as the character readout (CRO)):

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hooked track category (own ship, air friend, surface unknown, and so forth); track number (system track number (STN) and/or common track stores locator (CTSL)); track Cartesian coordinates; track latitude and longitude (LAT/LONG); track course/speed; track altitude and height source; track identification amplification (strike, tanker, DD/DDG, and so forth); IFF data (modes 1-4); and track bearing and range from own ship.

Command and Decision/Track Management Capabilities. The experiment director at the ECS and C&D operators perform track management using the following C&D functions: new track entry, old track update, drop track, and contact classification. C&D station operators can challenge contacts on any IFF mode. Contacts can be tracked automatically by the system (including automatic generation of NTDS symbology), or manually by the station operators (including manual generation of NTDS symbology).

AEGIS Display System Display Capabilities. The ADS is a geographic presentation of a selected portion of the world map. The ADS station operator has the capability to: alter display range scale, change display center, define and display tags, enable/disable display of course/speed vectors, define and display circles, enter general reference points, define lines and patterns, and filter C&D track symbology. ADS track data is represented by appropriate NTDS symbology.

The ADS station operator is provided with a ball tab capability. The ball tab is controlled by a trackball. Using the ball tab, the operator can hook and sequence tracks, select items from the CRO, and select ADS functions. Data for a hooked track is displayed in the CRO.

Electronic Warfare Simulation Capabilities. The AN/SLQ-32(V)3 simulation provides polar and tabular displays of ESM contact data and controls for launching chaff. Emitter detections are a function of AN/SLQ-32(V)3 performance characteristics as applied to a simplified line-of-sight (LOS) equation. At each time step (six seconds), emitter detection is simulated by comparing the positions of own ship and the emitter. If the emitter is in the LOS of own ship and within the AN/SLQ-32(V)3 frequency range, the emitter is detected and appropriate symbology/ emitter data appears on the display. The EW display provides the EW station operator with the following data: emitter alerts, threats summary, frequency bands enabled, and inhibited alert status.

Controls are provided to allow the EW station operator to control the following EW station functions: polar display orientation (true or relative); alert inhibit status (friendly, all, or none); ESM inhibit status (friendly, hostile nonmissile, or unknown); ESM inhibit sectors; super rapid bloom offboard chaff (SRBOC) employment; and ball tab position.

Operator functions. During a scenario run, functions performed by the DEFTT operators include: Ship control -- engine and rudder orders; aircraft control -- course, speed, and altitude; sensor control -- on, off, and pulse; weapon control -- torpedo and missiles; and track management.

Communications system. A communications system to replicate the communication capabilities available aboard ship was considered an essential feature of the DEFTT laboratory as communication of tactical information is an ongoing and critical element of tactical decision making. Specific capabilities of this system include the ability to: (1) replicate on and off ship communications simultaneously, (2) allow operator monitoring of two channels simultaneously, (3) record all channels separately, (4) insert background noise, and (5) configure system to support opposing team play. Additional features include (1) a robust, yet flexible and easily expandable

system, (2) indicators for all stations when initiating communications on various channels, (3) transportability, and (4) the ability to operate individual stations from desk mounted controls.

The internal net provides communications between the six team members and is monitored by the operations director and the radio/telephone talker, who act as confederates simulating various people with whom the team would need to communicate (internal to the ship and off ship, e.g., battle group commander, Saudi combat air patrol controller, foreign pilots, etc.). The command execution net connects ownship command level decision makers, the commanding officer and tactical action officer, with higher level command external to the ship. The antiair warfare command and reporting net is used by the non-command personnel, i.e., AAWC, TIC, IDS, and EWS to communicate sensor and contact identification information. The military air distress net, or MAD, used by the tactical information coordinator, and the international air distress net, or IAD, used by the identification supervisor, are both used to issue warnings and communicate with foreign aircraft. All communications during the experimental runs of the scenario will be recorded for later analysis.

SCENARIO DESCRIPTION

The scenario to be used for TADMUS was intentionally developed to be highly ambiguous so that the decision maker may never be certain about the threat represented by the contact or the intent of a threatening contact. The worldwide proliferation of sophisticated weaponry presages an increasing intensity and danger in this type of warfare, and the 2010 combat system upgrade must take this important driver into consideration. Basic requirements for the scenario and the nine decision vignettes were: (1) operation in shallow/confined waters, (2) neutral and hostile countries in close proximity, (3) modern blue/gray systems and weapons among neutral, friendly, and hostile nations, and (4) heavy neutral/friendly traffic in the vicinity. These last three features contribute to creating a scenario with many ambiguous situations, i.e., where loyalties may shift rapidly; third world countries possess first world, high technology weapons; and tactics are ill-defined for the situation.

The scenario is set in the Persian Gulf where several of the nations initially classified as friendly have reason for suddenly changing their loyalties. Thus, the continued applicability of the rules of engagement is uncertain and the intent of an approaching threat from any one nation is uncertain. Also, the wide distribution of blue/gray equipment causes uncertainty as to the national origin of a contact (Riffenburgh, 1991). The vignettes were designed to be independent for experimental control with the intent that a decision in one vignette would not influence decisions in later vignettes. The scenario includes the overall structure into which the nine vignettes, or brief incidents, are incorporated. This overall structure is comprised of a mission statement, geopolitical background, and rules of engagement. Each vignette follows the pattern of being set in a poorly defined situation where one or more threats of uncertain origin and uncertain intent approach either own ship or the ship being protected and do not respond to warnings. The team must decide on a sequence of responses as the situation evolves.

Development Issues. Nine decision vignettes were developed within one scenario setting. Each vignette poses a cumulative, critical decision event which the decision makers must resolve. A major issue in the development of the vignettes was the decision not to incorporate an "obvious ending" to each of these decision events. Because fidelity to tactical problems was paramount, the scenarios were built to remain ambiguous to the decision maker. For example, a hostile airplane may be engaged and weapons fired, but whether critical battle damage was generated remains unknown to the decision maker for the duration of the scenario. This was used to mimic the type

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of situations that occur in real wartime contingencies, such as Desert Storm, where battle damage reports often arrive hours to days aft.. the engagement. This also obviates the problem of "game playing" (trying to outwit the con-uter) and learning effects which may bias subsequent decision vignettes. This tactic on our ... forced us to provide relatively fast-paced decision events, so that pondering the tactics of the "last incident" are kept to a minimum.

Given this constraint, measurement issues are very complex. Typical measures of the number of "kills" are not particularly useful. Recall that the ultimate objective of this program is to develop the most f. *ctive decision support tools for tactical decision making processes in CALOW situations. Number of kills becomes inappropriate as a measure of system effectiveness. Therefore, measures that capture the nature of the situation assessment and the timely response to that assessment are our focus. For example, one of the mission objectives may be to maintain air control over a particular air corridor under complex rules of engagement. This requires immediate identification of all radar contacts in that sector. The speed and accuracy with which this is accomplished by the identification supervisor becomes a viable process measure for that position; communication of this information to relevant team members then becomes a team coordination measure; and finally, analysis of what action was taken given the radar contact information under the prescribed rules of engagement becomes a measure of team effectiveness. Latencies and errors in this process are alternative measurements that combine to paint a picture of team effectiveness.

The decision support prototypes discussed earlier will be incorporated into the DEFTT and tested for their effectiveness in enhancing situation assessment and decision making of the tactical team under varying stressful conditions. It is expected that because the decision vignettes are modular and fairly robust, future research will be conducted on various other issues of individual and team tactical decision making in technologically complex settings.

Scenario Task Demands on Team Members.

Antiair warfare decision-making hierarchy. Antiair warfare decision making aboard an Aegis cruiser is structured hierarchically with four levels of responsibility: command, coordination, supervision, and operation. Ownship command includes the commanding officer and the tactical action officer who sit in the front of the combat information center, each with a large screen display mounted in front of them in addition to their computer system display. The next level of decision making involves coordination, which involves the antiair warfare coordinator and the tactical information coordinator. At the supervisory level, we are including the identification supervisor and the electronic warfare supervisor. These six positions were identified as critical for the types of low intensity conflict decisions we are interested in investigating.

Crisis and Limited Objective Warfare. The types of decisions which will be the focus of our efforts include determining threat identification, threat intent, and application of the rules of engagement under conditions of crisis and limited objective warfare (CALOW). Despite the fact that the primary design criteria for navy ships are based on the support of a major conflict on the high seas, CALOW situations are expected to represent a major proportion of future naval operations. CALOW situations are characterized by their own unique problems and system stresses, particularly within the information processing and decision-making domain. Key characteristics of CALOW are: (1) uncertain motivations of various forces in the area; (2) operating under complex rules of engagement; (3) the presence of friendly, neutral, and suspect shipping and aircraft; (4) risk of damage to own, friendly, and neutral elements must be held low despite ongoing hostile activities; and (5) the worldwide proliferation of sophisticated weapons adds to the complexity of the problem. These types of conflicts add many layers of complexity to

the decision-making problem by including several levels of threat, multiple combinations of engagement rules, and an extremely high level of uncertainty about the intentions of contacts. When decisions have to be made within extremely short time windows, with varying degrees of degraded and/or ambiguous information, and with ROEs that have not covered all the potential situations, the process of decision-making can break down.

Task Demands. The scenarios require a considerable amount of effort to (1) deconflict contacts of interest from background clutter tracks, then (2) determine the identity and intent of the contacts of interest. Additionally, the team is required to apply the complex rules of engagement throughout the vignette. While these vignettes do not necessarily call for an engagement decision, there are several instances where engagement criteria are met under the rules of engagement; yet in some instances, the appropriate response would be to not engage. Considerable communications are also required of team members. These include communications external to the team to issue warnings to approaching air contacts. For example, the team can issue a warning to an approaching aircraft over the International Air Distress Net. Other external communications are required to off ship assets, such as the officer in tactical command (the Battle Group Commander), the foreign combat air patrol aircraft controller, and other off ship information sources. Internal communications are required among team members to clarify ambiguous data and to share information. In general, very little support from off ship assets is provided, thus forcing multiple ownship decisions.

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