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TACTICAL DECISION MAKING UNDER STRESS (TADMUS) DECISION SUPPORT SYSTEM

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A prototype decision support system (DSS) was developed to enhance Navy tactical decision making based on naturalistic decision processes. Displays were developed to support critical decision making tasks through recognition-primed and explanation-based reasoning processes and cognitive analysis of the decision making problems faced by Navy tactical officers in a shipboard Combat Information Center. Baseline testing in high intensity, peace keeping, littoral scenarios indicated that experienced decision makers were not well served by current systems, and their performance revealed periodic loss of situation awareness. A study is described with eight, expert Navy tactical decision making teams that used either their current system alone or in conjunction with the prototype DSS. When the teams had the prototype DSS available, we observed significantly fewer communications to clarify the tactical situation, significantly more critical contacts identified early in the scenario, and a significantly greater number of defensive actions taken against imminent threats. These findings suggest that the prototype DSS enhanced the commanders' awareness of the tactical situation, which in turn contributed to greater confidence, lower workload, and more effective performance.

INTRODUCTION

For sensor data to be effective, the data they generate must be integrated and organized so that it is useful information to the user. Information must be meaningful, timely, and easily accessible if it is to be useful. Understanding how an operator uses information is complicated by the effects the operational environment may have on the human operators of a system. The U.S. Navy has recognized the criticality of such factors in assuring mission effectiveness and minimizing incidents of blue-on-blue (friendly) or blue-on-white (neutral) engagements. The *Tactical Decision Making Under Stress* (TADMUS) program was initiated in response to one such incident: the accidental shoot down of an Iranian Airbus aircraft by the USS Vincennes in 1986. The congressional investigation of this incident suggested that emotional stress may have played a role in contributing to this incident and the TADMUS program was established to assess how stress might affect decision making and what might be done to minimize those effects.

Development of a prototype decision support system (DSS) was one thrust of the TADMUS project. The objective of this effort was to evaluate and demon-

strate display concepts derived from current cognitive theory with expert decision makers in an appropriate test environment. The focus of the DSS was on enhancing the performance of tactical decision makers (viz., the Commanding Officer (CO) and Tactical Action Officer (TAO) working as a team) for single ship, air defense missions in high density, ambiguous littoral warfare situations. The approach taken in designing the DSS was to analyze the cognitive tasks performed by the decision makers in a shipboard Combat Information Center (CIC) and then to develop a set of display modules to support these tasks based on the underlying decision making processes naturally used by the CO/TAO team.

Cognitive task analyses identified two higher order tasks performed by the CO/TAO team: situation assessment and selection of alternative courses of action (Kaempf, Wolf, & Miller, 1993). The analyses indicated that 87% of the information transactions associated with situation assessment involved feature matching strategies (trying to match the observed events in the scenario to those previously experienced), while 12% of their actions were related to story generation strategies (developing a novel hypothetical explanation to explain the observed events). With regard to selecting courses

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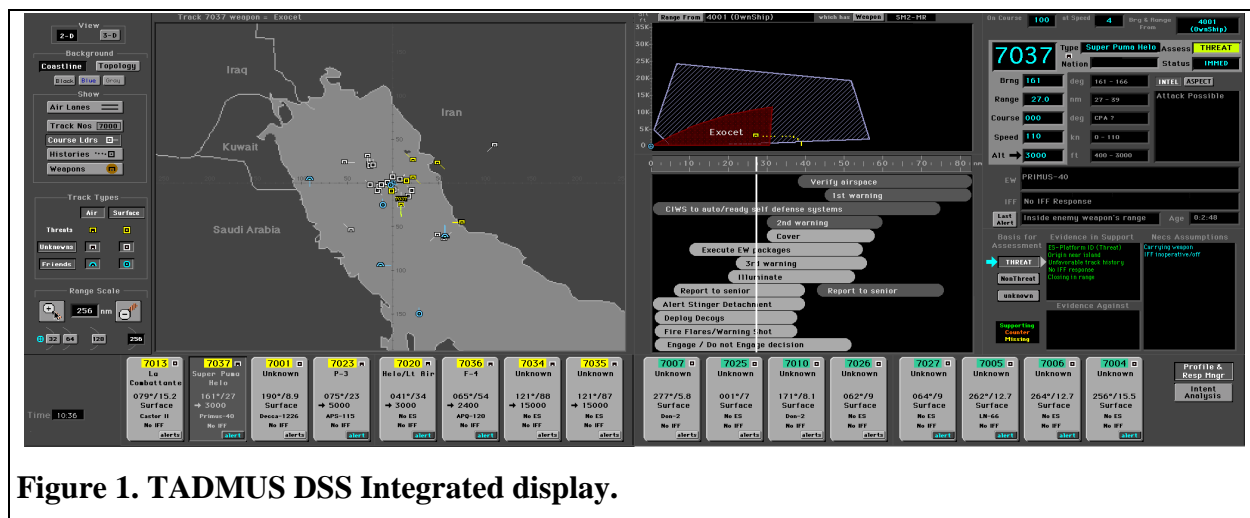


Figure 1. TADMUS DSS Integrated display.

of action, command level decision makers relied almost exclusively on recognition of applicable tactics based on rules of engagement (94%), while much more rarely developed a general selection strategy extrapolated from previous experience (6% of actions selected).

Baseline tests in representative littoral scenarios corroborated these analyses (Hutchins & Kowalski, 1993; Hutchins, Morrison, & Kelly, 1996). The communications analysis indicated a predominance of feature matching strategies in assessing the situation typically followed by the selection among preplanned response sets (tactics) that were considered to fit the situation. These tests also suggested that experienced decision makers were not particularly well served by current systems in demanding missions. Teams exhibited periodic losses of situation awareness, often linked with limitations in human memory and shared attention capacity. Environmental stressors such as time compression and highly ambiguous information increased decision biases, e.g. confirmation bias, hypervigilance, task fixation, etc. Problems associated with short term memory limitations included: (a) mixing up track numbers (track being recalled as 7003 vs. 7033) and forgetting track numbers; (b) mixing up track kinematic data (track recalled as descending vs. ascending in altitude, closing vs. opening in range, etc.) and forgetting track kinematic data; and (c) associating past track related events/actions with the wrong track and associating completed own-ship actions with the wrong track. Problems related to decision biases included: (a) carrying initial threat assessment throughout the scenario regardless of new information (framing error) and (b) assessing a track based on information other than that associated with the track, e.g., old intelligence data, assessments of similar tracks, outcomes of unrelated events, past decision maker experiences, etc. (e.g. confirmation bias).

DECISION SUPPORT SYSTEM DESIGN

In effect, the CO and TAO decision makers were behaving in a manner consistent with those predicted by “naturalistic” decision making theory (Klein, 1993). Therefore, this theory became central to the design of a human-computer interface to improve tactical decision making. A prototype DSS was developed with the objectives of: (1) minimizing the mismatches between cognitive processes and the data available in the CIC to facilitate decision making; (2) mitigating the shortcomings of current CIC displays in imposing high information processing demands and exceeding the limitations of human memory; and (3) transferring the data in the current CIC from numeric to graphical representations wherever appropriate. It was determined that the DSS should not filter or extensively process data; i.e., it should support rather than aid (automate) decision making and leave as much decision making with the decision makers as possible. The design goal of the DSS was to take the data that are already available in the system and present it as meaningful information where, when, and in the form it was needed relative to the decision making tasks being performed.

The DSS was designed expressly for the evaluation of display elements to support feature matching, story generation (viz., Explanation-Based Reasoning (EBR)), and Recognition-Primed Decision making (RPD) with the goal of reducing errors, reducing workload, and improving adherence to rules of engagement. The design was significantly influenced by inputs from subject matter experts to ensure its validity and usefulness for the operational community. It is implemented on a personal computer which may operate independent of, synchronized with, or linked to a scenario driver simulation.

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Figure 1 shows the current DSS-2 prototype display. The DSS-2 is a composite of several display modules, which are arranged in a tiled format so that no significant data are obscured by overlapping windows. The DSS-2 is implemented with two 1024x768 CRT / touch screen displays. The display features an integrated geo-plot and a variety of modules designed to solve specific decision making problems encountered by the tactical decision maker. These modules will be described below as an illustration of how the information requirements of tactical decision making tasks were mapped with cognitive processes described in naturalistic decision making theory.

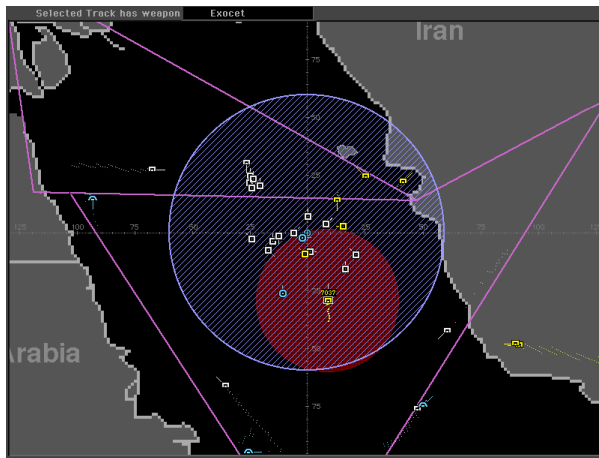


Figure 2. Geo-plot with desaturated map, variable coded symbology.

Geo-plot.

The left side of the display uses variable-coded NTDS symbology (Osga, et al., ????) to represent the position of air, surface, and sub-surface tracks over a geographic region. The module is intended to be the primary focus of decision makers and is designed for quick decision making associated with situation awareness. Symbols are color and shape coded to indicate track identification and threat evaluation, and may be toggled between NTDS symbols and track numbers. Track numbers are the “language” of the CIC and allow rapid location of various tracks. Conceptually, the map consists of several layers which may be altered to suit particular mission requirements. Shown is a desaturated map (Osga, et al., ????) which provides sufficient spatial reference for most tasks while minimizing screen clutter and color for most decision making problems. For strike or search and rescue missions, a topographical map may be overlaid. In addition, overlays for infrastructure (highways, population densities, power grids, etc.) may be added when necessary. The use of a 2-dimensional representation ensures tracks can be located quickly with precision. An optional 3-

dimensional display may be optionally displayed when appropriate for assessing general spatial relations. Controls for altering the geo-plot are arranged along the left edge of the module. In addition to selecting map layers, scaling, and panning controls, the decision maker may supplement the display with velocity leaders to show the relative speed of all the tracks, with course histories which show a track’s path over time relative to landmarks, with air corridors, and with other tracks. Weapon threat envelopes may be displayed for potential threat tracks along with own ship to rapidly assess the criticality of a threat.

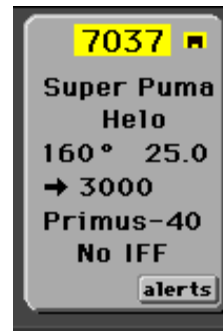


Figure 3. Sample Mini-CRO

Multi-CRO Access Panel

Across the bottom of the displays is a series of buttons for quick access to highest priority tracks. The buttons serve as miniature character read outs (Mini-CROs) displaying critical identification and kinematic information about the track and allowing the status of the most critical tracks to be monitored without any additional interaction with the system. The buttons are arranged by a fairly simple algorithm from highest priority on the left to lowest on the right. As situations evolve, the movement of the buttons quickly draws attention to the changes, which helps preclude attention fixation to a single track or task when the decision maker is under stress.

Inside each track button is an alert button which is cyan colored when a new alert has occurred since that track was last accessed by the decision maker, and gray when there are no new alerts. Pressing and holding the alert button generates a pop-up window to display a chronological list of alerts that have occurred for the selected track. Track age is shown rather than the time at which they occurred (as is the case with current systems) because decision makers are interested in how old the alert is rather than when it occurred.

Track Profile

The track profile module complements the geo-plot by showing a horizontal display of track altitude and

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range from own ship. Information requirements addressed by this module include the need to: (1) see where the track is now, (2) what the track has been doing over time, (3) recognize whether the track can shoot you, and (4) recognize whether you could shoot the track - all at a glance. An important aspect of this display is that it shows a historical plot of what the target

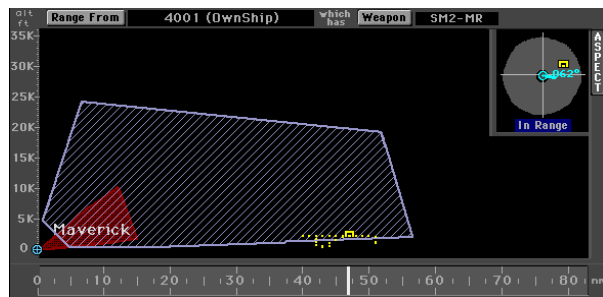


Figure 4. Track Profile with Aspect inset.

has done in space and time (the history is replayed each time the target is selected). This greatly reduces the short term memory requirements on the CO and TAO in interpreting the significance of the selected target and inferring intent. This historical dimension of the display allows the decision maker to see what the track has done and primes his recognition of a template for likely mission profiles which would account for the actions a track has taken. In addition, the profiles show own-ship weapon and target threat envelopes displayed in terms of range and altitude so that the decision maker can visualize and compare mental models (templates) as he considers possible track intentions and own ship options. To further facilitate these evaluation, the track profile incorporates two pull-down lists. The “perspective picker” allows the decision maker to jump to other friendly (joint / coalition) forces in the area so as to assess the possibility that other assets are the target of interest to a potentially hostile track, and to assess whether those friendly units could assist in engaging a prospective threat. When an alternative perspective is chosen, all modules in the display reflect the perspective and capabilities of the chosen asset. The second pull down list is a “weapons picker” that further elaborates on capabilities and limitations of own ship and other friendly units showing how different weapons could be used against the selected track. In the event that a weapon system goes off-line, such information would automatically be reflected in the weapons displayed in the pull-down list. These capabilities are expected to play a significant role in Joint and Coalition operations.

Embedded within the track profile is an inset window which shows own ship heading relative to the

selected track. The display quickly shows radar cross section and weapons cut outs for assessing whether own ship should be maneuvered to optimize these parameters.

Response Manager

The response manager is located immediately below the track profile and is tied to it via a line indicating the target’s current distance from own ship. It represents a Gantt chart type display showing a template of pre-planned actions and the optimal windows in which to perform them. The display serves as a graphical embodiment of battle orders and doctrine, and shows which actions have been taken with regard to the selected track. The display is intended to support RPD and serves the need to: (1) recall the relevant tactics and strategies for the type of target being assessed, (2) recognize which actions need to be taken with the target and when they should be taken, and (3) remember which actions have been taken and have yet to be taken for the selected target.

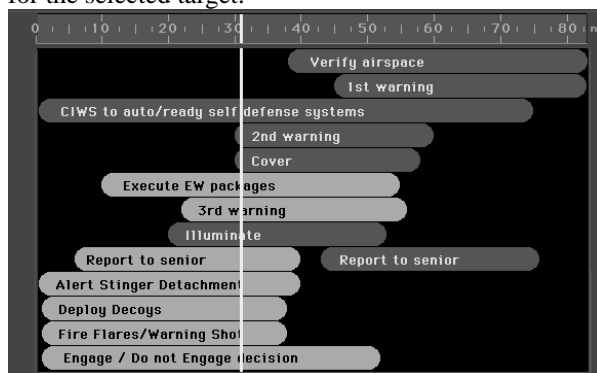


Figure 5. Response Manager.

Track Summary

The track summary module, located in the top-right corner of the display provides a more detailed summary of current and historical data for the currently selected track and represents an enhanced CRO. The display provides a quick-look at the tracks kinematics as well as ancillary data such as available intelligence, electronic warfare (EW) and Identification-Friend-or-Foe (IFF). Current information is shown as a cyan color, while historical or supplementary data is grayed-out. Kinematics, (quantitative data), are read down from the track number while track ID (verbal data) is read across. Embedded within all CROs is a unique feature of the DSS - an altitude trend arrow which shows increasing, constant or decreasing altitude. This is a critical feature of assessing threat intent which must be inferred by the tactical decision maker using conventional systems. There is a large pop-up window which may be accessed to provide a larger view of (possibly) more detailed

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alerts. This module is expected to be used when more detailed information is required for EBR.

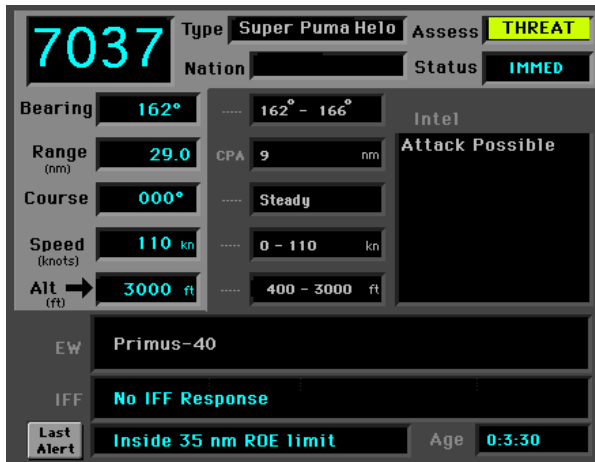


Figure 6. Track Summary.

Basis for Assessment

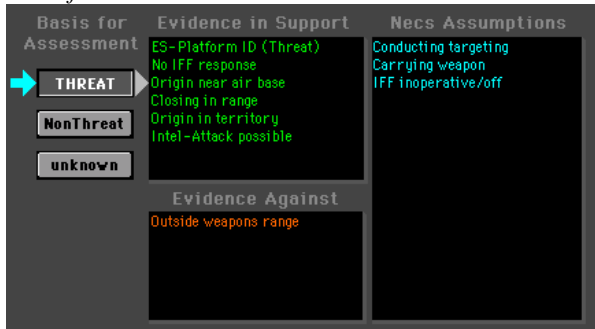


Figure 7. Basis for Assessment.

The basis for assessment module was explicitly designed to support EBR by providing a detailed list of evidence for and against the current assessment of the selected track. It also presents unknown information and implicit assumptions being made in accepting the assessment of potential threat, non-threat or unknown. This module supports EBR (story generation) by allowing the decision maker to explore alternative hypotheses and to see how the available data does or does not support them. The basis for assessment module presents the underlying data used to generate the DSS's threat assessment for the displayed track. The display was designed to present the relevant data necessary for a commander to consider and evaluate all likely explanations for what a target may be, and what it may be doing (i.e., assess "intents") through the generation of alternative stories to explain the available and missing data regarding the target in question. The display is also intended to highlight data discrepant with a given hypothesis in order to minimize confirmation and framing biases. Assumptions listed are those necessary to "buy into" the selected assessment. Further, the as-

sumptions are intended to prompt the decision maker to consider ways to resolve ambiguity. For instance, in order to assess a track as a threat, it may be necessary to assume that the track is carrying a weapon. The decision maker could then use organic assets such as friendly aircraft in the vicinity to fly out to the track to assess whether this is in fact the case. As a result, the basis for assessment module is expected to be particularly effective in helping sort out and avoid "Blue-on-Blue" and "Blue-on-White" engagements.

DSS EVALUATION EXPERIMENT

The ultimate goal of any display design is to positively impact the performance of the person-machine system of which it is a part. Therefore, a study was performed to examine how the DSS impacted the decision making of COs and TAOs relative to performance in a traditional CIC in a medium-fidelity simulation. Although the contributions of individual display modules could not be assessed objectively due to resource limitations, overall effects of the DSS on decision performance were examined in terms of a variety of performance criteria¹.

As we have discussed, there is substantial evidence that experienced tactical decision makers employ feature matching and, to a lesser degree, story generation strategies. Moreover, various errors observed during tactical scenarios and exercises have been linked with basic cognitive limitations (memory, attention, etc.). To build on the naturalistic decision strategies that experienced COs and TAOs use and to help overcome their cognitive limitations, a series of decision support modules were developed. Since these decision support modules were developed with a user-centered design perspective, we expected that they would be effective in reducing decision maker errors. Also, we expected that COs and TAOs would consider these modules to be useful and easy to use, since they were consistent with

¹ The results reported here are for an earlier version of the DSS, similar but not identical to the one described above. The tested DSS did not feature an integrated geo-plot (but relied on the geo-plot currently in tactical systems and the DEFTT simulator). The tested DSS had a "comparison to norms module" which provided color-coded squares to show how well a set of critical parameters for the selected track fit a template for known threats and support pattern matching. This module was not well liked or used as had been intended and was, therefore, dropped from the DSS-2. The DSS-2 is a refined version of the one tested, and it was refined based on the results of this study. The DSS-2 is being tested as this paper is written.

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the strategies that they use in processing information and making decisions.

Despite these expectations, empirical tests are necessary to determine whether the DSS was indeed helpful to tactical decision makers. Therefore, a study was performed to examine how the DSS impacted the decision making of COs and TAOs relative to performance in a traditional CIC in a medium-fidelity simulation. Although the contributions of individual display modules could not be assessed objectively due to resource limitations, overall effects of the DSS on decision performance were examined in terms of a variety of performance criteria.

Method

Eight expert Navy tactical decision making teams (with emphasis on the CO and TAO) used either their current display systems alone or in conjunction with the prototype DSS at NRAD's *Decision Evaluation Facility for Tactical Teams* (DEFTT) CIC simulator. A within-subject factorial design was employed across four test scenarios such that each team performed two scenarios with the DSS and two scenarios without it. Scenarios were constructed to simulate peace keeping missions with a very high number of targets to be dealt with in a short period of time (i.e. were time compressed), and with a significant number of highly ambiguous tracks regarding assessment and intent. Subjects were given appropriate geo-political and intelligence briefings prior to each test run. The order of the scenarios and DSS conditions was counterbalanced using a Latin Square. Criterion-referenced training with the baseline DEFTT display system and with the DSS was provided, and two practice scenarios were run prior to beginning the test session. In addition to collecting objective data on tactical actions, display usage, control inputs, and voice communications, subjective assessments (via questionnaires and a structured interview) were solicited from each CO and TAO at the conclusion of the test session.

Results

Several classes of research questions were examined as part of this study. These concern DSS utility, situation awareness, team communications, and DSS usability.

DSS Utility

If COs and TAOs considered the DSS to be useful for tactical decision making, we would expect them to make use of it during the test scenarios when it was available. Similarly, we would expect them to report

that the information provided by it was useful for their decision processes.

At 1 min. intervals throughout the test scenarios, subject matter experts recorded whether or not the COs and TAOs were attending to the DSS. On the average, participants were observed to be attending to the DSS at 66% of the time samples. In many cases, it was possible to determine to which module(s) they were attending, and these data are shown in Figure 8. It can be seen that the COs tended to use the DSS somewhat more than the TAOs, particularly for purposes of maintaining awareness of individual track's behavior, responses completed and pending, and the relative priority of active tracks. TAOs, on the other hand, tended to spend more of their time using the DSS to acquire quantitative track status and sensor data. Both COs and TAOs tended to use the upper half of the DSS (i.e., Track Summary, Track Profile, and Response Manager modules) most often. Self-reports of module usage from the participants corroborate these findings.

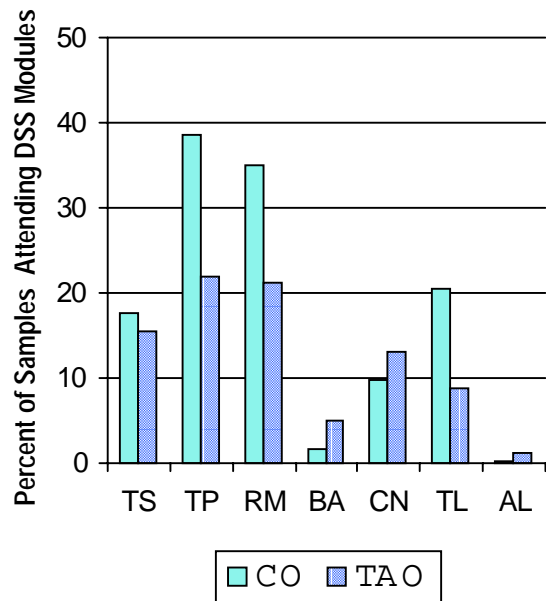


Figure 8. Mean percent of time samples where the CO and TAO were observed attending to DSS modules.

Note: TS = Track Summary, TP = Track Profile, RM = Response Manager, BA = Basis for Assessment, CN = Comparison to Norms, TL = Track Priority List, AL = Alerts List.

At the completion of the test session, participants were asked to complete a questionnaire that called for a variety of ratings of the DSS. Figure 9 shows the average ratings (on a 7-point scale) of how useful the COs

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and TAOs felt the information provided in the DSS modules was. Ratings indicate that most modules were considered to be quite useful for tactical decision making, particularly those parts of the DSS designed to support quick decision making. COs and TAOs noted that these modules enabled them to extract key information rapidly and to visualize track behavior easily. Participants considered that the DSS overall offered high utility (average rating = 5.97 of 7-points) for tactical decision making in littoral warfare situations.

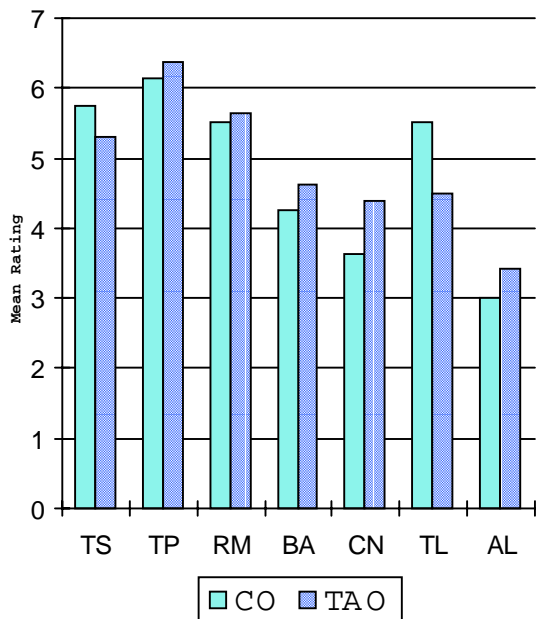


Figure 9. Mean rating of the usefulness of DSS modules.

Note: TS = Track Summary, TP = Track Profile, RM = Response Manager, BA = Basis for Assessment, CN = Comparison to Norms, TL = Track Priority List, AL = Alerts List.

Feedback from the expert CO/TAO teams who participated in this experiment indicated that the DSS provided them an excellent summary of the overall tactical situation as well as of key data for individual tracks. In particular, COs and TAOs considered that both the Track Profile and the Basis for Assessment modules provided important information not readily available in present day systems. Since the Track Profile module supported feature matching, which is the most commonly used decision strategy, its high rating was anticipated. Yet, when the track data are conflicting or ambiguous and when the decision maker has time available, the Basis for Assessment module was rated as helping substantially. Note that by encouraging decision makers to consider the full range of available evi-

dence along with various explanations for it, this module reduces the likelihood of mistakenly engaging friendly or neutral tracks, and was rated highly with regard to avoiding Blue-on-Blue and Blue-on-White engagements.

Situation Awareness

Awareness of the tactical situation was examined via several performance measures. Specifically, it was predicted that if the CO/TAO team was more aware of the tactical situation in a peace-keeping mission, they would:

- identify the critical contacts earlier and more accurately;
- take more of the defensive tactical actions required by the rules of engagement earlier, and more of the provocative (offensive) actions later; and
- ask fewer questions to clarify previously reported track data and the relative locations of tracks.

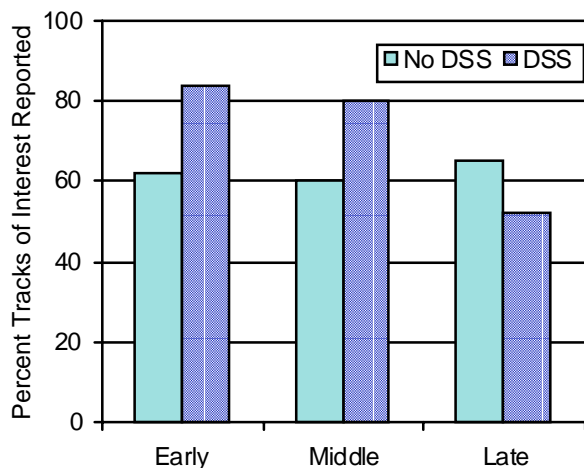


Figure 10. Percent of critical contacts reported as tracks of interest.

Critical contacts. During the scenario runs, the CO/TAO team was probed at prespecified times to identify the tracks that were considered to be of greatest tactical interest at that time. Their responses were contrasted with those of an independent group of five subject matter experts. As shown in Figure 10, significantly more of the critical contacts were identified when the DSS was available. Significant differences ($p < .05$) were noted at both the early and mid-scenario probes; performance was comparable at the late probe, however. Late in the scenario the critical tracks may become more obvious even without the DSS. Neverthe-

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less, earlier recognition of critical tracks earlier in the scenario affords decision makers a broader array of response options and permits more effective coordination of response actions.

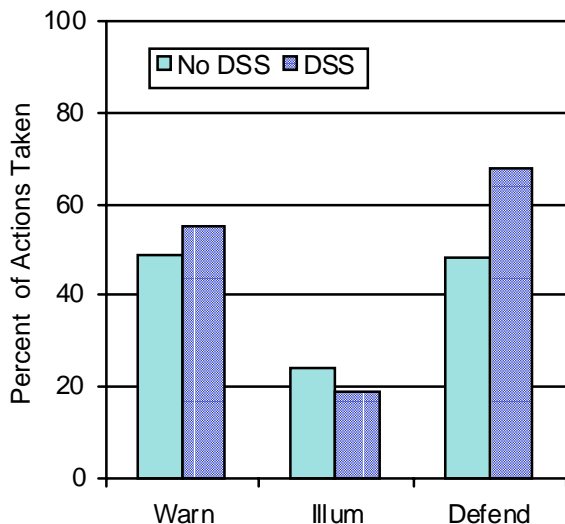


Figure 11. Team performance of tactical actions required by the rules of engagement.

Tactical actions. Using the rules of engagement as a benchmark for decision performance in the scenarios, a group of subject matter experts assessed whether the CO/TAO teams warned and/or illuminated threat tracks at specified times and took appropriate defensive actions. A modified form of the Anti-Air Warfare Team Performance Index (ATPI) was used for scoring tactical performance (Dwyer, 1992), and these data are summarized in Figure 11. In scenarios when the DSS was available, CO/TAO teams were significantly more likely to take defensive actions in a timely manner against imminent threats ($p < .05$). This indicates that the DSS promoted an earlier recognition of the emerging risks of the tactical situation. By contrast, no difference was observed in the number of tracks that were warned or illuminated (i.e., provocative actions) when the DSS was available. However, several subject matter experts contended that warnings and illuminations may not be diagnostic performance indices in these scenarios since they represent provocative tactical actions that commanders may consider to be inappropriate against certain tracks in a littoral situation. Not taking provocative actions would be appropriate and expected if commanders had assessed that the track was not an imminent threat, and felt comfortable with prolonging those actions because they had a good tactical picture - as would be expected if the DSS was being effective in meeting its design objectives.

Team Communications

Although the DSS was primarily designed to support an individual decision maker, the information that it provides could be expected to influence the team's collective decision process. One way that influence could be observed is by changes in the team's communications. Therefore, the communications rate, the pattern of communication, and the content of the communications were compared with and without the DSS.

Communications rate and pattern. It was hypothesized that when using the DSS, teams would have less need to exchange data verbally and would, thus, communicate less often. To test this, all voice communications that requested or provided information were tabulated for each of the 32 test runs. Since the length of the scripted test scenarios differed, the total number of voice communications observed was divided by the scenario duration to give a communications rate.

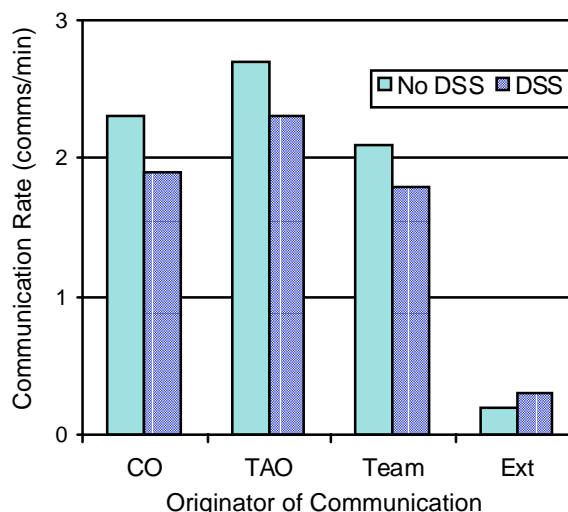


Figure 12. Voice communications rate by message originator and DSS condition.

Figure 12 shows the mean rate of communications originating with the CO, TAO, other members of their team, and others external to the ship's combat center (e.g., the battle group commander, the bridge). A general decrease in communications rate with the DSS was observed. This decrease remains fairly consistent regardless of who originated the communication. In fact, the pattern of communications was unaffected by the presence of the DSS. About 40% of the communications occurred between the CO and TAO, and another 35% occurred between the TAO and the team. Each of the remaining links accounts for about 5% or less of the

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total communications. The decrease in communications across positions suggests that the DSS supported the entire team by providing basic data about tracks, thereby reducing their need to request or provide such data verbally.

Communications content. While the pattern of communications was not found to be affected by the presence of the DSS, the content of the teams' communications may be altered by the DSS. That is, without the DSS, teams might need to spend more time exchanging basic track data while those with the DSS might spend the bulk of their time assessing track intent or evaluating alternate courses of action. To explore the possibility of a qualitative trade-off in communications, voice communications were coded by their message content according to the following scheme:

- *Information* – exchange of sensor-based data;
- *Status* – exchange of procedure-based data;
- *Clarification* – redundant communication to: elucidate, interpret, or correct other communications;
- *Correlation* – association of two or more data;
- *Assessment* – discussion of expected track behavior, likely intent, or future actions;
- *Orders* – commands to perform an action.

Figure 13 shows the overall average proportion of communications observed for each of these content categories. The largest proportion involved Information communications, in which sensor-based data were exchanged. This, of course, is not surprising since these data effectively drive the decision processes. The *rate* of these communications, however, was found to be lower when the DSS was available². Since the DSS provides much of these data, there was less need for verbal exchanges among the team. Similarly, fewer Correlation communications were observed when using the DSS. Although decision makers were less likely to ask about or report correlation data with the DSS (since much of it is displayed automatically), they were somewhat *more* likely to talk about correlations in the data that they observed on the DSS. No differences between DSS and No DSS runs were observed in the other communications content categories.

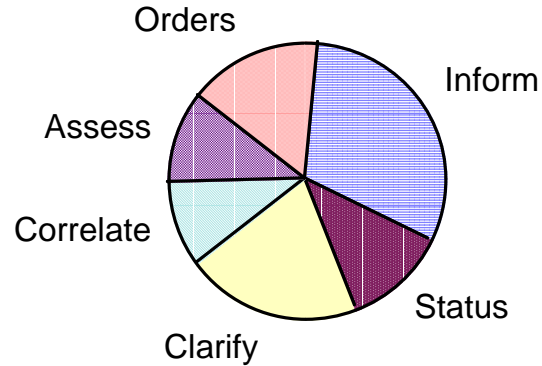


Figure 13. Mean proportion of communications by content category.

Clarification communications. Overall, about 20% of the communications were for clarification purposes, reflecting uncertainty about track location, kinematics, identification, status, or priority. Figure 14 shows the type of information that was discussed during clarification communications. The relative percentage of each type of clarifying communication is shown when the DSS was available and when it was not available. Thus, it can be noted that clarification communications about Track Location (e.g., locating the symbol on the geographic display that corresponds to the track of interest) and Track Status (e.g., response to warnings) were equally likely whether or not the DSS was available. In contrast, clarification communications about Track Kinematics (e.g., speed or altitude), EW Information (e.g., IFF and emitter signature), and Tactical Picture (e.g., track identity and relative position) were less likely when the DSS was available. Clarifications regarding Ambiguous Orders (e.g., incorrect track number) were somewhat more likely to occur when the DSS was available.

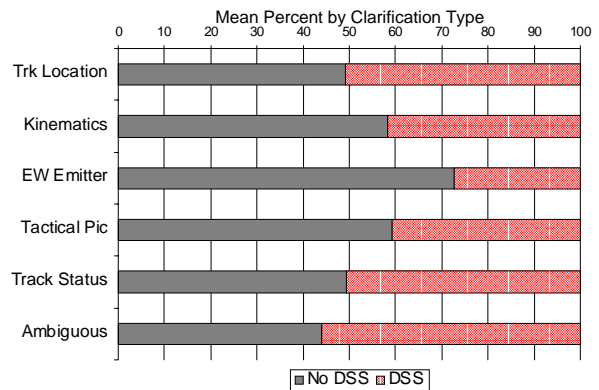


Figure 14. Relative percent of clarification communications with & without the DSS.

² $t(15) = 2.16, p < .05$

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The pattern of these findings is actually quite revealing about the information in the DSS that was used by tactical decision makers. Since the multi-track geographic display and the DSS were not linked in this study, the DSS by itself provided little help in locating tracks in relation to each other. Similarly, the DSS provided no information to decision makers about the status of actions taken or about tracks' responses to warnings. Thus, no difference between DSS and No DSS conditions was expected for these types of clarifications, and the data confirm this prediction.

In contrast, the DSS Track Summary module showed available track kinematic data, the supplementary data read-out in the Comparison to Norms module summarized EW information, and the Track Profile and Track Priority List modules helped decision makers prioritize and maintain awareness of the overall tactical picture. Therefore, the DSS was expected to reduce the need to clarify these types of information. Again, these predictions were confirmed, especially for the EW information which was consulted frequently in making threat assessment decisions.

Although not statistically significant, the tendency for there to be more clarification communications about ambiguous orders when using the DSS was interesting. In fact, we observed a tendency for decision makers to be more precise in referencing tracks when using the DSS. This increased precision thereby encouraged the team to ask for clarification about which track was being referenced when ambiguous orders occurred.

This detailed analysis of clarification communications confirmed that decision makers did indeed use the information that was displayed in the DSS, even with only very limited experience with it. This analysis also revealed ways in which the DSS might be enhanced to further reduce the burden of clarification communications. For example, linking the geographic display with the DSS such that selecting a track on either display would highlight it on the other would probably reduce the communications to clarify track location. Similarly, enhancements to the Response Manager module to show the status of actions and responses by tracks would be likely to reduce the need for decision makers to repeatedly ask about such track status information.

Communications about critical contacts. The tracks to which the teams' communications referred were also examined under the DSS and the No DSS conditions. The hypothesis was that the DSS would enable teams to focus on the critical contacts more

quickly, resulting in a greater proportion of their communications about those tracks. The average proportion of communications about the critical contacts was slightly greater (but not significant) when using the DSS³. It is not particularly surprising that these teams concentrated the bulk of their communications on the critical contacts regardless of whether or not they were using the DSS. After all, these were highly experienced tactical decision makers who are accustomed to functioning effectively with their current (non-DSS) systems. Thus, greater effects might be obtained with less experienced decision makers.

DSS Usability

Even if the DSS provides useful information, promotes better situation awareness, and facilitates team communications, it must also be usable. That is, decision makers should consider it easy to learn, easy to understand, and easy to use.

Participants were asked to complete a questionnaire following the test session in which they rated the usability of the DSS and its modules. Comments about the DSS interface were also solicited in the questionnaire and during a follow-up interview. The overall rating of DSS usability was high (average rating of 4.16 of 5-points). Similarly, most modules were considered easy to use, as shown in Figure 15. The modules that promoted "quick-look" assessments of track status, location, and priority were rated as more usable. The modules that were predominately text-based, particularly the Alerts List, were rated as less easy to use.

The COs and TAOs offered many valuable suggestions for improving the DSS to make it more useful and usable for tactical decision making and were incorporated into the DSS-2 described above. Frequently heard suggestions included the need to (a) integrate the DSS display with the geo-plot to simplify track selection procedures and to display multiple tracks, (b) allow user-customizable display areas and content, particularly for control window size, range scale, and Response Manager actions, (c) allow command-override of track priorities and threat assessments, and (d) provide an expanded Track Priority List that shows more tracks in a more graphic/spatial format.

³ $t(15) = 0.96$

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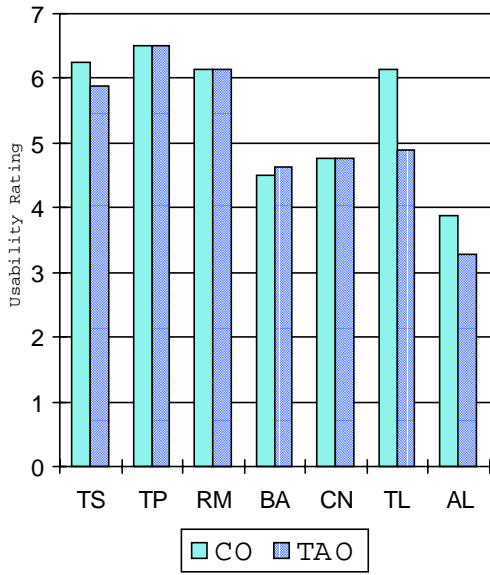


Figure 15. Mean rating of the usability of DSS modules.

Note: TS = Track Summary, TP = Track Profile, RM = Response Manager, BA = Basis for Assessment, CN = Comparison to Norms, TL = Track Priority List, AL = Alerts List.

While several of the usability suggestions by experienced tactical decision makers concern improvements to the “look and feel” of the DSS interface, others have substantial implications for our understanding of their underlying naturalistic decision processes. Their call to integrate the DSS and geo-plot displays and to provide more tracks in the Track Priority List reminds us that feature matching decision strategies involve evaluating tracks within the context of other related tracks and events. Decision makers’ requests to permit them to customize their displays and to override system defaults have implications for their story generation / explanation-based reasoning strategies. Namely, decision makers seem to use a “stepping stone” approach whereby they use available data to reach an intermediate conclusion about a track, say its priority. Based on that intermediate conclusion, they then continue to use other data to explore further implications for that track, given its priority. To support such a process, it is clear that decision makers would want to have the ability to override and customize their DSS displays.

CONCLUSIONS

Operational decision making predominantly relies on feature matching strategies. To a lesser extent when faced with conflicting or ambiguous data, decision

makers employ story generation or explanation based reasoning strategies. Displays that are consistent with these naturalistic decision making strategies provide the most useful support to commanders, facilitating the rapid development of an accurate assessment of the situation. Displays that support both feature matching and explanation based reasoning are recommended for complex decision making tasks. While the feature matching displays will likely be used far more often, the explanation based reasoning display is of substantial value under certain circumstances, particularly with less experienced decision makers.

The DSS was developed for application to Navy tactical decision making on a single ship in support of AAW in dense, fast-paced littoral settings. With some adaptation, it could support other military decision situations, including concurrent decisions involving other warfare areas, higher-level, supervisory decisions involving multi-ship battle groups, and even collaboration among tactical decision makers in joint service or multi-national operations. Several new research projects are underway to explore these applications. In addition to these direct applications to support military decision making, the decision support and display principles identified through this effort are relevant to other complex decision making settings, such as nuclear power control, flight control, process control, and disaster relief planning. Further, additional work is looking at developing derivative displays reflect emerging theories of decision making, extension of the DSS concepts to other workstations within the CIC, as well as better integration of DSS modules with shipboard data processing systems.

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