

Application of Multi-Media Technology to Training for Knowledge-Rich Systems

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ABSTRACT

Tactical decision making (TDM) can be defined as a process whereby an individual must gather, process, integrate and assimilate information in order to choose or develop a course of action that will lead to attainment of tactical goals. In order to support this process, tactical knowledge must be cognitively accessible to tactical decision makers so that they are able to recall and apply it in crucial situations. At present, the bulk of tactical knowledge is presented initially to surface warfare tactical decision makers in print format (e.g., tactical memoranda, tactical notes, and other publications). However, recent research into decision making in complex environments has shed light on the manner in which expert decision makers use knowledge in support of a decision, suggesting alternative strategies for presenting tactical knowledge in the learning process so that it is easier for tactical decision makers to remember and apply in required situations.

The purpose of this paper is to address the issue of how tactical knowledge can be presented to tactical decision makers so as to improve its retainability and useability in crucial decision making situations. To accomplish this goal, several activities were completed: (1) leveraging the work conducted under Tactical Decision Making Under Stress (TADMUS) project, a description of manner in which expert tactical decision makers employ knowledge in crucial decision making situations was formulated; (2) using this information, conclusions regarding the manner in which tactical knowledge must be initially presented to decision makers were drawn; and (3) based on the first two activities, a description of an automated system for presenting tactical knowledge that increases its retainability and accessibility in crucial decision making situations was formulated. The results of these activities are documented in this paper.

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INTRODUCTION

Navy tactical decision makers operate in a knowledge-rich environment--they must remember and apply great deals of tactical knowledge in order to make crucial decisions in time-compressed situations. Briefly, this knowledge relates to the characteristics of friendly and threat assets, situational features, doctrine, applicable tactics, and rules of engagement (ROE), some of which change as a scenario unfolds. Research conducted under the Tactical Decision Making Under Stress (TADMUS) project indicates that in such situations, decision makers rely on well-established knowledge structures that are built up in memory over time. Therefore, it is essential that tactical decision makers initially encode and learn required knowledge in a manner that supports the rapid, complex decision making typical of a combat scenario.

Currently, Navy tactical decision makers acquire knowledge from a variety of sources in the training pipeline, with much of this sort of knowledge acquisition occurring on-the-job. In fact, the bulk of knowledge relating to tactics is contained in paper-based tactical publications--e.g., tactical memoranda (TACMEMOs), and tactical notes (TACNOTEs). These documents are a primary mechanism for disseminating tactical information. However, the effectiveness of these documents as a means to *teach* tactical decision makers necessary tactical knowledge

is limited because the presentation of knowledge contained in them is: 1) linear in nature, 2) passive, and 3) static. At present, a number of technologies are beginning to become available that can improve training for tactical knowledge, including: multi-media reference data bases; low-cost simulation and animation capabilities; graphics presentation techniques; and advanced training technology. Moreover, data regarding the manner in which experts accomplish complex decision making tasks has led to new theories regarding how domain knowledge supports decision making; these are ripe for application to this problem.

The purpose of this paper is to address the issue of how tactical knowledge can be presented to tactical decision makers so as to improve its retainability and useability in crucial decision making situations, with emphasis on applying multi-media technology. It should be noted that the focus here is on presenting tactical knowledge during the learning or knowledge acquisition process, and not in the operational environment. That is, the idea is not to address real-time decision aiding or displays. Rather, it is to investigate how tactical decision making and tactical employment can be improved by enhancing the methods of presenting tactical knowledge to decision makers so as to optimize its comprehensibility, understandability, and ultimately, the probability that it is applied in crucial tactical decision making situations.

The remainder of this paper is structured as follows: First, the concept of tactical decision making is defined in cognitive terms, along with a description of how traditional decision making theories have viewed this process. Next, two more modern lines of thinking regarding decision making are described, and the implications of these theories for tactical decision making are offered. The reason that these theories are reviewed is because they have important implications for the manner in which tactical knowledge is best presented to decision makers during the learning process. Finally, the vision of a system for preparing multi-media, interactive, electronic tactical publications is described. Such a system would be designed to address both the effectiveness of tactical publications in supporting tactical decision making, as well as the practical and logistic issues associated with the publication process.

THE NATURE OF TACTICAL DECISION MAKING

Tactical decision making (TDM) can be defined as a process whereby an individual must gather, process, integrate and assimilate information in order to choose or develop a course of action that will lead to attainment of tactical goals. In fact, in cognitive terms, the employment of a tactic can be thought of as a complex "cue-strategy" association. That is, when confronted with a situation, a decision maker must recognize and assess information (cues) provided by the environment, and then apply an appropriate course of action (strategy, or in this case, tactic). Therefore, the task of a tactical decision maker can be characterized as 1) applying tactical knowledge in order to achieve rapid, accurate situation assessment, 2) recognizing that a particular tactic applies, and 3) taking action that is consistent with the tactic.

Research into decision making has most often focussed on situations where varying degrees of risk or uncertainty characterize the decision making event, since these factors affect the manner in which a decision is made. For many years, "classical" decision making theories assumed that expert decision makers engage in a rational, analytical process in reaching a decision under uncertainty (Beach & Lipshitz, 1993). Briefly, these theories suggested that

decision makers engage in a rational process that involves selecting the optimal choice among several options by applying probability theory. In practice, these theories assumed that decision makers seek all information available to them, generate a series of viable options, assess each option based on a probabilistic determination of what they believe is likely to happen, and finally select the option that maximizes the expected outcome.

Many years of research into these classical decision theories has led to a fairly consistent conclusion: they do not describe accurately how decision makers make decisions in the real world. There are a host of reasons why this is the case (see Klein, Orasanu, Calderwood & Zsombok, 1993). Most important to the current discussion is the fact that these theories failed to account for the context in which a decision is made. As a result, several more modern approaches to the study of decision making have evolved in recent years. These are reviewed briefly in the following sections.

Naturalistic Decision Making

An approach to studying decision making popularized recently emphasizes the importance of investigating decision makers in their natural (operational) environments (Orasanu & Connolly, 1993). Called "Naturalistic Decision Making" these theories assume that several characteristics describe the typical decision environment in 'real world' operations. According to Orasanu & Connolly (1993), these include:

- ill-structured problems
- uncertain, dynamic problems
- shifting, ill-defined, or competing goals
- action/feedback loops
- time pressure
- high stakes
- multiple players
- organizational constraints

Further, these theories suggest that decision making behavior develops over many years of experience, through exposure to many decision situations. In addition, they reject the notion that decision makers engage in a rational, analytical process in making a decision, recognizing instead that expert decision makers

must sometimes make rapid decisions that necessarily short-cut the rational process. Moreover, naturalistic decision making theories assume that even the most expert decision makers can err due to situational factors, and that naturally-occurring decision biases may characterize decision making under stressful conditions.

One of the more promising naturalistic decision making theories developed to help explain expert behavior contends that decision makers employ a "recognition-primed" strategy in assessing a situation. That is, expert decision makers make a rapid situation assessment by recognizing patterns of cues in the environment (this process is referred to as "recognition-primed decision making"). Once the situation assessment is made, Recognition-Primed Decision (RPD) theory contends that the expert uses his/her memory of similar situations in the past to help decide on a course of action. Typically, the process of generating and evaluating options is bypassed, since expert decision makers usually know what action to take based on past experience (Klein, 1993). In a Navy tactical decision making situation, this appears to make sense—once a tactical action officer or commanding officer has made an accurate assessment of the tactical picture, ROE and doctrine often dictate (or at least delimit) what his response options may be. The result is rapid, seemingly effortless decision making, that is often characterized as "intuitive".

Evidence to support the validity of the recognition-primed decision making model for combat information center (CIC) decision making was recently found in an investigation conducted under the TADMUS program. Briefly, Klein and associates, (Klein, G., Kaempf, G. L., Wolf, S., & Thordsen, M. L., in prep. conducted interviews with 28 active duty Navy personnel from various commands (e.g., SWDG; Tactical Training Group, Pacific; Aegis Training Center and various ships). These participants represented a variety of experience levels and CIC duty stations. The interviews sought to understand more fully the processes that CIC personnel employ in making crucial decisions, and to identify critical cues that decision makers use in reaching anti-air warfare (AAW) decisions. Results of these interviews and subsequent analyses indicated that CIC decision

makers appear to invoke recognition-primed processes when making most of their decisions. In fact it appears that over 90% of the situations experienced by the AAW team are either highly or moderately familiar to them. This recognition then triggers recall of many associated pieces of information, including expectancies, goals, and appropriate actions. Moreover, decision makers rarely generate and/or consider more than one response option once a situation assessment is made.

Several aspects of recognition-primed decision making theory are particularly important to the dissemination and learning of tactical knowledge. First of all, the theory suggests that expert decision makers develop a series of situation "templates" in their memory over time. These templates are generalized cases of common situations that contain knowledge about situations they have encountered (e.g., the cues that describe the situation), along with knowledge regarding the correct responses or course of action associated with that situation. When a decision maker is confronted with a new decision making situation, the theory suggests that he/she might solve it by using memories of past situations as a guideline. Of course, there may be aspects of the current situation that are novel (i.e., not in the expert's memory). In these cases, the expert must rely on knowledge of similar situations or modify the template in order to make a decision (see Klein, 1993 for a more detailed description of this process). Of importance here is the notion that exposing decision makers to numerous decision making scenarios is a useful means to build necessary situation templates.

Another feature of RPD theory worth noting is that it is particularly applicable to situations where time compression is a factor. In fact, RPD may be best at explaining decision making in situations where time pressure limits a decision maker's strategy. In these situations, decision makers appear to spend little, if any, time decomposing a situation in order to understand it. Instead, it appears that entire *patterns of cues* are perceived simultaneously by decision makers, and that the significance of each of the individual cues is some how "digested" along with other cues in the situation.

A study of chess masters supported this idea.

Briefly, it was found that expert chess players were significantly better than novices in remembering the placement of pieces on a chess board when the placement was a "legal" one—that is, one in which the pieces could have conceivably landed during the course of a game. In contrast, chess masters were no better than novices at remembering the placement of pieces when it was random (i.e., where pieces were placed haphazardly with no regard for whether the placement was feasible). This study suggests that expert decision makers may, over time, encode entire patterns of situational cues. Once again, the implication here seems to be that in order to improve expert decision making, decision makers must be exposed to likely scenarios so that they can build appropriate memory structures.

Finally, RPD predicts that when a decision maker is uncertain regarding whether or not to take a course of action, he/she engages in a kind of "mental simulation" of the solution. That is, the decision maker plays out the implications of the decision in his/her mind in order to evaluate it before taking action (Klein, 1993). If this mental simulation indicates to the decision maker that the option is a viable one, then the option is exercised. If potential problems are encountered, then the decision maker will modify the course of action so as to ameliorate the problem. This concept is important because it suggests that fostering the mental simulation process may improve the quality of decision making.

Knowledge Structures

A second line of inquiry that bears on the discussion of TDM involves the study of knowledge structures or mental models. "Mental models" can be defined as dynamic cognitive representations that allow people to describe, explain and predict events in their environment (Rouse & Morris, 1986). Mental models contain organized information that describe objects, properties, causal connections and relationships in systems or situations in the environment (Cannon-Bowers, Tannenbaum, Salas & Converse, 1991). For example, a car mechanic may have a mental model of how a car's engine operates. This model (which describes how and why certain components of the engine are related) helps him/her to diagnose problems,

troubleshoot, and ultimately repair car engines. Similarly, it has been suggested that Navy tacticians (particularly CIC personnel) have mental models of the tactical task and situation (Rouse, Cannon-Bowers & Salas, 1992). For example, an Aegis Anti-Air Warfare Coordinator (AAWC) may hold a model of the 1.) Aegis system containing knowledge about how the system works, its components, the rationale behind its operation, and the like; 2.) the console with which he is interacting containing proceduralized knowledge regarding how to interact with the console (which buttons to push, etc.) in order to accomplish various goals; and 3.) the more general AAW task containing knowledge about the physics of missile and platform movement, likely air threat characteristics, appropriate tactics, and so forth. Each of these models contributes to his ability to make decisions by providing an organized framework in which tactical knowledge can be cast.

It should be noted that the concept of a mental model described here is similar to the notion of a "situation template" discussed above. That is, experts appear to rely on pre-existing knowledge structures when making a tactical decision. Moreover, it is important to note that these theories contend that *tactical decision making effectiveness depends on well organized tactical knowledge*. In fact, the study of differences between expert and novice decision makers has revealed that experts have mental models that are organized around "deep" underlying principles, whereas novice models are organized around more shallow surface features (Chi, Feltovich, & Glaser, 1981). In addition, expert models seem to be more abstract, pattern-oriented and highly integrated (Cannon-Bowers et al., 1991). Taken together, these findings suggest that in order to be most effective, *expert tacticians must hold accurate and complete mental models to support the TDM process*.

TACTICAL KNOWLEDGE AND TDM

The work cited to this point has important implications for the manner in which tactical knowledge should be presented in the learning process to support comprehension and later TDM. In fact, the overriding message of this paper is that the manner in which tactical

knowledge is initially presented to decision makers will have an impact on the extent to which they are able to effectively encode and use that knowledge in decision making. Before addressing the topic of information presentation directly, several issues regarding the properties of tactical knowledge itself must be discussed.

The Nature of Tactical Knowledge

Tactical knowledge can be thought of as "knowledge with a purpose". That is, the role of tactical knowledge is to support effective TDM (as opposed as simply being interesting to know). Therefore, it is useful to examine the manner in which pre-existing knowledge in a situation can foster the rapid, flexible type of TDM performance demanded by modern warfare.

Traditionally, the discussion of knowledge and decision making has centered around identification of "decision rules" in a task domain. That is, it was often assumed that knowledge was stored (or at least accessed) in the form of an "IF...THEN" rule. For example, "if the contact is coming towards me and descending, then it is probably hostile". The problem with this perspective is that it cannot accurately describe decision making in situations that are ambiguous, complex, dynamic, time pressured, or not well specified--all characteristics of many tactical decisions. Therefore, modern research has sought to examine the knowledge required for decision making in terms of *flexible* knowledge structures (or mental models) as described above (e.g., see Cannon-Bowers et al, 1993).

In addition, researchers of late have begun to distinguish among different types of knowledge that characterize decision making. These include "declarative" knowledge, which is knowledge about the facts, concepts, rules and relationships in a task area; "procedural" knowledge, which is knowledge about the steps required in performing a task or accomplishing a task; and "strategic" knowledge, which is a more complex form of knowledge that combines declarative and procedural knowledge with situational knowledge that indicates how and when to apply pertinent knowledge.

Figure 1 relates this discussion of knowledge

type to the notions about mental models presented above. According to this figure, a decision maker's pre-existing mental models contain declarative and procedural knowledge about various components of the system or situation. For example, an AAWC's mental model of the Aegis system might contain facts about the system itself (e.g., how it operates, how it is related to other systems, why it works the way it does, etc.), along with procedural knowledge about how to interact with the system in order to accomplish particular tasks or goals. Knowledge in these mental models may also be more situational in nature. For example the situation model may contain facts about the geographic region in which the event is occurring (e.g., likely scenarios, appropriate responses, etc.), while the team model might contain information about the strengths and weaknesses of particular teammates (see Figure 1).

Figure 1 specifies further that these preexisting mental models contribute to TDM performance by formulating a current "problem model". This problem model includes strategic knowledge that helps the decision maker to arrive at a situation assessment by selecting from memory important declarative and procedural mental models. In other words, the problem model matches the cues (or cue patterns) perceived by decision makers in a situation with appropriate *knowledge templates from memory that will help him/her to make the decision.*

From a practical standpoint, the line of thinking proposed here would suggest that when an expert decision maker is confronted with a decision problem, patterns of cues are perceived that trigger the recall of particular knowledge structures (mental models) that together form the basis of a dynamic problem model (dynamic in the sense that it is *continually updated by new information from the environment*). This model then suggests which, if any actions apply. Going back to the question posed early in this paper, namely, how does tactical knowledge affect TDM, it is now possible to draw the following conclusions:

- TDM requires decision makers to hold accurate, complete declarative mental models regarding the systems and situations of interest

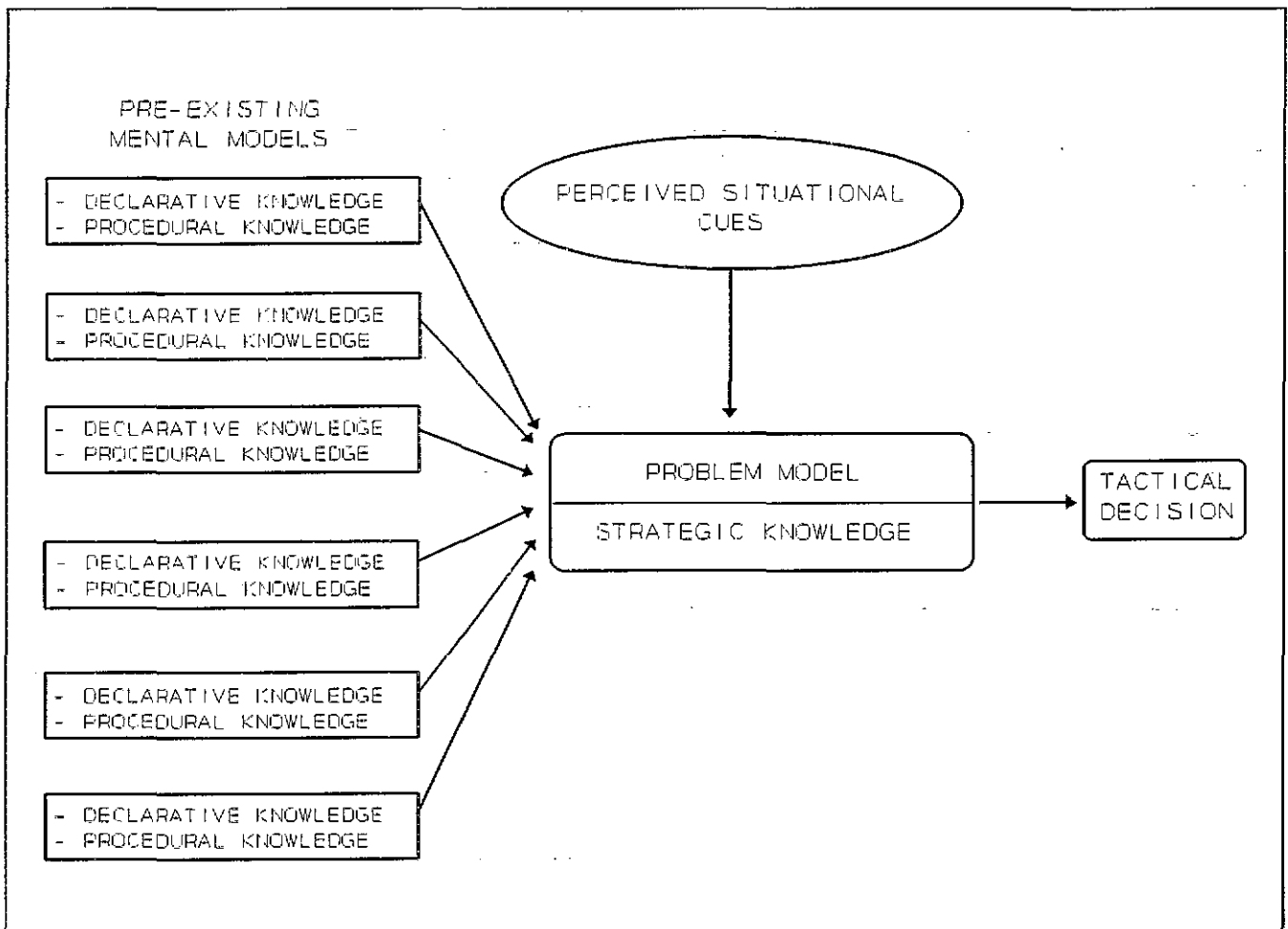


Figure 1: Model of TDM

- TDM requires decision makers to hold accurate, complete procedural mental models of the systems, tasks and routines associated with the decision situation

- TDM will be fostered to the extent that pre-existing mental models are well structured in the decision maker's memory

- TDM requires the formulation of accurate problem models through application of appropriate strategic knowledge (which is built up through experience)

Supporting Application of Tactical Knowledge

In a general sense, the notions about decision

making and tactical knowledge presented thus far have important implications for improving the tactical decision maker's ability to optimally apply tactical knowledge to a TDM situation. These include:

1. Present tactical knowledge to decision makers (initially) in a format that fosters development of accurate and complete declarative, procedural and strategic mental models using guidelines specified above

2. Foster the formulation of appropriate cue-strategy associations by:

- Identifying important situational cues that trigger particular responses

- Creating scenarios that expose decision makers to various cues and associated TDM strategies

-- Providing ample exposure to a variety of scenarios via simulation

3. Provide a context in which tactical knowledge can be comprehended, understood, and encoded into memory

OTHER ISSUES IN TDM

Now that the cognitive requirements of tactical knowledge presentation have been established, attention can turn to other issues that must be considered in the tactical publication and employment arena. These include team performance issues and motivational issues. The following sections address these topics.

Team Issues

Recently, researchers working in the team training and performance area have extended mental model theory (see above) to incorporate the team aspects of TDM (see Cannon-Bowers et al., 1993). Briefly, the idea here is that tactical decision makers in the interdependent, hierarchically-organized CIC environment must depend on one another to provide information that is crucial to effective decision making. As such, it is assumed that team members who have common or shared mental models of the situation, task and team will be better able to support the information needs of their teammates. A sports analogy may help illustrate this point: the blind pass in basketball is an example of a situation where two team members make an assessment of a complex set of environmental cues (the physical position of players, time left on the clock, the coach's style, the ability of teammates, and the like), and then execute a *compatible* (not identical) behavioral response (i.e., one throws the ball, while the other catches it). Team researchers have labeled this type of behavior as "implicit coordination" because it is coordinated performance that occurs in the absence of explicit strategizing or communication, (Kleinman & Serfaty, 1989). In a CIC, the same type of coordinated behavior is desirable, particularly when time constraints mitigate the amount of discussion that can occur regarding a tactical situation.

The role of mental models in implicit coordination is that they provide team members

with underlying knowledge required to anticipate the needs of the decision and their teammates. The implication of this contention for tactical knowledge presentation is, once again, that the manner in which tactical knowledge is initially presented to decision makers will have an impact on the compatibility of their mental models with other team members. For example, if tactical knowledge is presented such that multiple team members can encode the information (i.e., make correct cue-strategy associations), discuss its implications (e.g., talk out the possible scenarios in which the tactic might apply), share their understanding of the tactic (e.g., why it might work, its limitations), and practice employing it, then team tactical decision making should benefit. Therefore, attempts to improve the process of presenting tactical knowledge should allow for all relevant team members to become involved in learning the tactic initially.

Motivation

It has been well established in the research literature that the learning and retention of information is affected greatly by the learner's motivation (Tannenbaum, Cannon-Bowers, Salas & Mathieu, 1992). In fact, motivation to learn and to transfer knowledge and skill back to the job are both potent factors in determining training effectiveness. With respect to the current discussion, it is clear from interviews and observation that motivation to read and retain tactical knowledge in print format could be improved. A viable way to do this is to host tactical knowledge in a manner that is more engaging to users. More importantly, it has been found that making the learning process "active" (i.e., letting learners ask questions, simulate decisions, etc.) is more effective than "passive" learning. Once again, this fact supports the notion that an interactive, multi-media presentation of tactical knowledge might be more effective than current hard-copy presentation.

APPLYING MULTI-MEDIA TECHNOLOGY TO TACTICAL KNOWLEDGE

As has been stated, modern computing technology provides a basis to improve the presentation of tactical knowledge. Specifically, a system can be conceived that will not only

address the cognitive issues raised above, but also reduce the cost to produce tactical publications, and reduce the Navy's dependence on contractors to write them. Such a system could benefit from the following technologies: referenced data bases, advanced graphics presentation, cognitive engineering, user authoring tools, animation/simulation, performance measurement, knowledge organization, and multi-media presentation formats. By way of review, such a system could be developed expressly to accomplish the following goals:

- enhance the comprehensibility and useability of tactical knowledge
- increase the accessibility of tactical knowledge on board ship
- enhance the training/learning value of tactical publications
- increase the users' motivation to learn tactical knowledge
- improve the team's ability to coordinate TDM and tactics employment
- decrease the Navy's dependence on contractor support
- decrease the cost of tactical publications
- ultimately, enhance the quality of TDM and tactics employment

To accomplish these goals, a PC-based, multi-media system was conceived that could provide the decision maker with organized knowledge about the tactic and tactical situation in which it applies. Based on work conducted under TADMUS, this knowledge would be categorized into six related knowledge bases (situation/ship, tactics, team, system, task, equipment) that form the basis of mental model development. Knowledge in these areas would be classified further as supporting "why", "how" and "what" questions regarding the tactic. For example, for a particular tactic, the team model would contain information on *what* role each of the team members play in employing the tactic, *why* various team members are involved in the tactic

(and associated TDM), and *how* team members interact to achieve the tactical objectives.

The vision of how such a system might be used is as follows: Beginning with the subject matter expert, the system would guide him/her through a process of extracting the tactical knowledge that underlies TDM. This process would proceed in a structured manner, organized around the knowledge categories listed above, and guided by a series of probe questions. The overriding goal of this procedure would be to describe accurately the various situations for which the tactic applies, identify and make salient the important cues in the situation that should trigger employment of the tactic, explain in detail how all pertinent equipment and systems are involved in the tactic, and delineate the role of all team members involved in the tactic employment and associated TDM task. For example, a tactical publication may contain information regarding which cues in the *situation* will trigger use of the tactic (particularly deviations from "normal") and why these cues are significant, which *ship* systems will be affected by the tactic and how these will be affected, which *team* members are involved in the tactic and their particular roles, which *systems* are affected/employed by the tactic and how these are affected, which *task* procedures are appropriate to accomplish the tactic, and how the *equipment* needs to be configured and why it needs to be configured this way.

Once developed, the tactical publication would be sent to the ship via computer media. As conceived, the this system would provide ample flexibility in how knowledge is presented to the user. To begin with, different levels of knowledge would be available so that users could tailor the information they receive to meet their specific needs. Second, the system would provide the knowledge required to build necessary mental models in order to support TDM. Third, the system would be useful for multiple players, since tactical knowledge could be presented to a team simultaneously, with intermittent discussion (to foster compatible knowledge structures). Forth, the system would incorporate multiple media presentation capabilities (e.g., video, audio, simulation) so that cues from different modalities could be represented. This feature would also help ensure that motivation to understand the

material was high. Fifth, the system would allow users to access information in a sequence and at a pace that is comfortable to them.

Finally, a simulation capability would be incorporated into the system that would allow users to simulate situations to see and hear how a scenario requiring the tactic might unfold. This feature could be developed expressly to ensure that all important situational cues are made salient, and used as a mechanism to provide the decision maker with exposure to pertinent scenarios. Going back to the discussion of decision making, this would help to build crucial mental models, and foster rapid recognition-primed decision making. This capability could also allow decision makers to pose "what if" questions to see the implication of various decisions on the outcome, thereby aiding their ability to mentally simulate the implications of a decision. In addition, by allowing team members to "see the world" from the perspective of their teammates, the building of common mental models would be enhanced. This would be accomplished by providing team members with the ability to experience scenarios from various CIC positions.

With respect to cognitive functioning, the system described here would meet the four requirements noted earlier. Namely, it would present knowledge to decision makers in a format that fosters development of accurate, complete mental models; it would help to identify necessary declarative and procedural knowledge required to support tactics employment, it would foster formation of appropriate cue-strategy associations via simulation (i.e., exposure to scenarios), and it would provide a context in which tactical knowledge can be understood and encoded into memory. Moreover, the described system meets the more general objective delineated above. Specifically, it could help to enhance the useability of tactical knowledge, increase the accessibility of tactical knowledge on board ship, enhance the training/learning value of tactical publications, increase the users' motivation to learn tactical knowledge, improve the team's ability to coordinate TDM and tactics employment, decrease the Navy's dependence on contractor support, and decrease the cost of tactical publications. Ultimately, such a system could enhance the quality of TDM and tactics

employment, and improve the efficiency of the tactical publication process as well.

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