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Abstract

The Tactical Decision Making Under Stress (TADMUS) program is being conducted to apply recent developments in decision theory and human-system interaction technology to the design of a decision support system for enhancing tactical decision making under the highly complex conditions involved in antiair warfare scenarios in littoral environments. Our goal is to present decision support information in a format that minimizes any mismatches between the cognitive characteristics of the human decision maker and the design and response characteristics of the decision support system. Decision makers are presented with decision support tools which parallel the cognitive strategies they already employ, thus reducing the number of decision-making errors. Hence, prototype display development has been based on decision-making models postulated by naturalistic decision-making theory. Incorporating current human-system interac-tion design principles is expected to reduce cognitive processing demands and thereby mitigate decision errors caused by cogni-tive overload, which have been documented through research and experimentation. Topics include a discussion of: (1) the theoretical background for the TADMUS program; (2) a description of the cognitive tasks performed; (3) the decision support and human-system interaction design principles incorporated to reduce the cognitive processing load on the decision maker; and (4) a brief description of the types of errors made by decision makers and interpretations of the cause of these errors based on the cognitive psychology literature.

1 Introduction

Recent changes in U.S. Naval priorities stress the requirement for navy ships to operate in the littoral regions of the world, that is, in the coastline regions. Operating in the congested and confined water and airspace close to land presents additional challenges to the tactical decision maker. Littoral operations involve scenarios characterized by rapidly unfolding events which fit multiple possible hypotheses with respect to con-

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tact identification, intent, available responses and their consequences. For example, the close proximity of U.S. Navy forces and potential adversary forces makes interpreting the actions of an inbound aircraft who does not respond to radio warnings much more difficult. Should the aircraft's behavior be interpreted as an attack profile, or does the pilot merely intend to harass, or does the aircraft in question not carry the equipment necessary to receive verbal warnings, leaving the pilot unable to receive radio warnings directed toward him and unaware of his precarious position? 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 catastro-phic) consequences for errors. While current real-time battle management systems are well-suited to the demands of all-out conflicts, they may not be optimized for littoral situations where human intervention in decision-making is even more important (Office of Naval Technology [ONT], 1992). (Since 70 percent of the world's population lives within 200 miles of the sea, most future contingencies are likely to involve littoral warfare (Mundy, 1994).)

Two unfortunate and highly publicized events focused attention on the difficult types of decisions confronting naval commanders and provided the impetus for this research. In the case of the U.S.S. Stark, the commander made the decision to not engage an inbound aircraft which was believed to not be a threat to his ship, and 27 U.S. naval personnel lost their lives as a result. In the case of the U.S.S. Vincennes, the commander made the decision to engage the inbound aircraft believing it was a threat to his ship—which turned out to be a commercial airliner—and all personnel aboard the airliner were killed as a result. In recognition of the complex and difficult decisions required in these types of situations the Tactical Decision Making Under Stress (TADMUS) program was initiated to conduct research in the areas of human factors and training technology. The objective is to develop and apply principles that can help avoid these types of situations in the future. This paper, and a two companion papers (Hutchins, Kelly, & Morrison, 1996; Kelly, Hutchins, & Morrison, 1996), report on a multi-year, multi-experiment research effort conducted under the TADMUS program to apply recent developments in decision theory and human-system interaction technology to the design of a decision support system (DSS) for enhancing tactical decision making under highly complex conditions.

1.1 "Naturalistic" and Classical Decision-Making Paradigms

In the same time frame that these tragic accidents occurred, a radical shift was occurring in the way psychologists viewed human decision making. Research was now focused on experienced decision makers performing their normal tasks in natural settings. "Naturalistic" decision-making research studies the decision strategies people actually use in bringing their expertise to bear under challenging real-world conditions. Decision making milieus encompassed under the naturalistic paradigm include hospital emergency rooms, aircrew flight coordination, military command and control settings, process control systems, and police and fire units.

The naturalistic perspective, also known as "everyday cognition," is based on a belief that cognitive functions "elicited in natural settings (are) likely to differ, either quantitatively, or qualitatively, from those that occur in artificial or contrived situations, and results from sterile and contrived situations may not generalize to less constrained and more natural environments" (Salthouse, 1992, p. 982). There is a growing body of work that demonstrates that experienced, real-world decision makers rarely use traditional resource intensive strategies to make decisions in the face of dynamic, adverse conditions and time-pressure (Kaempf & Militelo, 1992; Klein, 1989; 1993). Instead, experts rely on their abilities to recognize and appropriately classify situations: these abilities are based on having much experience in the task domain. Once they know what they are facing they also tend to know what response option to apply, based on retrieval from memory of typical responses and outcomes that worked well in past similar situations. They use the limited time available to evaluate the feasibility of that option before implementing it. Experienced decision makers recognize the situation or scenario based on a comparison of the features of the current situation with stored memory representations, or schemata. Schemata are highly intercon-nected clusters of knowledge concerning certain situations, or particular problem types, and associated actions or solution procedures (Federico, 1995). Once the situation is recognized, solutions are stimulated by activation of these memory representations.

In contrast to the naturalistic perspective, earlier analytical methods applied in decision support systems were primarily used for option generation and evaluation, rather than for situation assessment. Traditional decision theorists argue that optimum decision making involves thorough analysis of all the available data and the evaluation of all possible hypotheses; these approaches tend to rely on extensive calculations designed to arrive at optimal solutions. Processes for making decisions where the person weighs the pros and cons of various options and selects the one option that provides the most benefit are described in the decision making literature. The extensive time requirements and complicated mathematical calculations involved (e.g., Multi-Attribute Utility Analysis), however, make these approaches unrealistic for situations requiring rapid decision making. Generally, these analytical strategies involve the following steps (Kaempf & Militello, 1992):

- specify all relevant features of the task;
- identify the full range of options;
- identify the key evaluation dimensions;
- identify weights for each dimension;
- rate each option on each dimension;
- tabulate the results, and
- select the best option.

These analytical strategies may be appropriate for inexperienced subjects making decisions about novel tasks, but not for experienced personnel making real-time decisions. In natural settings, time constraints and the difficulty in assigning weights and rating the dimensions involved render classical analysis techniques untenable. Typically in realistic settings experts employ recognition-based reasoning, not classical analytical approaches. Experienced decision makers use their extensive knowledge to seek information, identify and interpret the problem, understand the significance, derive the intention (where possible), model the situation (as time allows), select the action, evaluate the choice, and anticipate the consequence. "This decision cycle is distinctly different from classical models, which are based on the assumption that all options, outcomes, and preferences are known and calculated in advance" (Federico, 1995, p. 106).

Traditionally, research in decision making has been directed largely toward situations in which (1) decision makers have sufficient time to generate options, conduct option assessment, and select a course of action; (2) the consequences of an incorrect response are not immediately severe; (3) decisions are reached via consensus of a group; and (4) workload is manageable. Little research has been conducted into the development of tactical decision support systems for use in naturalistic situations characterized by time pressure, high risk, uncertainty and information ambiguity, high workload, team coordination demands and task complexity (ONT, 1992).

The central hypothesis for the research reported here is that presenting decision makers with decision support tools which were designed to parallel the cognitive strategies employed by experts, as observed in naturalistic settings, will reduce the number of decision making errors. This is accomplished by developing the architecture and algorithms to process information the same way research indicates humans do under similar circumstances.

2 Tactical Decision Making Tasks

The global tactical decision-making task involves identification of and responding to numerous contacts. When an aircraft (or a surface contact) is detected the CIC personnel work as a team to determine the identity and to try to determine whether or not the aircraft poses a threat. The high degree of inherent ambiguity associated with contact information can often make threat assessment a very difficult task. This is because many pieces of data fit multiple hypotheses regarding threat assessment. The global response choices (that is, engage, monitor, do nothing) are largely determined by the ship's orders and the current geopolitical situation. Specific actions (such as, change course, issue verbal warnings, illuminate with radar, challenge with other sensors, etc.) depend on the local conditions and the relative positions of the inbound contact of interest and ownship. Determining which of these actions is likely to be effective depends on maintaining an accurate threat assessment which requires "continual updating in accordance with recurrent situation assessments" (Sarter & Woods, 1991, p. 52).

This decision problem presents a highly challenging cognitive task, that is, making inferences and deductions from incomplete and uncertain information derived from multiple sources and relating to several concurrent threats (or potential threats) under time-compressed conditions. The cognitive functions performed by the tactical decision maker are both data and resource limited (Norman & Bobrow, 1975). Decisions are resource limited by the mental resources of the decision makers, who must maintain large amounts of information in memory under conditions of high workload and stress. The decisions are data limited by the inability of the sensors to provide complete, error-free, unambiguous data to support the identification process. In particular, the experimental scenarios were designed to follow the pattern of being set in an ambiguous situation where one or more threats of uncertain origin and uncertain intent approach either own ship or the ship being protected and may not respond to warnings. Scenarios were designed to be highly ambiguous, as this quality of uncertainty is indicative of the types of decisions to be made in current and future scenarios.

2.1 Threat Assessment

In the antiair warfare problem, threat assessment is particularly difficult because the available information is often incomplete or ambiguous. The ambiguity could be due to (a) the information transmission characteristics of the transmission medium, such as a radar transmission or a radio report that is only intercepted on an intermittent basis, (b) deliberate deceptive actions (such as radar jamming) by the pilot flying the aircraft, or (c) the overlapping classification categories typical of many parameter measure-ments. For example, aircraft can typically fly at altitudes ranging between 2,000 and 40,000 feet. Generally, an aircraft that is flying above 20,000 feet is not considered to be a threat. Conversely, an aircraft below 10,000 ft is considered to be more of a potential threat. However, aircraft flying in the middle range, (that is, below 20,000 ft. and above 10,000 ft.) can be much more difficult to categorize. Because many aircraft do fly in this middle range, other variables need to be considered in conjunction with altitude. This same situation of overlapping categorization categories exists for several other variables. These variables include radars that are found on both threat and non-threat platforms, country of origin, and measures of course and speed. In the case of speed, for example, when an aircraft flying at a low altitude decreases speed this could be viewed as indicative of a threat action (that is, slowing down in order to obtain better targeting information); however, at the same time, there could be other viable explanations for an aircraft's decreasing speed.

If the decision maker had access to all data about a contact approximately twelve variables would be used to determine identity and to infer intent. Two or three of these items, alone, do not provide definitive answers because, in many cases, these parameter values do not fall within clear-cut ranges for a particular assessment category (i.e., threat, non-threat). Thus, a single time slice of information provides an incomplete picture of the situation. In the dynamic, ambiguous conditions characteristic of littoral operations, the rate and direction of change (data history) can help one better assess the threat and predict the future state of the situation. When the incoming information changes over time, the integration of information as it changes can help the user extract the message (Kirshenbaum, 1992). The DSS was designed to do precisely this: to facilitate the integration process and present a synthesized picture of the situation to the user in a format that can be quickly assimilated. The variables, that are used to develop a threat assessment, can be divided into two classes: sensor information (raw or computer-processed information) and the contact's response, or lack of response, to actions taken by the team. These other actions, and the integration of the information received via the contact's response or lack of response to them, are necessary to clarify the tactical picture.

2.2 Situation Awareness

While recent increasing interest among researchers regarding the concept of situation awareness (SA) has generated a debate on the precise definition of this term most researchers acknowledge the importance of the concept. In general, SA refers to the decision maker's moment-by-moment ability to monitor and understand the state of the complex system and its environment (Adams, Tenney, & Pew, 1995). These authors state the essential idea which is that when emergencies arise, the completeness and accuracy of the decision maker's SA are critical to the ability to make decisions, revise plans, and manage the system. Specific decision-making tasks included under SA include the ability to: (1) maintain an accurate perception of the surrounding environment (both internal and external to the ship); (2) identify problems and/or potential problems; (3) recognize a need for action; (4) note deviations in the mission; and (5) maintain awareness of tasks performed (Shrestha, Prince, Baker and Salas, 1995). To maintain an accurate SA the decision maker should take into account both information that is available and that which can be activated from memory (Sarter and Woods, 1991).

However, a difficulty arises as a result of the heavy workload imposed by this process. When the decision maker is faced with several concurrent contacts of interest, all of which have numerous associated data items (i.e., as many as a dozen), some or all of which may change over the course of the scenario (e.g., intelligence, active radar emitters, various kinematic parameters, etc.) memory load easily exceeds human capacity. Moreover, changing parameters may impart different interpretations to what is occurring. In some cases the moment-to-moment attentional demands of a tactical situation are relentless and unforgiving (such as, a terrorist aircraft directly inbound toward "own-ship" which can result in "task fixation"), sometimes relevant background knowledge is unavoidably incomplete (such as, an unfamiliar aircraft), and sometimes the decision maker is already thinking and working as hard as possible, even when there are no unanticipated events when there is a high contact density (Adams, et al, 1995). These instances provide a few illustrations of situations that can degrade situation awareness.

Complex information gathering and processing systems have been designed to aid the decision-maker in the past. However, these systems often increase the decision-maker’s burden due to the inherent system complexity and the failure to design them in a way that they will fit the user's cognitive processing limitations. Often, these systems require operators to perform difficult cognitive tasks under heavy workloads. They must perceive, synthesize and determine the relevance of a continual stream of incoming information, often pertaining to several concurrent contacts, while projecting future anticipated events and making decisions regarding actions to be taken. Decision makers must assess, compare, and resolve conflicting information, while making difficult judgments, and remembering the status of critical contacts along with the contact's response to actions taken by the CIC team. These decision-making tasks are interleaved with other required tasks, such as keeping other team members informed (both on and off the ship). Furthermore, these complex tasks are performed under conditions where adverse environmental (noise, vibration, temperature extremes, etc.) and internal stressors (boredom, fatigue, anxiety, and fear) are part of the environment.

3 Decision Support Principles

A case has been made that previous generations of decision support systems, which focus primarily on solution optimization and base decision support on normative models of human decision making, are less applicable than a DSS that parallels the cognitive strategies used by domain experts in situations characterized by time-constrained situations with uncertain and ambiguous data (Smith & Grossman, 1993). These authors point out that rarely, if ever, were earlier tactical decision aids intended as psychological models of human cognitive behavior. Instead, these aids performed "complex and burdensome calculations, reducing the work-load on personnel, speeding up the dissemination of information, and providing more time for command decision making" (Tolcott, 1991, p. 44).

3.1 Feature Matching and Story Generation

We have applied two of these new models of human decision making—which parallel the cognitive strategies used by domain experts—to the design of a DSS for enhancing antiair warfare tactical decision making. These two models that people use in assessing a situation are feature matching and story generation. The feature matching model, described by Noble (1989), involves an organization of memory, or "schemas," and information-processing where decision makers use their previous experiences to assess a situation and identify promising actions. Incoming information is categorized, selected, edited, and organized on the basis of a person's general knowledge about a domain. Both story generation and feature matching occur under conditions where a large base of implication-rich, conditionally dependent pieces of evidence must be evaluated before choosing an alternative from a set of prospective courses of action. The feature matching model applies a spatio-temporal dependence, whereas story generation is an example of causal dependence. According to the explanation-based model, decision makers construct a causal model to explain the available evidence (Pennington & Hastie, 1993). At the same time, the decision maker creates a set of alternatives from which an action will be chosen. A decision is made when a story is successfully matched to an alternative in the choice set. Story generation occurs in complex situations where the decision maker may not have all the necessary information or when a series of facts may appear to contradict each other. The decision maker must then develop causal links between these facts to produce a coherent picture of the situation (Klein, 1989; 1993).

The explanation-based reasoning model is based on research which found that jurors develop a narrative story to organize trial information where causal and intentional relations between events are central (Pennington & Hastie, 1992). Pennington & Hastie propose four certainty principles—coverage, coherence, uniqueness, and goodness-of-fit—that govern (*i*) which story will be accepted, (*ii*) which decision will be selected, and the (*iii*) confidence or degree of certainty with which a particular decision will be made. This organization of the evidence by the decision maker is believed to facilitate evidence comprehension. A central component of this model is that the story the juror constructs determines the juror's decision. This explanation-based decision process is employed when the body of evidence relevant to a decision is large, complex, and the implications of its components are interdependent.

Feature matching, also referred to as the recognition-primed decision (RPD) model, "occurs when the decision maker recognizes the features of the present situation as similar or identical to those of a previous situation" (Kaempf & Militelo, 1992, p. 6). An adequate match triggers recall of information learned about this type of situation: (a) plausible goals, (b) critical cues to be monitored, (c) expectations of what should happen, and (d) a course of action that worked in similar situations. According to this recent approach, expert decision makers may rely on well-developed memory representations to guide decision making in new (but similar) situations. The RPD model of decision making fuses two processes—situation assessment and mental simulation (Klein, 1993). In the simplest case the situation is recognized as familiar or prototypical, using feature matching, and the obvious response is implemented. In a more complex case the decision maker performs a conscious evaluation of the response, using mental simulation to uncover problems prior to implementing the response. In the most complex case the evaluation reveals flaws requiring modification, or the option is judged inadequate and rejected in favor of the next most typical reaction.

3.2 Situation Assessment

In general, the overall task of responding to antiair warfare scenarios consists of situation assessment ("what's going on") and course of action selection ("what to do about it"). Recent theories of decision making emphasize the importance of situation assessment for good decision making in naturalistic, event-driven situations. Moreover, they stress that decisions regarding actions to be taken are a by-product of developing the situation awareness that precedes action selection. Klein (1989) has found that usually the situation itself either determines or constrains the response options and that experienced decision makers make up to 90% of all decisions without considering alternatives. If the situation appears similar to one that the decision maker has previously experienced, the pattern will be recognized and the course of action is usually immediately obvious. On the other hand, if the situation does not seem familiar complex RPD will be involved where the decision maker adjusts the option after evaluating it.

Additional evidence was found in the specific task domain of interest to the TADMUS program which added support to these findings on the way real-world decision makers make decisions in the context of their normal jobs. Research was conducted to determine decision requirements for command-level decision makers in the combat information center (CIC) of an Aegis cruiser. Analysis of 14 incidents from actual problems revealed 183 decisions. Of these, 103 concerned situation assessments. Results obtained after analysts coded these situation assessments indicated that decision makers arrived at approximately 87% of their situation assessments through feature matching and the remaining 13% through story generation (Kaempf, Wolf, & Miller, 1993). The other eighty decisions that were identified, from analysis of the real-world incidents mentioned above, involved course of action selection. These course of action decisions served a variety of functions, although, relatively few were intended to end the incident. Twenty were intended as a final course of action decision; 14 were implemented to obtain more information, 22 to manage resources, and 24 to put themselves in a more favorable tactical position. A recognition-based strategy was also used by decision makers to develop a course of action, accounting for 95% of the actions taken in the 14 incidents. The decision makers generated and compared multiple options in only 5% of the cases. In line with these findings, the TADMUS program has adopted the position that decision aiding systems should assist in the decision making *process*, and focus on aiding the situation assessment portion of the decision-making task.

A DSS was developed to support decision-making processes which research has shown are used by decision makers in real-world settings (Hutchins, Kelly, & Morrison, 1996). Specifically, the DSS parallels the strategies used by experienced decision makers to perform situation assessment (Nobel, 1989; 1993). This approach to supporting the user's intuitive approach to dealing with dynamic decision-making situations should produce tools that are both more easily understood and used, and that more effectively "exploit the decision maker's knowledge and expertise that might facilitate adaptation to complex, novel situations" (Cohen, 1993, p. 265).

4 Human-System Interaction Principles

The vast majority of research on human-computer interaction design has been devoted to characteristics of displays that impact human perception, such as symbol legibility or detectability, and on relatively simple cognitive functions such as memory tasks. Fewer efforts have been devoted to understanding the effects of the format and manner in which information is presented on more complex levels of human cognition such as decision making. Consequently, principles that can be applied to the design of the interface between the user and a decision support system for the purpose of enhancing cognitive changing situations, are not available to any significant degree (ONT, 1992).

4.1 Graphic Presentations

Several advantages are offered by graphic presentations over a text-based presentation format (Larkin and Simon, 1987). Graphic presentations should (1) reduce the amount of mental computation required to perform tasks; and (2) allow users to spend less time searching for needed information. Casner (1991) elaborated on these ideas and found that graphics allow users to substitute less demanding perceptual opera-tions for more complex logical operations. For example, determining a change in altitude (and the degree of change) is immediately apparent when the user glances at the track history module. (Note that the words contact and track can be used interchangeably. The reader is referred to Figure 1.)

The objective for the track history module is to facilitate the contact identification process by providing information that is integrated in a way that supports a recognitional decision strategy. This module depicts a contact's speed, altitude, course and range on a two-dimensional graphical display along with a geometric representation of both the contact's 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 user can see, at a glance, a synthesized picture of the contact's behavior. Compare this rather simple perceptual operation with the more complex logical operation involved in current operational systems which require the user to recall and subtract numerical values for past and current altitudes.

Graphics also allow users to omit steps that are otherwise necessary when a task is performed without a graphic. An example of this advantage is also illustrated in the track history module which includes templates indicating weapon's coverage for both the inbound contact and "own-ship." To determine whether the aircraft is within its weapon's launch range there is no need to recall the specific launch range values and then compare them with the aircraft's current range. Instead, the user can determine if the aircraft is within its launch range by a quick glance at the display.

Graphics help users save time when searching for needed information when several related dimensions of information are encoded in a single graphical object. This is accomplished by integrating the kinematic parameters of speed, course, altitude, bearing, and range for a contact. The user can see, at a glance, a synthesized picture of the contact's behavior. Compare this process with reading, in a text-based format, the individual pa-

Figure 1. Decision Support System Display Modules.

rameters which need to be integrated by the user into a coherent picture of the contact's behavior.

5 Limited Cognitive Processing Capabilities

Since there are limits to the cognitive processing capability of humans, it is important for the system to provide the needed information in a format that best supports the user operating under dynamic decision-making conditions. It may be the case that current systems are inadequate to support the cognitive processing demands required by certain littoral scenarios. For example, according to Gruner (1990, p. 41), the U.S.S. Vincennes officers and system operators "could not make better decisions because they did not have time to confirm or deny the information uncertainties presented them." Gruner maintains that the rapid pace involved in these types of situations can exceed the capacity of the human to comprehend the rapid flow of information presented by complex systems. In the case of the Vincennes, the CIC team had three minutes and 40 seconds to make their decision. This includes the time required for the operators to perceive and interpret sensor data and for the commanding officer to make informed judgments from these data (Roberts & Dotterway, 1995). The result of the human's limited cognitive processing capabilities is that the decision makers may fail to remember critical pieces of data, overlook stored information, draw hasty conclusions, and produce flawed answers.

Evidence of the effects of limitations in memory and shared attention capacity on human decision making were found during baseline testing (Hutchins & Kowalski, 1994; Hutchins & Westra, 1995) and during empirical evaluation of the DSS (Kelly, Hutchins, & Morrison, 1996; Kelly, Morrison, & Hutchins. 1996).

Simon (1978, p. 273) states, "...the human information processing system...operates almost entirely serially, one process at a time, rather than in parallel fashion. This seriality is reflected in the narrowness of its momentary focus of attention." However, the AAW problem forces the decision maker to operate in a parallel processing mode when several contacts demand attention at the same time. The requirement to monitor and maintain an accurate SA for these concurrent contacts, over the course of the evolving situation, imposes an additional load of strategically managing the overall situation. Several researchers have argued that "managing the attentional and conceptual processes that permit cogent SA involves significant cognitive resources" (Adams, et al, 1995, p. 91; Endsley, 1988). The tasks of prioritizing contacts and the associated actions to be taken by the team, updating the status of critical contacts, responding to the other requisite tasks in the queue and, more generally, of strategically managing the workload of current multitask systems under dynamically changing scenarios can place an unrealistic cognitive load on the decision maker.

A major advantage offered by the experimental DSS is that it should "buy time" for the user by (1) performing many of the cognitive processing tasks for the user and (2) by presenting information in graphic format. The DSS will synthesize much of the information used to develop situation awareness and present a coherent picture of the situation to the user. This integrated picture will be portrayed graphically—rather than in the current text-based format—which should further reduce the amount of time required to assimilate this information. By performing several information processing steps for the decision maker the decision maker's limited cognitive resources can be used for the types of decisions which require human abilities (e.g., the decision on whether to engage).

5.1 Working Memory Requirements

An essential information processing step required by this task—and one which levies a heavy load on working memory—involves integrating kinematic and sensor variables and maintaining an awareness of changes in these variables over time. Changes in a contact's behavior such as, decreasing altitude, increasing speed, changes in electronic emissions, etc., can provide key indicators of possible hostile intent. With current systems, the decision maker receives numerous reports from CIC team members who provide various pieces of the overall tactical picture (such as, kinematic parameter values, active electronic emitter identifications, and behavioral responses of the contact in response to queries by the team) regarding a particular contact. Some of this information is also displayed in a text-based format for the user when a contact is "hooked" (that is, selected for display) by the decision maker. However, to recognize a change in certain variables, current systems require the user to retain parameter values in short-term memory in order to recognize a change in the parameter, such as altitude.

When the decision maker is monitoring several concurrent contacts (such as, cycling through three or four contacts in a 1-minute period) human working memory capabilities may quickly be surpassed. To detect a change in a critical parameter value, the decision maker must maintain the parameter values for the contacts of interest in working memory as he or she cycles between several contacts. For example, the decision maker must be able to recall that contact 7022 was at 14,000 ft. altitude one minute ago, and then subtract the current altitude value of 10,000 ft., which will then indicate the aircraft is in a rapid descent. The DSS was developed to aid the decision maker by performing several of these cognitive processing tasks, thus, reducing the cognitive load for the user. By presenting the synthesized picture of the contact's behavior over time, through the use of graphical displays, critical changes should be immediately apparent to the user.

A second memory-intensive task involves maintaining, in working memory, a current list of actions taken by team members, the contact's response to these actions taken by the CIC team, and pending actions. Research has established that "memory is limited and that list maintenance is effortful and fallible—more so if the list must be ordered and still more if the membership of the list must be dynamically reordered and modified during retention" (Bower, 1970, as cited in Adams, et al, 1995, p. 91). The DSS should reduce the cognitive effort required for distributing attention among the many contacts to be attended to and actions that are required. Working memory requirements should be reduced by having the DSS act as an intelligent "assistant," reminding the user regarding what actions are to be taken and when the actions are to be taken.

A third way the DSS will reduce memory and information processing requirements is by displaying templates depicting weapons' envelopes for both the inbound contact and "own-ship." This should facilitate critical comparisons and judgments regarding timing of actions. During a scenario decision makers have to either rely on memory to recall the launch range for various weapons or query a team member for this information. Both of these methods waste limited resources. The high workload and high tempo characteristic of littoral scenarios produce a stress-ful decision-making environment. The phenom-enon that increasing stress leads to decreasing working memory is well documented (e.g., Hockey, 1986). The latter method for obtaining the desired information wastes limited resources by increasing the communications load and requiring more time to wait for a team members' response to the query

Under these high-tempo and high workload conditions human memory and attentional resources can easily be surpassed. Several cognitively resource intensive information processing steps are eliminated for the human decision maker by having them performed by the DSS. We predict that the decision support tools will reduce the cognitive workload imposed on the decision maker in the following three ways: (1) by reducing the amount of information processing to be performed, (2) reducing working memory requirements, and (3) assisting the user in allocating limited attentional resources.

5.2 Reducing Human Error

The study of human cognitive processes and related error mechanisms has gained rapidly increasing interest in the past decade. Rasmussen (1987) argues that the emphasis in attempting to understand human errors must shift from tasks to the human-task mismatch. For example, Gruner (p. 39), in discussing the Vincennes incident, maintains that "the system was poorly suited for use by human beings during rapid military action." He ascribes this lack of suitability to a human-machine mismatch between the rate of data flow possible with modern computer systems that can process and display information at phenomenal data rates and the "comprehension capability of users which has remained almost static for thousands of years." This causal approach to understanding human error is based on the premise that errors are rarely random and can be traced to causes and contributing factors. Once these contributing factors are identified they can be mitigated.

The impact and vulnerability of systems and human interfaces, because of incompatibilities between the way people perceive, think, and act, are documented in the popular and technical literature (Buck, 1989; Casey, 1993; Norman, 1988; Perrow, 1984; Wilson & Zarakas, 1978). Newly developed systems will succeed or fail based on our ability to minimize these incompat-ibilities between the characteristics of the things we create and the way we use them. There are many well-documented instances of critical systems or parameter changes going unnoticed or unheeded because the operating procedures, or the human machine interface, provided no historical trace. For example, an unnoticed increase in altitude contributed to the shoot down of the Iranian airbus by a U.S. Navy ship—when the team mistakenly believed the aircraft to be descending—because there was no historical trace to make the aircraft's actual *increasing* altitude apparent (Dotterway, 1992). Five personnel in the U.S.S. Vincennes's combat information center, all viewing separate displays, reported the aircraft as descending while the Aegis data tapes later revealed a flight pattern of ascent (Roberts & Dotterway, 1995). One of the official investiga-tions of this incident, the Fogarty Report (1988, p. 45), states that "stress, task fixation, and an unconscious distortion of data may have played a major role in this incident." A panel of five psychologists from the American Psychological Association who testified before Congress concluded that there were "predictable failings of human judgment under intense stress compounded by complex technology [which] clearly contributed to the accidental shooting of Iranian airliner Flight 655" (APA, p. 4).

It is generally accepted that between 60-80 percent of the accidents and malfunctions in transportation, manufacturing, process control, weapon, and other systems are attributable to human error (Senders & Moray, 1991; Van Cott, 1993; Weiner, 1994). Reducing tactical decision making errors is one goal of the TADMUS program. The following section presents a brief review of an experiment conducted to develop a baseline on tactical decision making performance in response to fairly stressful scenarios. A companion paper (Hutchins, Kelly, & Morrison, 1996) describes the experimental DSS modules and the way they are hypothesized to enhance tactical decision making performance.

6 TADMUS Baseline Experiment

Early research involved data collection in the Decision-Making Evaluation Facility for Tactical Teams (DEFTT) Laboratory using simulated existing shipboard displays to establish a baseline on decision-making performance. The purpose of this effort was to document baseline decision-making performance for experienced naval officers. During the baseline phase of testing, a detailed understanding was developed of the cognitive processes underlying the various tasks involved in situation assessment—and where the bottlenecks occur. This understanding was then used to design the way the information is presented to the user in order to facilitate performance of the required tasks.

6.1 Subjects

This study focused on the command-level decision makers of an antiair warfare team on an Aegis cruiser—the commanding officer and the tactical action officer. Subjects in the study consisted of six commanding officer/tactical action officer teams drawn from twelve active duty Naval personnel; some were from training commands while others were from operational commands aboard ship or assigned to group staffs.

6.2 Procedure

Data were collected in the DEFTT Laboratory, a six-station test-bed environment that simulates console positions in a Navy Aegis cruiser combat information center. (For a detailed description of the DEFTT Laboratory see Hutchins, 1996.) Four stations were filled by confederates (active duty Navy personnel) who play antiair warfare support-team member roles. These roles included the antiair warfare coordinator, identification supervisor, tactical information coordinator, and electronic warfare supervisor. After approximately 1 1/2 hours of orientation to the laboratory and training in the use of the computer consoles the subjects engaged in four scenarios. The scenarios were each about 25 minutes in length and contained between 11 and 14 contacts of interest per scenario, in addition to numerous background contacts.

6.3 Treatment of Data

Team communications were recorded on a multichannel audio recorder; these included all intra-team exchanges, as well as all communications with simulated off-ship personnel. Audio tapes were used to produce verbatim, time-stamped transcripts of all team communications. A modified version of the TapRoot® Incident Investigation System (Paradies, 1991; Paradies and Unger, 1991) was then applied to identify errors. The objective was to identify tactically significant errors committed during the scenario. Tactically significant errors were defined as those errors that may lead to loss of life or significant political embarrassment. The following criteria were used for counting an error as tactically significant: (1) loss of situation awareness, (2) failure to take defensive action when within the weapon's range of an approaching contact, or (3) a violation of rules of engagement (ROE). Video recordings were made of the commanding officer and tactical action officer computer screens. Detailed analyses of all audio and video recordings were conducted. (For a more detailed coverage of the methodology and results see Hutchins and Westra, in preparation).

6.4 Results

The complex, time-constrained, decision-making situations embodied in the experimental scenarios resulted in a large number of decision errors. The mean number of tactically significant errors documented across six teams and four scenarios was 14; the number of errors ranged from nine to twenty-two. The standard deviation was 3.7. Subjects performed an average of 50% of the required behaviors as specified in the rules of engagement. The ordinal agreement between three raters (navy subject matter experts) on error count ranks from TapRoot® analyses was computed. Results showed a high degree of agreement with the Kendall's W of .93 indicating that 93% of the possible rank variance is accounted for.

6.4.1 Decision-Making Errors

Detailed examinations of the information processing sequences performed during tactical decision making have revealed a variety of errors. On average, subjects failed to take required actions, about half of the time. Explanations based in the cognitive psychology literature have been pursued, as a major goal of the TADMUS program is to develop a DSS based on an understanding of the way in which human decision makers actually process information under rapidly evolving situations.

The majority of documented errors involved errors of omission, that is, "failure to take defensive measures" and "failure to adhere to ROE." Failure to take defensive measures included failure to take actions to defend own-ship when an approaching aircraft had reached its weapon's release range. An example involved a case where two contacts were within the specified ROE limit, yet no action had been taken. The types of actions included in the "failure to adhere to ROE" category include failure to take action regarding the items listed and defined below: (a) issuing warnings is part of the usual identification process and involves three levels of warnings with increasing levels of urgency; (b) establish friendly force criteria refers to establishing a plan with other friendly ships in the area to coordinate how they will respond to potential threats; (c) changes in kinematics/ identification friend or foe—subjects are expected to notice significant kinematic changes and/or identification friend or foe parameter changes; and (d) other identification procedures includes actions such as illuminating with fire control radar.

The other major category of tactically significant error involved "loss of SA." Loss of SA errors were grouped under errors of commission and errors of omission and then further categorized into subgroups. Fifty-five percent of the loss of SA errors involved taking the wrong action (error of commission) while 45% of the errors involved failing to take some required action (error of omission). Error categories included under errors of commission involved incorrectly engaging a track (3%), incorrectly warning a track (29%), other incorrect actions (16%), and incorrect reporting (7%). The two instances of incorrectly engaging an aircraft, which were F-1 Mirage aircraft, were considered errors because the decision maker failed to take certain actions prior to engaging—not necessarily because the aircraft should not have been engaged. The actions that the decision makers failed to take involved ascer-tain-ing the identification of the aircraft for one case and failure to warn and illuminate the aircraft prior to engaging for the second case. Most instances of incorrectly issuing warnings to the aircraft involved issuing the warning when the aircraft was within its territorial airspace (that is, inside the 12 nautical mile limit which is internationally recognized as under control of that nation) or issuing a warning at a level different from what was required. Other incorrect actions included illuminating the aircraft, “locking up” with radar, or ordering the aircraft to divert when the aircraft was still within its territorial airspace. Incorrect reporting involved inaccurate reports on the status of the tactical situation (such as, indicating to the battle group commander that certain actions had been taken when they had not, misidentification of an aircraft, or omitting critical tracks from a report).

Errors of omission categorized under the “loss of SA” category included: (a) failure to identify or attend to a contact; (b) failure to take action (e.g., to issue “hold-fire” when a contact turned outbound); (c) failure to recognize a threat (e.g., designating an aircraft as a non-threat because it had passed its closet point-of-approach, yet it was still within missile-launch range); (d) instances of confusion or forgetting (e.g., forgetting or ignoring critical data, forgetting whether or not it had been warned, illuminated, or “locked-on,” or forgetting the aircraft's response, or lack of response to these actions, forgetting the status of a contact, and confusing contacts); (e) misperception of data (e.g., reporting a contact as turning outbound when it is still inbound); (f) unclear communication (issuing vague orders regarding actions to be taken by team member, such as, failure to specify which weapon system is to be used or which contact is to be engaged).

6.4.2 Cognitive explanations

The cause of failures to take required actions is, in many cases, attributed to the extremely high task demands levied on the decision maker by the scenario and the human decision-maker's limited attentional resources. Many cases are also attributed to working memory limitations. Maintaining an awareness of the status of each contact and the status of many actions to be taken by the antiair warfare team—which actions have been taken and what the contact's response to the action was—severely taxes the decision maker's working memory. The high workload entailed in the scenarios produces a highly time-compressed decision making situation. This time-compressed decision making situation—where attentional resources and working memory capacity are limited—do not allow the decision maker to maintain accurate SA for all tracks at any given time. We anticipate that the decision support modules in the DSS will mitigate these types of errors.

Human information processing capabilities are not well suited to dealing with a "multiplicity of simultaneous and disjointed tasks. Thoughtful attention is modular: People can consciously think about only one thing at a time" (Adams, et al, 1995, p. 92). As a result, they do not handle interruptions very well. Research indicates that when an operator is faced with as few as two tasks that consist of merely the detection or recognition of simple signals, a cost may be incurred in terms of a significant loss in sensitivity or time that can be allocated to either by the requirement to divide or switch attention between them (Broadbent, 1957; Schneider and Detweiler, 1988; Swets, 1984).

The memory demands of managing complex, multi-task situations can easily surpass human limitations. The decision maker must not forget any of the contacts or tasks requiring action. In addition to remembering all the tasks needing attention, however, are the complexities entailed in keeping track of the data and substeps associated with each contact and prior action. The aviation literature provides many examples of incidents with explanations similar to the root causes for errors that were found in the TADMUS program. One category includes the potentially disastrous effects of interruptions in the task for air traffic controllers and pilots. Similarly, in the AAW environment, momentary intervening attention to another task or contact, or an interruption in a procedure can leave the procedure, or processing of a contact incomplete with potentially catastrophic results.

A fairly consistent pattern of tactical decision-making errors was documented from data collected during the baseline data collection period. The root causes of these errors were traced to cognitive mechanisms such as limited attentional resources and working memory limitations. By developing an understanding of the pattern and types of errors most frequently observed in this task domain we hope to provide a DSS which will mitigate these errors.

7 Discussion

Failure to take appropriate actions may be explained by the limited resource capacity of human memory. In these scenarios a large number of contacts are monitored for changes in any of several key parameters. Three modules in the DSS are hypothesized to assist with recognizing a problem and taking the appropriate actions: track history; response manager; and the track priority list and alerts.

Features offered by the DSS to address errors attributed to limited attentional resources include focusing attention on (1) high priority contacts (i.e., track priority list and alerts), as well as on (2) missing data (e.g., basis for assessment), and (3) enabling the decision maker to use more data than is typically used in current systems (e.g., track history, comparison to norms). Current systems require the user to retain previous contact data in memory to compare with current values for critical parameters. Current systems also require the user to rely on recall of vast amounts of information from training and experience. Presenting all known data on a contact in a synthesized way should reduce working-memory requirements and facilitate recognition. Additional potential performance enhancement features, offered by the DSS, include displaying the complete kinematic contact history, presenting graphic displays of location and trends, highlighting missing data, providing alerts, and providing assessments of current contact identity that go beyond what existing systems currently present.

Focusing the user's attention on trend and history data should decrease the cognitive workload imposed by these scenarios where many contacts must be identified and responded to under severe time constraints. Similarly, delineating trend and history data can assist in the identification of a contact where noticing changes in critical parameters is essential. Presentation of trend and history data, as well as threat assessment and comparison to norms, should also mitigate cognitive "tunnel vision" effects where the decision maker attends to a smaller number of cues when under stress.

The notion of time is an important characteristic of situation awareness (Harwood, Barnett, and Wickens, 1988). The past is critical to understanding the present, and both past and present information must be used to predict future events (Shrestha, et al, 1995). Endsley (1988) referred to the "projection of their (perceived elements) status in the near future" when discussing situational awareness. However, Endsley also noted the task of attending to incoming information and subsequently predicting future events places a heavy load on working memory. Several decision support modules were developed to assist the user in remaining aware of the contact's history and changes over time. Remembering which actions are to be taken at what time levies an additional burden by placing a heavy load on working memory. A secondary time savings should be achieved by the DSS acting as an intelligent "advisor," that is, by assisting the decision maker in knowing what actions to take, when to take them, and which actions have already been taken. A tertiary time savings can be achieved by including a template depicting the weapons' release ranges so the decision maker does not need to rely on fallible human memory or query a team member regarding weapons ranges. By graphically depicting a synthesized view of a contact's kinematic history, with the focus on changes in the contact's behavior over time, along with the contact's weapons envelope in relation to both own-ship's radar and weapon coverage, information processing time can be saved for the decision maker.

8 Conclusions

The research reported here focuses on developing a DSS which reflects the natural decision-making strategies of humans. Presenting synthesized information in the form of graphic presentations is expected to reduce the cognitive processing load for the decision maker when performing situation assessment. The intention is to aid the decision maker by providing information in a way that will minimize the need to maintain information in working memory, reduce information processing demands, help focus attentional resources on the highest priority contacts, remind the user of actions which need to be taken, help make decisions under stress, and support higher levels of situation awareness.

Decision support systems require that the human's strengths be used in synergy with the advantages offered by the DSS. Limitations associated with the current generation of automated decision aids include the idea that (1) they cannot adequately capture the expertise developed by experience over time and (2) since all contingencies cannot be anticipated, the expert's abilities to use intuition is indispensable (Mosier, in press). Mosier's review of the limitations of automated decision systems delineates the characteristics of human expertise that surpass the capabilities of automated systems. These include the human capacity for creativity, adaptability, the ability to incorporate experience, the presence of a broad focus, analogical reasoning, and commonsense knowledge. The goal for the DSS is to capitalize on the strengths of the human along with the advantages provided by the decision support system.

9 Testing the DSS

The prototype DSS display modules are currently being empirically evaluated in the simulated tactical environment provided in the DEFTT Laboratory. Experienced naval decision makers engage in experimental scenarios with and without access to the DSS display. The various decision support modules will be tested individually and in combination in future experiments. Data on reduction of errors, improvements in users' situation awareness scores, changes in communication patterns, and subjective responses to the decision support system will be collected.

10 Future Research

While tools based on both the RPD and explanation-based reasoning models of decision making are included in the DSS there is no direct connection between the two. Research is currently being conducted to extend schema theory to dynamic decision-making situations. This involves developing and testing a hybrid model of cognitive behavior in decision making to incorporate both types of knowledge, i.e., feature matching and story generation, as elements of the same schema model of naturalistic decision making (Smith & Marshall, in press). Schema theory as described by these authors, offers a context for integrating these two models which have typically been viewed as separate entities.

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The requirement to interleave a multiplicity of tasks—although not necessary an ongoing characteristic of shipboard scenarios—represents the type of situation where providing decision support may make the critical difference in the outcome for a scenario. For example, during the experimental scenarios the decision makers may have to perform the following:

- monitor ship location (relative to other ships and objects in the vicinity)
- monitor and apply rules of engagement to all applicable tracks in the local operating area
-
- receive and send radio messages to the battle group commander and other operating units in the area
- monitor tracks on the Aegis display system and maintain situation awareness for all contacts of interest
- monitor performance of actions taken by team members to assess the situation
- monitor the tactical action officer's/commanding officer's performance
- maintain communications with CIC team members regarding their assessment of tracks and various actions taken
-
-

In broad perspective, although team members spend much of their time in routine activities, a number of different attentionally demanding, knowledge-intensive, and procedurally complex tasks may demand attention at any moment. Each of these tasks is usually triggered by a stimulus event, such as a communication from a team member or an alert, and, in order to obtain proper interpretation, may require additional information-seeking behavior. The cognitive challenge of selecting and interpreting information to maintain and revise one's SA is inherently complex. (Jager, Tenney, and Pew, 1995 HF) Problems arise when, in the dynamic and multidimensional environments of some littoral antiair warfare scenarios, the situation-critical data become more time-compressed or ambiguous than humans can handle within the inherent time constraints of the evolving scenario.

Resources are such things as processing effort, the various forms of memory capacity, and communications channels (Bobrow & Norman, 1975, in Rasmussen et al).

Topics to be discussed include: (1) a description of the difficult tasks identified for analysis; (2) the general methodological approach; (3) development of the performance measures and issues related to their development; (4) discussion of the ; and (5) discussion of the types of errors made by decision makers and interpretations for the cause of these errors based in the cognitive psychology literature.

tactical operations require decision making conditions of time pressure, stress, ambiguous, inaccurate and missing information, uncertain communications, and shifting conditions. These conditions make it difficult to perform careful analysis prior to making decisions. Traditionally, most decision research and decision support system development have focused on well-defined tasks in carefully controlled environments. Recent research has suggested that tactical decision makers use experience to generate a likely course of action and then evaluate its feasibility using mental simulation.

One way to prevent the same type of casualty from being repeated is to thoroughly investigate and analyze root causes of actual mishaps, as well as data collected in a simulated tactical environment, and apply the findings in a concrete manner to improve tactical decision making.

According to the recognition-primed decision-making (RPD) model, experienced decision makers can make rapid, high-quality decisions by associating a situation directly with the actions that normally work well in that kind of situation.

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The comparison to norms tool is based on a cognitive model of human information processing which uses a feature matching strategy. The model proposes a data-driven process. As such, the comparison to norms tool is a knowledge-based tool with the knowledge represented as templates. Each template is a linked timeline associating individual features, through a series of feature matches, with expected actions. This allows the tool to make an assessment of the situation presented to the decision maker. A related module is the response manager. This assessment consists of a categorization of the situation (e.g., "hostile aircraft attacking") and presentation of an associated template. The response manager module shows a template for an assessment of the current situation. This is a timeline display for template features, or events. The response manager module also provide inputs to the Prioritized track list, Alerts, and Responses and Tripwires.

SABER is a model of another cognitive strategy employed in making decisions. This strategy is known as explanation-based reasoning, or story generation. 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 of internal assumptions. It is assumed that there are a fixed number of pre-defined possible conclusions and each data item points directly to one of those possible conclusions.

Once the explanations are constructed, SABER evaluates them to determine which seems most plausible. Plausibility is based on three criteria: simplicity, completeness, and importance. SABER provide data products which relate data to explanatory hypotheses for the current situation. Hypotheses are presented in rank order, with evidence for and against each hypothesis and missing data is presented below the corresponding hypothesis. For a more detailed description of the DSS the reader is referred to Hair & Pickslay, 1992; Hair, Pickslay, & Chow, 1992; Hutchins and Rummel, 1994.

Hair, D. C. and Pickslay, K. (1992). Explanation-Based Reasoning in Decision Support Systems, Proceedings of the 9th Annual Conference on Command and Control Decision Aids, June 1992, Monterey, CA.

Hair, D. C., Pickslay, K. & Chow, S. (1992). Explanation-Based Decision Support in Real Time Situations. Proceedings of the 1992 IEEE International Conference on Tools with AI. Nov. 1992, Arlington, VA.

Various studies have indicated that as much as 90 percent of industrial and system failures are produced by human error (Senders & Moray, 1991).

At the same time, a shift was occurring in U.S. Navy doctrine, away from a "blue-water" strategy to a doctrine of littoral operations aimed at potentially hostile regional powers.

Tactical decision makers in today's operating environment are required to perform complex tasks in a highly dynamic environment. Numerous interactive surface units and aircraft whose parameters are in flux and which must be continually sensed, processed, their future status projected (development of hypotheses regarding their future behavior) and actions taken to assure the successful outcome.

Operating close to land presents additional challenges to the tactical decision maker. In littoral (i.e., near-land) settings, which most likely 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. When civilian and neutral nation resources are in the conflict area incoming information carries an added element of uncertainty. In these situations, interpretation of the rules of engagement, contact identification, determining the capability and possible intent of the potential threat, and the shoot/no-shoot decision often pose extremely difficult decision problems. (Since 70 percent of the world's population lives within 200 miles of the sea, most future contingencies are likely to involve littoral warfare (Mundy, 1994).)

as opposed to replacing "*the user's approach to the problem*" (emphasis in original, Cohen, 1993) with tools based on decision analysis or mathematical optimization,

A considerably smaller number are attributable to other causes such as mechanical, electrical and materials failure (Meshkati, 1993).

The purpose for this phase of the TADMUS program is to empirically evaluate the effectiveness of a DSS based on these recent approaches to decision support

, to the extent possible,

"This focus on why errors occur is...different from...the typical study of human errors which solely emphasize what occurs, a point of view which has received considerable criticism." (Rouse & Rouse, 1983, p. 539)

DSS which will mitigate typical types of errors. The objective during this phase of the research was to develop an understanding of the decision-making problems presented by current and future Navy scenarios in order to identify the types and forms of information that are likely to facilitate performance of these activities.

Rouse, W. B. & Valusek, J. (1993). Evolutionary Design of Systems to Support Decision Making. In G. A. Klein, J. Orasanu, R. Calderwood, & C. E. Zsambok (Eds.) Decision Making in Action: Models and Methods (pp. 270-286). Ablex Publishing Corporation, New Jersey.

The Naturalistic Decision Making (NDM) model (Klein, 1989, 1993) seems more applicable than traditional decision-making models to the types of decisions involved in tactical decision-making. Early work conducted under the TADMUS program to determine the cognitive strategies employed by Navy AAW decision-makers found that when performing situation assessment 87% of the time a recognitional strategy was used and 13% of the time story generation was used (Kaempf, Wolf, and Miller, 1993). We have applied these new models of human decision making—which parallel the cognitive strategies used by domain experts—to the design of a DSS for enhancing antiair warfare tactical decision making. These two models for situation assessment are feature matching and story generation.

(The scenarios were intentionally developed to have many tracks with a high degree of uncertainty associated where it is not always clear whether a particular track should be engaged. Our interest in the TADMUS program was in gaining insight into and aiding the decision process. The reader is referred to Hutchins, 1995, for a detailed coverage of performance measurement issues and scenario development issues.)

These conditions include dynamic, fluid situations, time pressure, high risk, multiple decision makers, shifting and competing goals, action-feedback loops, and situations with uncertain and incomplete data (Orasanu & Connolly, 1993).