Decision Support for Tactical Decision Making Under Stress*

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Abstract

A decision support system was designed for naval shipboard command-level decisionmakers to enhance decisionmaking in a littoral environment or in any short-fused, ambiguous, decisionmaking situation. Design of the prototype DSS was based on (1) an understanding of the cognitive strategies people bring to bear when dealing with the types of decisions requir-ed in tactical decisionmaking, (2) applying human-system interface design principles which are expected to help compensate for human cognitive processing limitations, and (3) the extensive involvement of subject matter experts with vast command decisionmaking experience. Each DSS module will be described in terms of what decision/s it is designed to support.

1 Introduction

The decision support system (DSS) was developed for the command-level decisionmakers within a Navy combat information center—the commanding officer and the tactical action officer. These two officers are responsible for the following combat-related decisions: (1) recognizing and correctly interpreting the nature of the threat; (2) predicting which preplanned responses and/or countermeasures may be effective if the situation evolves in certain ways; and (3) interpreting information to determine whether the situation actually is evolving a particular way. An additional task is to ensure that team members provide critical information that would enable the team to resolve ambiguities. The six modules which comprise the DSS were designed to facilitate the decisionmakers' performance of the tasks listed above and, in general, promote an accurate situation awareness while minimizing the decision-maker's cognitive processing requirements.

This paper is intended as a companion paper to the papers on principles for aiding complex military decisionmaking (Hutchins, Morrison, & Kelly, 1996) and the empirical evaluation of the decision support system (Kelly, Hutchins, & Morrison, 1996). Topics to be discussed include the functionality of the six decision support modules and the differences between existing tactical systems and the DSS developed under the Tactical Decision-Making Under Stress (TADMUS) program. These differences include (1) the presentation of synthesized data to support critical sub-

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tasks; (2) constructing explanations for the available evidence; (3) evaluating the plausibility of hypotheses regarding the situation; (4) providing the ability to compare multiple hypotheses; (5) processing and presenting information in a format that parallels the decision-maker's cognitive strategies; (6) prompting the user regarding required responses; and (7) providing a better mapping between the geographical display of data and alerts. In addition, one of the unique aspects of the TADMUS program at NRaD has been the extensive involvement of subject matter experts (SMEs). These SMEs have vast command decisionmaking experience as well as an understanding of current Navy procedures and capabilities across relevant tactical scenarios.

1.1 Status and Command Displays

All modules included in the DSS are what are referred to as "status" displays, as opposed to "command" displays, in the human factors literature (viz., Andre & Wickens, 1992). A command display tells the user what to do without displaying the reasons for the command. Status displays include the "why" information, informing the user regarding what is known about the current situation. A separate, yet related, idea is that information is not filtered. User's who participated in subjective evaluation studies of earlier versions of the DSS indicated they wanted to have access to the raw data when making decisions to engage (Rummel, 1995). All modules were developed to *support* the decisionmaker in performing the requisite tasks without removing the user from the decisionmaking process. Hence, raw data can be displayed when requested for any contact.

Research indicates that providing decision support in the form of status displays increases the accuracy of comprehending system states (i.e., situation awareness). Andre and Wickens attributed the superior performance of subjects with a status aid as resulting from negating the decision-maker's need to "traverse the display processing stages in the reverse order (i.e., from a commanded response to a cognitive interpretation)," which is required of the user with the command type display. The analogy in the TADMUS DSS situation is the decisionmaker would want to mentally create a list of reasons, or a checklist, for why the track ought to be engaged before issuing the "engage" command. The severity of the results in the decisions to be made demands that the user have the ability to verify the accuracy of the recommended action (Crocoll and Coury, 1990). Several modules included in the DSS incorporate elements of both types of displays. This is best illustrated in the response manager which is described in section 2.1.3.

2 Decision Support System Description

Currently available decision support systems typically provide indications of the presence of various data items and their values. Indications of the relations between features, structural similar-ity between sequences of features, or evidence of underlying relationships among features is usually not depicted. The TADMUS decision support tools were designed to provide precisely these types of evidence. All of the DSS modules focus on providing information to the user in a manner that will support situation awareness. These modules will be discussed in terms of the underlying theoretical concepts and in terms of the expected payoff for each decision support tool.

The experimental DSS receives tactical data input from many sources, integrates the data to present a synthesized picture, and displays it in various ways for aiding individual subtasks. (This tactical data is inserted directly into the DSS from the scenario generator in the Decision-Making Evaluation Facility for Tactical Teams Laboratory where this research was conducted. This information would come from the various sensor systems found aboard ship in the operational application of DSS.)

2.1 Decision Support System Modules

The prototype DSS comprises the six display modules shown in Figure 1. These modules are arranged according to an increasing level of information complexity from top to bottom of the display. The top half of the display contains the track summary (upper left corner), track history, and the response manager modules. (The track history module occupies the rectangle in the upper right-hand corner and the circular display below track summary in the upper left. These two areas present different views of the same information and are thus considered as one module.) These three modules focus on analysis and identification of a single contact and would be used to make a quick shoot/no-shoot decision.

The lower half of the display presents the basis for assessment, comparison to normal values, and the track priority listing and alerts modules. Basis for assessment and the comparison to normal values modules provide more detailed analysis of a single contact while the alerts and track priority listing (bottom of the display) presents information on all contacts currently requiring attention or action.

2.1.1 Track Summary

Track summary presents current data for a selected track (bearing, range, course, speed, altitude, etc.) but with an improved human-computer interface format. As shown in Figure 2, all data items are appropriately labeled and aligned to facilitate extraction of key parameters by the user. Subjects who participated in the empirical evaluation of the DSS remarked that the information was much easier to read in this format. An additional item included in this module is the DSS assessment, that is, whether the track is considered a threat or a non-threat.

Figure 1. Decision Support System Developed for the TADMUS Program.

Figure 2. Track Summary Module.

2.1.2 Track History

When a rapid decision is required regarding whether the track should be engaged, the track history and response manager modules should present useful assistance in two ways: by facilitating the decisionmakers' use of a recognitional strategy when developing a threat assessment (via track history) and by assisting the decisionmaker in performing the requisite actions. For tasks involving rapid decisionmaking (e.g., several seconds to one or two minutes) a recognitional strategy appears to be highly efficient (Klein, 1993). The track history module, depicted in Figure 3, was designed to support the recognition-primed decision (RPD) model of decisionmaking. To generate a reasonable course of action, the decisionmaker must accurately identify familiar elements in the situation. The objective for this module is to facilitate the track identification process by providing information that is integrated in a way that supports a recognitional decision strategy. The track history module presents a highly synthesized view of the situation regarding a specific track.

The track history module depicts a track’s speed, altitude, course and range on a two-dimensional graphical display along with a geometric representation of both the track’s worst case weapon release envelope and own-ship’s weapons coverage. A large amount of parametric data is portrayed graphically for rapid assimilation by the user. The track history module is designed to be used when the decisionmaker has to make a rapid shoot/no-shoot decision. Changes in the track’s speed, course, altitude or range are immediately apparent with this graphical depiction of the track history. This graphical representation was hypothesized to be particularly useful, as in previous systems the user had to remember the previous parameter values (e.g., speed, altitude) and compare them with the current values for those parameters. However, as short-term memory degrades under stress, the user may not be able to accurately perform this function.

2.1.3 Response Manager

The response manager, depicted in Figure 4, provides assistance in using preplanned responses. This decision support module was designed specifically to mitigate errors document-ed in previous research (Hutchins & Kowalski, 1993; Hutchins & Westra, 1995). The response manager was developed to provide support to the user regarding required actions and when they need to be taken, and to lesson the task load imposed on the user's limited attentional resources during high track density. Maintaining an awareness of the status of each track and the status of many actions to be taken by the CIC team (e.g., issuing warnings, illuminating with radar, executing electronic support measures

Figure 3. Track History Module.

packages, verifying airspace, readying self-defense systems, making reports to the battle group commander, etc.)—as well as what the track's response to these various actions were—severely taxes the decisionmaker's working memory

Figure 4. Response Manager Module.

During TADMUS baseline experiments, the majority of documented errors involved errors of omission, e.g., failure to take defensive measures, and failure to adhere to rules of engagement (ROE). The cause of these failures to take required actions is, in many cases, attributed to the extremely high task demands levied on the decisionmaker by the scenario. The scenarios were intentionally developed to be highly stressful (albeit realistic) by including high levels of ambiguity, workload, and time-pressure. The phenomenon that increasing stress leads to decreasing working memory is well documented (e.g., Hockey, 1986). Effective maintenance of the queue of pending tasks requires considerable cognitive effort.

Competent management of the task constellation requires that the decisionmaker respond to each task, ideally at the most efficient possible moment, or minimally before it is too late. This requires the person to stay abreast of the urgencies, opportunities, and constraints on all of the tasks. The response manager module graphically depicts preplanned responses which need to be taken regarding a selected track, using a series of bars (on a range scale) that show the earliest and latest time each action can be taken to be effective. This module also depicts the track's current speed and range via a moving pointer that indicates where the track is in relation to the various actions which need to be taken. The response manager module thus cues the decision-maker to take actions specified by the ROE or ship's battle orders. Color coding is used to keep track of which actions have been taken and which actions remain to be taken.

2.1.3.1 Example of Integrated Command and Status Display

Within each bar the action to be taken is listed (such as, execute EW packages), which represents the command type of information. This module also depicts the track's current speed and range via a moving pointer that indicates where the track is in relation to the various actions which need to be taken. This synthesized representation of kinematic information thus presents the "why" information: "this track is now at a range where chaff/jamming/etc. would be effective." The goal is not to subject the decisionmaker to a "checklist mentality" where individual initiative has been removed, but to have the response manager act as an "intelligent" assistant, keeping track of actions taken and suggesting future actions in a timely manner.

2.1.4 Basis for Assessment

Basis for assessment, depicted in Figure 5, is based on a model of a cognitive strategy employed in making decisions where the decisionmaker is confronted with a situation involving contradictory or incomplete information. In this situation, the decisionmaker constructs a causal model which explains the available evidence. This strategy is known as explanation-based reasoning, or story generation (Pennington & Hastie, 1993). In this approach, available data are assembled into explanatory structures, with one structure for each possible conclusion. Each of the explanations attempts to explain how every piece of data can be accounted for in support of each conclusion, even though some of the data items would naturally contradict reaching some conclusions. Contradictory data are explained through the use of internal assumptions. It is assumed that there are a fixed number of predefined possible conclusions and each data item points directly to one of those possible conclusions.

2.1.4.1 Avoiding Decision Biases

Basis for assessment, shown in Figure 5, provides a contact threat assessment and presents all the information used to form the assessment. Basis for assessment will usually generate multiple hypotheses to explain the available evidence because many of the contacts behave in a way that makes determining whether they are a threat or non-threat very difficult due to the

Figure 5. Basis for Assessment.

inherent ambiguity in the scenarios. In addition to reflecting a naturalistic decision strategy based on explanation-based reasoning, this decision support module should have the corollary benefit of reducing decision bias. Human decisionmakers have been shown to be deficient in generating alternatives. Specifically, in situation assessment they tend to generate only a few hypotheses based on early data and find it difficult to enlarge their hypothesis set, even in the face of contradictory data (Tolcott, 1991). Basis for assessment presents all the supporting evidence, counter-evidence, and assumptions the decision-maker would need to make to accept the presented hypothesis (that is, threat or non-threat). The advantage is that the decisionmaker should be less susceptible to many of the typical biases which are well documented in the decisionmaking literature, such as, "availability" bias, "confirmation" bias, effects of "framing," etc. (Kahneman and Tversky, 1982). By presenting all available evidence in a structured way, grouped under the three evidence categories mentioned above, the decisionmaker is less likely to make a decision based on a subset of the available evidence. The decisionmaker will also be made explicitly aware of the absence of data which may be as important as the presence of data. For example, when studying Army intelligence analysts, it was found that the confirmation bias could be reduced by displays that made explicit the uncertainties about enemy unit locations (Tolcott and Marvin, 1988). In research conducted to investigate whether Navy decisionmakers responding to antiair warfare scenarios would be susceptible to these biases, the results supported earlier research findings. A study was designed to assess whether naval personnel, trained and experienced in antiair operations, exhibit biases when performing their normal duties. Results strongly supported existence of the availability, representativeness, contrast, and confirmation biases in the surface antiair warfare context (Barnett, Perrin, and Walrath, 1993). Threat assessment should help ameliorate the effects of these pervasive biases.

2.1.4.2 Avoiding "Blue-on Blue" Engagements

A second advantage of the threat assessment module is it should reduce the occurrence of "blue-on-blue" incidents (fratricide) where a decisionmaker mistakenly identifies a friendly contact as an enemy. By pointing out the counter-evidence associated with a particular threat assessment category and listing the assumptions one has to "buy into" to accept the conclusion that the contact is a threat the decisionmaker may be better able to weigh all the information about a contact and reach a more accurate assessment regarding its threat potential.

2.1.5 Comparison to Normal Values

Comparison to normal values, depicted in figure 6, compares known information about a contact with information representative of specific types of contacts. The comparison to normal values module was designed to support the user in performing feature matching. Klein and associates (Klein, 1993) found feature matching to be the predominant cognitive strategy used by decisionmakers when performing situation assessment. The decisionmaker matches the features of the present situation with a template, or mental model, of a previous situation. Comparison to normal values presents a comparison of data associated with the selected contact with exemplars for other types of contacts (i.e., threat or non-threat) and graphically depicts whether the selected contact is a fit or misfit with these categories. Discrete coding of key variables is used to determine whether a contact's data falls within the specific ranges that categorize threat versus non-threat.

Figure 6. Comparison to Normal Values.

2.1.6 Track Priority Listing and Alerts

The track priority listing and alerts, depicted in Figure 7, summarizes key information on all system contacts in order of tactical priority and allows the user to monitor more than one contact. This module presents multiple contact information, focusing on high priority contacts, the next action to be taken and status of that action, (e.g., immediate, watch, low priority), the last alert given regarding the contact and the time it was given, and an alert history function. The user can click on the last alert to view a history window which displays all previous alerts received regarding this contact. Alerts are based on preset criteria for key events and required responses. Lines included in this decision support module are ordered by the operational priority assigned to the corresponding contact. Users could check what the DSS listed as tracks requiring immediate attention to make sure they had not failed to attend to any critical track/s. Then, if they questioned the DSS's recommendation, they might look at the basis for assessment to determine why the DSS considered that track a high priority.

One type of tactically significant error observed during early TADMUS experiments was a failure to attend to a contact of interest (Hutchins, Morrison, & Kelly, 1996). This is attributed to the high workload imposed by the ambiguous contacts, and very limited time that decisionmakers have to process contacts. The track priority listing and alerts was designed to ensure that the user is made aware of new contacts of interest and their status. This module will prompt the user on required actions and specify when these actions are to be taken. The behavior that triggered the last alert is also presented along with the capability to review the history of alerts for any selected contact.

Figure 7. Track Priority Listing and Alerts.

3 Decision Support System Features

In summary, key features of the prototype DSS include the ability to:

- Track multiple hypotheses
- Present patterns of tactical activities
- Develop explanations for observed events
- Evaluate plausibility of explanations
- Use graphics to support intuitive processes and reduce cognitive processing requirements
- Prompt user regarding appropriate responses
- Support the decisionmaker's cognitive process

4 Conclusions

The TADMUS program has produced a prototype DSS which has been empirically evalu-ated as significantly improving the decisionmaking performance of experienced officers (Kelly, Morrison, and Hutchins, 1996). Feedback received from these officers has been very positive with suggestions made for significant improvements. Several unanticipated advantages were revealed during evaluation of the DSS. One of these advantages included having continuous access to data that would not be available with current systems. For example, in the comparison to norms module, a graphically-based comparison of key parameters which are representative of typical values for threat or non-threat, is presented. A series of color-coded "chips" indicates whether each parameter value is a "fit," is unknown, or is a "misfit" with the typical values indicative of the two threat assessment categories (i.e., threat, non-threat). An additional feature is the ability to have the *specific* parameter values displayed by sliding the cursor over the parameter of interest. For example, as shown in Figure 6, when EW emitter is selected, information similar to the following appears: "EW emitter verified as Cyrano IV, associated with F-1 aircraft. Threat: Exocet." This is essentially what a full EW report would consist of. The advantage here is that no communications are required between the CO or TAO and the EW operator, which saves both time and cognitive overhead. The information is readily available just by sliding the cursor over any of the eight parameters included in this module. Having instant access to specific parametric information, as it dynamically changes over the course of the scenario, at no "cost" to the user, allows the decisionmaker to spend more time attending to critical cues and thus to maintain a more current and accurate situational awareness. In these high workload, time-compressed scenarios the decisionmaker would, in many cases, not have time to request this information. However, subjects reported that they liked having ready access to this data without having to ask for it. Acquiring and maintaining situation awareness becomes increasingly difficult as the complexity and dynamics of the situation increase. When the status of several tracks is constantly changing, often in complex ways, "a major portion of the operator's job becomes that of obtaining and maintaining good situation awareness" (Endsley, 1995, p. 33).

Another way the DSS was used to maintain situation awareness is illustrated by the way a CO/TAO used the system. When the CO heard the TAO issue the order for a warning to be given, he looked at the track history module and he could immediately see why. Again, time and cognitive overhead are saved by negating the need for these two decisionmakers to communicate about these types of decisions.

Research on problem solving has shown that the way a specific problem is presented can determine how the problem is solved. Modules within the DSS were designed to have a synergistic effect. For example, the information contained in the track profile (what's going on with a track) and the response manager (what to do about it) create a holistic picture of the situation. The synergism results from having these two decision support modules share the range scale and the moving pointer. The moving pointer indicates where the track is relative to the kinematic and weapons' information (altitude, track history, track weapon's envelope, own-ship's weapon's coverage) presented in the track history module as well as the recommended actions to be taken presented in the response manager module.

5 Future Research

Many of the recommendations made by subjects in the initial evaluation of the DSS have been incorporated along with additional features the research team anticipates will enhance performance. The next phase of the TADMUS program will empirically evaluate the DSS II. These recommendations include the following: (1) integration of the geoplot with the DSS screen; (2) use of a touch screen to interact with the DSS (thereby making interaction with the system as easy as possible in contrast to other systems that require many complex steps to access informa-tion); (3) increasing the number of tracks included in the threat priority listing from 10 to 18; (4) adding a relative position indicator, as an inset, to indicate whether the ship has to maneuver to engage; (5) adding a shadow along the coast to indicate the 12-nautical mile limit for territorial airspace; (6) presenting additional layers of information via various maps that can be accessed by the user to depict information such as geopolitical boundaries, atmospheric effects, population densities, depending on the ship's mission; (7) track priority listing has been converted to include a quick access bar to make accessing additional information for a specific track easier as well as the use of additional color coding to provide more information in the limited space; (8) adding the capability to tailor the various actions (and the recommended times for taking them) included in the response manager to an individual user's preference; (9) use of color coding to distinguish historical information from current information in several modules; (10) time of the last alert is presented terms of how old the alert is (in minutes) versus the time it occurred (so no conversion is necessary); (11) the method of adjusting the range has changed dramatically in that it is no longer limited to changes in multiples of 2 (i.e., 16, 32, 64, etc.). Now the user presses the zoom button until the desired scale is achieved. Additionally, the user can pan around within a range scale instead of going through the additional step of off-centering the ship's position to enable the user to focus on a particular area of the display.

Many other research issues remain. Plans include testing the complementary roles of the DSS and training in critical thinking. Critical thinking is a form of critiquing the currently held threat assessment to ensure one hasn't succumbed to cognitive biases (Freeman & Cohen, 1996). Critical thinking is needed when pattern recogni-tion does not work; it involves training decision-makers to create, test, and evaluate stories to make sense of observations and to explain conflicting data, and finding alternative interpretations of events. An experiment will be conducted to examine whether practice and feedback provided by the DSS (using a modified version of the basis for assessment module) enhances training.

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