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ANALYSIS AND DESIGN OF A
MICROCOMPUTER-BASED
DECISION SUPPORT SYSTEM
FOR THE U.S. NAVY'S
SHIPBOARD TACTICAL ACTION OFFICER

by

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This thesis examines whether a Decision Support System(DSS) could be of practical assistance to the U. S. Navy's shipboard Tactical Action Officer (TAO). The environment of the TAO is one of tension and information overload as he monitors the data coming in from sensors and other watchstanders and attempts to determine the tactical situation from these clues. The thesis begins with the assumption that in order to help the TAO perform his duties and reach a correct analysis of the developing tactical picture, a knowledge-based Decision Support System could be developed to assist the TAO by figuring out the identity of, and associated threat presented by each contact and to help him remember what the identity so far has been. Through a series of interviews of qualified TAOs, a set of requirements for such a system was developed. The results were analyzed and the subsequent design made to include analytic capabilities, Rules of Engagement recommendations, and a trackball interface featuring pull-down menus and familiar symbology.

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Analysis and Design of a Microcomputer-Based Decision Support System for the U. S. Navy's Shipboard Tactical Action Officer

by

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ABSTRACT

This thesis examines whether a Decision Support System (DSS) could be of practical assistance to the U. S. Navy's shipboard Tactical Action Officer (TAO). The environment of the TAO is one of tension and information overload as he monitors the data coming in from sensors and other watchstanders and attempts to determine the tactical situation from these clues. The thesis begins with the assumption that in order to help the TAO perform his duties and reach a correct analysis of the developing tactical picture, a knowledge-based DSS could be developed to assist him by figuring out the identity of, and associated threat presented by each contact and to help him remember what the identity so far has been. Through a series of interviews of qualified TAOs, a set of requirements for such a system was developed. The results were analyzed and the subsequent design made to include analytic capabilities, Rules of Engagement recommendations, and a trackball interface featuring pull-down menus and familiar symbology.

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A special thanks also for the fourteen TAOs who generously contributed their time and expertise to this effort in the hopes of improving the TAO's ability to handle the developing tactical picture.

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I. INTRODUCTION

This first chapter will provide the reader with an overview of the duties and environment of the Tactical Action Officer (TAO), and describe how a Decision Support System (DSS) may be of potential benefit to the TAO.

A. BACKGROUND

1. The Environment and Duties of the Tactical Action Officer

The environment of the U. S. Navy's Tactical Action Officer (TAO) is one of stress, potential information overload, doubt, and sometimes confusion. It is the TAO who is charged with the awesome responsibility of fighting the ship, employing the ship's weapons against aggressor platforms in the Captain's absence.

In the days of World War I, the Commanding Officer fought his ship from the bridge where he visually identified the enemy and decided on the appropriate engagement method. Then came wars fought under the cover of darkness -- wars fought with weapons other than cannon -- wars fought without ever sighting the enemy.

Electronic detection became prevalent in World War II with the advent of surface search and air search radar and sonar. These devices not only provided non-visual target detection for the originator, but eventually were used to locate, identify, and target the emitting platform.

In today's high-tech world of phased-array radars, electronic surveillance methods, smart weapons, and multiple threats, war at sea is becoming increasingly complex. The Commanding Officer afloat needs help in discharging his responsibilities, he needs a highly trained watch officer prepared to advise him and fight the ship in his absence. Such an individual is the TAO.

When engaged in fighting the ship (sometimes just in keeping track of the tactical picture), the TAO experiences stress and sometimes an overload of information. Such stressful situations may threaten the ship, her crew, and her aoility to carry out her mission.

2. Evolution of the At-Sea Tactical Situation

The TAO gathers information about the contacts he encounters: size information, data about their electronic emissions, speed information, and finally configuration information gained through visual sighting by lookout or friendly aircraft. From these inputs the TAO tries to narrow down the possible identity of these contacts in order to keep track of the developing tactical situation.

Despite the doubt inherent in the TAO environment mentioned earlier, some TAOs will stick stubbornly to a decision they have made, no matter how unfounded this decision may be. This phenomenon is probably the result of a combination of factors, lack of sleep, stress, difficult subordinates whose attitudes makes the TAO even more adamant, and the tendency of the position of TAO to sometimes force the decision simply because he is the boss (I'm the TAO, and if I say it's a Krivak, then it's a Krivak). This can be dangerous and, in fact, potentially disastrous. Staw points out that because it is often possible for persons who have suffered a setback to recoup their losses through an even greater commitment of resources to the same course of action, a cycle of escalating commitment can be produced. [Staw 81 p. 577] By design, a DSS would reduce/eliminate this problem by offering another expert opinion and by allowing the TAO a graceful, face-saving way out of a bad decision. Computers, after all, are seldom smart-alec and difficult to get along with.

It is conceivable that if an automated decision aid had existed aboard the USS Stark in the Persian Gulf, that disastrous situation could have been avoided. From the time the Stark "was warned of the approach of an Iraqi F-1 Mirage by an E-3 airborne warning and control system (AWACS) aircraft" [Vlahos 88 p. 64-65] at 2000 local time until the F-1's "first missile was launched at 2107, 22.5 nautical miles from the Stark" the aircraft had closed a total distance of about 175 nautical miles, "locked onto the Stark" with its Cyrano IV air intercept radar, changed course to "a virtual constant bearing, decreasing range" path now coming right at the Stark, and fired two Exocet missiles. Stark's TAO forbade contacting the aircraft by radio until after the first missile had been launched. After the second missile had been fired the Phalanx Gatling gun was placed in 'standby mode'" and "permission was given at this time to arm the super rapid blooming offboard chaff (SRBOC) launchers." Evidently, despite all of the indications of the F-1's intentions, his hostile intent was never recognized. The added information and advice a DSS could have provided might have led to a better decision about the interpretation of the tactical situation at hand and to a better reaction on the part of the TAO to defend his ship.

B. OBJECTIVES OF RESEARCH

This paper describes research conducted to determine whether a micro- or mini-computer-based Decision Support System would be useful to the TAO in analyzing the input data, sorting the contacts by eliminating those which do not fit the data, and keeping track of what the contact could possibly be and presenting this information to the TAO. In effect, the system would act as an "analytic scratchpad."

The specific objectives of this thesis work were to:

- determine if a Knowledge-Based DSS could be helpful to the TAO for:

    a. determining the identities of other platforms

    b. remembering these identities for the TAO

    c. recommending courses of action

If the above proved feasible, to:

- analyze the specific requirements for such a system
- design a system to meet the need

C. BENEFITS OF THE STUDY

The advantages of such a system arise from the DSS's ability to determine from the input data the type of contact and to keep track of this information for the TAO to free his mind for other things.

A further advantage is seen in the very nature of a computer -- it is dispassionate and unemotional, and it does not become stressed. By allowing it to make these cool, calm, unbiased analyses, the Navy benefits by not having a stress-induced misjudgment on the part of some TAO cause the ship to take a missile hit.

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

It is important to note that the system designed was set up not as a reaction tool for the crisis environment of a "shooting war" -- it will not take over from a panic-stricken TAO and defend the ship or even advise him when the chips are already down. Rather, it will act as an advisor during the DEVELOPING tactical situation. It will take data input, and evaluate it based on the information in a platform database which meets the given criteria.

It was assumed that the TAOs at the U. S. Naval Postgraduate School (NPS) generally reflect the overall opinions of the TAOs at sea and that the school's influence on these students had not dulled or distorted their professional opinions due to their absence from the fleet. Further research might be required to confirm that, in fact, the cutting edge TAOs of the fleet do agree with the design specifications produced as a result of this survey.

E. RESEARCH METHODOLOGY

A survey of those qualified TAOs available at the U. S. Naval Postgraduate School was conducted to determine what they thought might be the most beneficial means of supporting the TAO in such an environment. These TAOs were interviewed by the author with a guideline set of questions to structure the interview (Appendix A). These guidelines were developed based on prior research in the DSS arena, although little of this research actually dealt with real world situations. Rather, it discussed mostly theoretical applications to a proposed area.

Although the use of questionnaires was considered for those unable to be scheduled for an interview, none were used, due to the extra information and different insights more likely to evolve in an interview than in a structured questionnaire and due to the complexity of the questions themselves and the possible resulting misinterpretation.

F. THESIS ORGANIZATION

The thesis is organized into five chapters. This first chapter is the introduction which has described the duties and environment of the Tactical Action Officer (TAO) and how a

DSS may be of potential benefit to the TAO. The second chapter explores the theory behind Decision Support Systems and Expert Systems in general and those specifically tailored to the emergency/crisis environment (previous attempts at this specific problem domain). The third chapter describes the TAO environment as it relates to the above theoretical basis, the research actually conducted as it related to this environment and the problem presented. The fourth chapter discusses the interview results and the design of the resulting system. Finally, the fifth chapter presents further potential research possibilities and discusses conclusions and recommendations drawn from this research.

II. THEORETICAL FOUNDATIONS FOR THE RESEARCH

In order to properly answer whether the Decision Support System (DSS) is appropriate for the environment of the TAO, it is necessary first to examine the theory behind DSS and their relatives Expert Systems (ES) and Knowledge-Based DSS. It is also incumbent on a researcher in this field to take a serious look at previous attempts to assist the crisis manager with these tools.

A. DECISION SUPPORT SYSTEMS

Much literature exists on the subject of Decision Support Systems (DSS). This chapter condenses the essence of the literature to describe a Decision Support System. Such an understanding will be necessary to determine whether this is an appropriate solution to the problem experienced by the TAO. The results come from a variety of sources, including actual experiments with DSS in crisis situations.

There is, as Hopple points out, a tendency to use DSS where they are not really appropriate. He compares this to the law of the hammer, "Give a child a hammer, and s/he will use it on everything encountered." He warns against methidolatry, which manifests itself at the most general level as the fetishistic belief that computer-based decision aids are appropriate solutions to (and potential panaceas for) every analytical and decision problem or task that confronts a command and control problem solver. [Hopple 86 p. 948-949) With this warning in mind, an examination of decision aids is in order.

Ford defines a Decision Support System (DSS) as "something that helps decision-makers utilize data and models to solve unstructured or semi-structured problems." [Ford 85 p. 21-22]. It is a highly touted tool for analyzing problems prior to decision making.

The computer's adeptness at manipulating data through storage, retrieval, arithmetic operations, and comparison makes it well suited to the operations desired by humans.

Sprague and Carlson define DSS as "computer-based systems that help decision makers confront ill-structured problems through direct interaction with data and analysis models." [Sprague & Carlson 82 p. 1] This is a different arena from that of Management Information Systems (MIS). As Sprague points out, MIS has an "information focus, aimed at middle managers. Its structured information flow and integration by function (i.e., production, marketing, etc.) provide inquiry and report generation, usually with a database." [Sprague 87 p. 198] With a DSS, the emphasis is on enhancing the quality of decisions.

Though each of these definitions seems to be aiming at the same area of computer support, there appears to be no concrete definition of a Decision Support System to allow direct comparison and contrasting with MIS. This thesis will use a more general description based on the components of the name, due to the simplicity it lends to the concept. Keen points out that the system can be broken into its component parts and described in terms of a computer-based system to support the making of decisions [Keen 87 p. 259]. A distinction should be made here -- a DSS is not designed to replace the decision-maker but rather to help him make the decision by presenting the information in a different format or with a different evaluation of the situation.

DSS are suitable for many diverse decision areas including financial planning, train dispatching, and marketing strategies. They are particularly adept in situations requiring a different representation or a sorting of data prior to its being useful to the decision-maker. This different representation may take the form of a graphical display like a pie chart or may involve sensitivity analysis (What if?) capability or both. In fact, DSS take many different forms. They may simply graph certain data as they relate to other data, they may contain formulae to calculate the optimal investment portfolio for a given set of financial data and priorities, or they may help the decision maker by allowing a particular simulation to be run with various combinations of input data. DSS are not just being tested and used by computer companies, either; they are being used by pharmaceutical companies, railroads, and paper giants and even tested by law enforcement agencies.

B. EXPERT SYSTEMS

A new variation, the Expert System (ES), is a computer-based system to emulate the judgment and reasoning of an expert. If an expert could be corralled and induced to tell his secrets, the process of his thoughts could be modeled in the form of a rule-based computer program. Morton points out that there is an "ES onus on cognitive processes underlying the notion of expertise." [Morton 88 p. 17] In other words, the ES tries to mimic the thought patterns and processes through a rule-based set of instructions for the computer to perform given a particular set of circumstances. Although the systems differ in that the DSS was designed to help the decision-maker decide and the ES was designed to make the decision, Ford points out that the "fundamental goal of DSS and ES is the same; they seek to improve the quality of the decision." [Ford 85 p. 24] Mason goes on to point out that"[An Expert System's] output is a single course of action. The decision-maker retains just a 'veto' power." [Mason 69 p. 87]

Expert Systems are probably best described as an evolution of DSS. Some would even argue that an ES is an intelligent DSS [Turbin & Watkins 86 p. 139]. Ford defines ES as a "problem-solving program that achieves good performance in a specialized problem domain that generally requires specialized knowledge and skill. The systems process the knowledge of experts and attempt to mimic their thinking, skill, and intuition." [Ford 85 p. 23]

Waterman and Jenkins go on to point out that an expert system is "particularly useful for problem domains that are not well formalized and for which no generally agreed upon axioms or theorems exist." [*Waterman & Jenkins 86 p. 96*]

An expert system is often made up of two components: a rule base which contains the "rules of thinking" and the inference engine which uses the rules to infer a conclusion.

1. Rule Base

The rule base of an Expert System is the set of instructions given to the system to determine what action it is to take or what conclusion it is to draw given a certain set of circumstances. The rule base represents the knowledge of the expert, put into a set of "if-then" rules for the system to follow in a certain situation. The rule base is the codification of the knowledge that the system is to possess. It is the written out form of the expertise the Expert System is to mimic when presented with a certain problem or a certain set of problems.

2. Inference Engine

The inference engine is the heart of an Expert System, performing two major tasks. According to Harmon and King, "it first examines existing facts and rules [in the rule base], and adds new facts when possible. Second, it decides the order in which inferences are made. In doing so, the inference engine conducts the consultation with the user." [Harmon & King 85 p. 49] Sage points out that the inference engine also acts "as an intelligent interpreter in the selection of those portions of the knowledge base which are most applicable to resolution of a given issue." [Sage 86 p. 197] One of the advantages of such a setup is the system's ability to generate an explanation of the reasoning process used to reach a conclusion. The user is then able to validate the conclusion and possibly enhance his decision-making skills by following the system's line of reasoning.

Several operations are involved with 'firing' the rule base including (1) forward and backward chaining, (2) depth and breadth searches, and (3) monotonic and non-monotonic reasoning. In forward chaining, the inference engine takes existing data (facts, sensor inputs, and the like) and examines the premises for rules to see if they are true, thus moving toward a conclusion. [Harmon & King 85] It is best suited for situations where the solution needs to be constructed, usually from a large number of possible outcomes. Backward chaining, on the other hand, starts with a conclusion (diagnosis, goal, etc.) and works back through the subgoals to choose an answer. Backward chaining is commonly used when the possible outcomes are known and are reasonably small in number.

Waterman and Jenkins describe this in terms of rules and goals. "The rules are antecedent driven. This means that when all the conditions of a rule are true relative to the database, the rule 'fires' causing the associated actions to be taken. The goals, however, are consequent driven. This means that the system is given a condition to make true, or in effect, a question to answer through deductive inference. Here, the right sides or consequents of rules are examined to find one that could make the desired condition true. When such a rule is found, its left side or antecedent is examined to see if all its conditions are true. If they are, the rule is fired." [Waterman & Jenkins 86 p. 100]

A depth-first search of the knowledge base follows a detailed line of reasoning concentrating on highly related facts. A breadth-first search sweeps across all premises in a rule before digging for greater detail. [Harmon & King 85]

Monotonic reasoning involves "locking" previously validated premises, that is, once the system accepts a premise as true, it cannot reverse the logic. Non-monotonic reasoning is more flexible in that the system can reverse accepted premises when contrary information is presented. The major drawback to such a capability is that the inference engine must be able to undo all premises based on the invalid premise.

C. CAN DSS AND ES WORK TOGETHER?

Sage contends that "there should exist many areas in which the proper form of knowledge-based support is a hybrid of an 'expert system' and a 'decision support system.'" This is to allow it to "support the decision maker in the formulation or framing of the decision situation in the sense of recognizing needs, identifying appropriate objectives by which to measure successful resolution of an issue, and generating alternative courses of action that may resolve the needs and satisfy objectives." [Sage 86 p. 196]

This idea of the use of DSS in concert with ES is not a new one. Henderson finds that a productive synergy can and should exist between research in the two domains [Henderson 87]. Turban and Watkins go on to point out that the combination of the two in an actual application would not only be able to answer the question "what-if?" but "will also be able to answer the question 'why?'" [Turban & Watkins 86 p. 150].

As the two systems become intertwined, it is sometimes difficult to differentiate where one stops and the other begins. This is not to say that the two are mutually exclusive. Shane et al. "test" the efficacy of using a decision support system with an expert system component." The results of their study "indicate that using Knowledge-Based DSS can improve the decision maker's ability to identify and assess problems in unstructured environments." [Shane et al. 86 p. 453]

We have examined the concepts and uses of DSS and ES as separate entities. DSS fit well into an environment where the decision-maker requires assistance in making the decision, while the ES replaces the decision-maker and comes up with the answer itself. The environment of the TAO does not call for replacement of the TAO, yet there is a tremendous amount of expertise for him to master, a huge amount of information to track, and sometimes a very short time in which to make a decision. A sort of hybrid may be in order.

D. KNOWLEDGE-BASED DSS

Based on the intended use of the TAO system, the term Knowledge-Based DSS is preferred since the system will be used to provide an expert decision based on its embedded knowledge. But, as will be seen, this information is used in an advisory role only. Goul and Tonge discuss the Knowledge-Based variation on the DSS theme. "Our perception is that the term incorporates (1) the application of DSS techniques to expert-based system construction and (2) expert-based system techniques applied to DSS construction." [Goul and Tonge 87 p. 451]

The systems apparently came into their own not because their assistance was so perfect but because as Benbasat et al. point out "people costs are greater than machine costs." [Benbasat et al. 81 p. 753]. The memory of computers is also advantageous to the user in that once the system is programmed to assist the decision maker or to emulate the expert, it can keep track of a number of variables without regard to how many other things are on its mind and how tense the situation might have become in the interim.

It is on these characteristics of computer operation which this thesis will capitalize: their speed and their ability to keep track of a number of simultaneous complex activities.

Numerous drawings of what such a system would look like attempt to point out the various interrelationships among the user, the computer, and the system components [Harmon & King 85, Sage 86, Ford 85, Arcidiacono 88, and Turban & Watkins 86]. In order to find a basis to work from on the TAO DSS, these drawings were examined to find a diagram that best fit the uses and relationships such a system would require. Although none of these specifically fit the needs of the TAO environment exactly, two were close and with some combination and modification have produced the generic diagram illustrated in Figure 1.

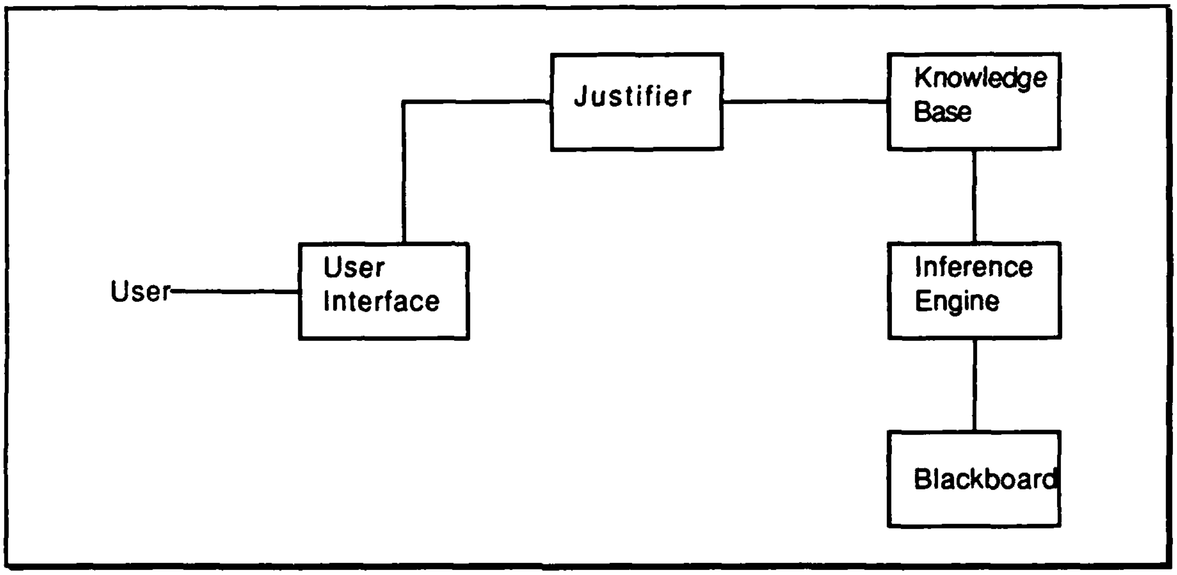

Figure 1. The Knowledge-Based DSS

[Adapted from Harmon & King 85: p. 49 and Turban & Watkins 86: p. 139]

This figure illustrates the interaction of the user with the system through the User Interface. The Justifier, described by Turban and Watkins, is the component that explains to the user the reasons for a particular conclusion (or interim conclusion) by the system. This is the same component referred to by Harmon and King as the Explanation Subsystem. The Blackboard is unique to the Turban and Watkins model and is the component "for recording intermediate decisions." [Turban & Watkins 86 p. 140] The Knowledge Base contains factual rules to allow the derivation of assertions. As Arcidiacono points out, "The Inference Engine uses assertions (facts) and problem solving expertise in the knowledge base to infer conclusions. Its design and function depends on types of knowledge structures it must process." [Arcidiacono 88 p. 47] He goes on to point out an important advantage of having a separate Inference Engine and Knowledge

Base since "a knowledge base for one domain can be replaced by one from another domain without the need for changes to the inference engine or user interface." Although this is a deceptively simple system, it contains the necessary elements to describe the Knowledge-Based DSS to be considered.

The result of combining DSS and ES into a Knowledge-Based DSS is what Kronenberg and Howard refer to as "judgment enhancement." They further point out that "the development of decision support capabilities of the character discussed here must be responsive to the unique style, priorities, and disposition of the manager." [Kronenberg & Howard 87 p. 52-53] Huber also notes that a manager's DSS must be compatible with whatever manual decision support systems (dss) he is already using if the system is to be used profitably. Huber states that "every manager has a 'decision support system' (a dss, a system consisting of the information sources and decision aids that the manager draws upon as the occasion requires)." [Huber 81 p. 1] This dss can take the form of something as simple as a notepad and pencil. Figure 2 illustrates the necessary relationship among the decision maker, his dss, and his DSS.

By using the combined DSS and ES advantages in a time-constrained, complex environment of an emergency, the system will accrue the advantage of a very fast response to the problem with the additional plus that it can keep track of a number of developing situations simultaneously. This is done with the hypothesis that these efforts can help the human TAO to make the decision better, more responsibly, with a decreased level of stress characteristic of an emergency (discussed later) or of an instance of information overload. He is provided with a much broader look at all of the possible alternative solutions and courses of action.

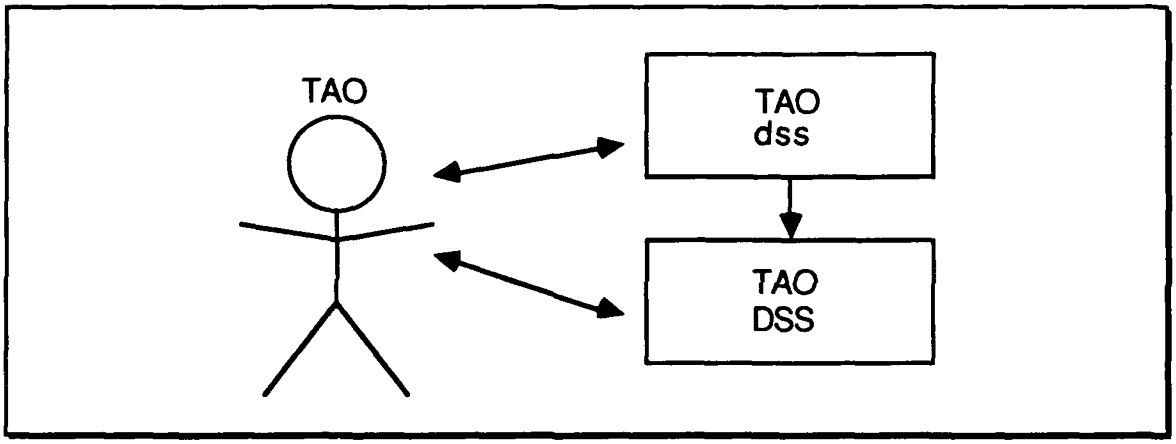

Figure 2. TAO DSS must be compatible with TAO dss

E. INTERFACE

Additional areas to be pursued by this research include the type of interface which would best assist the TAO in interacting with the system. As Hurley and Wallace point out, "Even an 'optimally' designed system may go unused if information is not presented in a form that supports the decision situation and the style of the user." [Hurley & Wallace 87 p. 168] Several scholars have wrestled with this problem, and numerous interface possibilities now exist. For example, Liang has even proposed a self-adaptive interface that watches the pattern of the man-machine interaction and adjusts itself to meet the need. [Liang 87] Shane et al. arrived at a dual mode system which allowed guided and non-guided sessions. "The Non-Guided Session is distinguished by the freedom provided the decision maker to examine file folders at will." They explain that "the sophisticated decision maker is provided a more facilitative interface." [Shane et al. 86 p. 455]

Another facet to be explored in the realm of the interface is whether the reasoning process followed by the system to reach the solution presented should be accessible to the user. The answer appears to be a resounding "yes." As Hurley and Wallace found in their

1987 study, "When the system's exact reasoning process is available, it is easier to convince the users that the solutions are valid and reliable." [Hurley & Wallace 87 p. 167]

F. CRISES AND DSS

Kronenberg and Howard point out that "sources of uncertainty and turbulence are magnified for those who must deal with the unpredictable arenas of defense, foreign policy, or emergency management." [Kronenberg & Howard 87 p. 49] They propose to solve this problem with a Decision Support System. They point out that "Crisis decision making under uncertainty and stress has special requirements. In addition to the physiological, skill, and experiential requirements of which we hear so much, there are extraordinary information requirements. The senior manager is called on to sort, validate, weigh alternatives, and act in an environment which inhibits all those cognitive processes."

At this point, we should define "emergency" in order to clarify the focal point for the issue. Elam and Isett point out that crises are events that have "no identical precedent on which to base a routine decision, and their precise characterization is difficult." [Elam & Isett 87 p. 4] Crises have never occurred before while emergencies have not only occurred before, but there exist for them contingency plans with which to react. The reader may consider this an artificial differentiation, but it is one that is relied upon in this research.

According to Smart and Vertinsky, "Designs for crisis decision making attempt to (1) prevent certain biases that are specific to stressful situations, (2) increase flexibility and sensitivity of line units, and (3) develop computational and processing capabilities in the organization to meet sudden increasing demands imposed upon the decision units." [Smart & Vertinsky 77 p. 655]. This definition seems to suit the emergency situation of the TAO by aiming at a much better solution to the problem facing the decision maker.

This thesis will make use of the phases of resolving a decision developed by Govindaraj et al. "1) uncertainty reduction and 2) threat classification" [Govindaraj et al. 85 p. 499] to apply to the solution of perhaps the most potentially lethal of all emergencies, the attack by a hostile military force on our own ships.

Further research into the area of such systems for support of decision making in the crisis arena point out that the decisions made under the stress of such a situation "are subject to error because the time sensitive nature of the activity prevents consideration of all of the viable alternatives and precludes thorough investigation of the selected alternatives." [Benoit et al. 82 p. ix]. The advantages of the use of their system, developed for the U. S. Air Force included "Thorough consideration of all relevant factors ..., Prompt response to crisis situations,... [and] Consistent behavior." They go on to point out that their system "models the human planning process by developing first a set of possible alternatives and then filling out the details in a series of successive steps." This is the approach that the TAO DSS will take.

Yet another study performed to determine knowledge requirements for Knowledge-Based DSS points out that "the decision maker starts with some uncertainty with regard to the true situation, and then looks for additional information which may reduce this uncertainty. Following a cyclic process new information is obtained and integrated into the existing information, the situation is reassessed and if final assessment cannot be made, further information is requested. The process ends when the decision maker decides that he knows enough about the situation to make up his mind, or that no additional sources of information can contribute significantly (compared to their cost) to remove the uncertainty which still remains." [Ben-Bassat & Freedy 83 p. 1]. This description seems to fit best the scenario of interest: a developing tactical scenario.

Ben-Bassat and Freedy point out that "As new findings come in, either as a result of the decision maker's request or 'voluntarily,' they should be sorted with regard to the entire battlefield structure, the triggered hypotheses and, on the highest priority, with regard to the current goals." This assessment cycle is terminated finally by "one of the following conditions: (a) A decision may be reached ... (b) Several triggered hypotheses have not yet been settled, however, the cost of removing the remaining uncertainty is relatively high ... (c) New developments (e.g., sudden enemy attack)." These are also valid points in the at-sea tactical situation of the TAO.

Ben-Bassat and Freedy continue by saying that the three key things that they feel are critical to the success of their system are "the elicitation and computer representation of the necessary military knowledge for battle field reading ... modeling the reasoning and inference processes which take part during situation assessment, [and] the human-machine interface." The situation, as they aptly point out, "may basically be considered as a puzzle building task."

Vedder and Mason found that for law enforcement puzzles their best results were ones whose human-machine interface featured "sharp, terse dialogue based on the scenario model of a hostage-taking incident." [Vedder & Mason 87 p. 405]

Despite these difficulties and the complications of solving the puzzle, such systems have been built. Callero et al. produced a tactical air targeting aid in the form of a rule-based Expert System. They emphasized the need for the structure of such a system to "permit rapid adaptation within the operational environment." [Callero et al. 86 p. 190] They took meticulous care in designing their system to examine the needs of the user, stating that "At the outbreak of hostilities, the officers cannot be expected to have broad experience in tactical planning .... clearly [there is] a need for sophisticated, automated aids to help regularize the process and assist the targeteer in making the best possible selection."

Klahr et al. produced TWIRL (Tactical Warfare in the ROSS Language), a ground combat simulation. Their study is particularly interesting for its extensive discussion of the system's object-oriented framework. In this setup, they explain, "Objects are organized in a hierarchy of class-subclass links [and] This hierarchy allows an object to inherit automatically the attributes and behaviors of the classes to which it belongs." They point out that the "organization of knowledge around objects facilitates modularity, modifiability, and maintenance of the simulation" and go on to assert that "most behaviors are associated with classes rather than instances. For our purposes, we are more concerned with the ability to represent various types of military units than we are with the ability to represent large quantities of any particular type of unit." [Klahr et al. 86 p. 231] This, too, will become an important concept in the design of a DSS for TAOs.

G. SUMMARY

DSS are designed to assist decision-makers in doing their jobs, while ES are intended to replace the decision-maker altogether by automating the process of making the choice. A marriage between the two results in a Knowledge-Based DSS, one capable of assisting the decision-maker through its internal database of expertise. This is certainly a field that deserves further examination, and a number of applications have already been built to allow these new fields to become available in the crisis decision-making environment. They can help by unemotionally dispensing the expertise in time of crisis, keeping track of myriad information for the decision-maker, and speeding up the decision process. It appears to be a logical choice for a TAO decision aid, but such a conclusion cannot be positively stated until more specific TAO requirements are characterized.

III. DSS APPLICATIONS FOR THE MILITARY.

A. BACKGROUND

The idea of DSS for military use is not a new one. In 1983, Vice Admiral Samuel Gravely, USN (Retired) wrote about the Integrated Information Display (IID) System which was designed to assist the Fleet Commanders-In-Chief (CINC) handle the voluminous amounts of information to "be collected, correlated, analyzed, and disseminated." [Gravely 83 p. 53] De Balogh points out that the military, in fact, developed the concept of "artificial intelligence - artificial instinct" systems, which are "sensor-based to monitor conditions within a complex environment and communicate a warning plus initiate immediate societal response within seconds." [De Balogh 85 p. 101] He also discusses requirements for such a system which would include "A combination of natural language and icon-based interactive dialog environment, a continuous, systematic updating effort of major proportions" to keep up with the dynamic environment [De Balogh 85 p. 86] The necessity for continuous, systematic update also exists in the TAO environment, where the burgeoning array of missiles available is astonishing, and where the parameters of each are changeable to keep the enemy off guard.

It seems strange that such a helpful tool has not been provided to the shipboard TAO who deals with much of the same data and has many of the very same information requirements as the CINC's Operations Duty Officer. Furthermore, the TAO is really where the rubber meets the road -- he's the one controlling the employment of missiles and other weapons against enemy forces. His need is, if anything, more critical than that of the shore-based CINCs'.

There is a danger here, too in that the system provided to a TAO might not fit his needs. Sage contends that "Perhaps the most damning charges of all that affect potential user willingness to use the system are the feeling that it significantly interferes with the 'normal' way of thinking about problems, or that it cannot adapt to changes in problem specifications, or that it does not produce intermediate results of value, or that it does not really address the actual problems that exist." [Sage 86 p. 202] The importance of design is evident here ; it is possible to actually make the job harder if the decision aid does not meet the requirements.

Goul and Tonge point out that critical to the design of any such system "are the needs and desires of the system user as they influence design." [Goul & Tonge 87 p. 450] They state that several of the approaches used today completely ignore these crucial elements.

Callero et al. point out that "Human decision making is inherently unstructured" and suggest "that automated aids specifically designed to reflect the human decision process can contribute to better judgments." To do this, they favor the "knowledge-engineering problem-solving approach in which human domain knowledge is essential, and judgment, experience, and intuition play a larger role than mathematical algorithms and stochastic formalisms." [Callero et al. 86 p. 186]

Weiss suggests that "perhaps the most powerful reason for the success of the Order of Battle Version 1 Knowledge Base [OB1KB], a U. S. Army battlefield advisor, was that the end user played a key role in scoping, designing, and implementing the system." [Weiss 86 p. 93] She also points out that "Because of the inherent transparency of the logic of the system operations and the ease of access to information, OB1KB was used in the field as an accepted, powerful aid in the decision making process. More importantly, in order to use OB1KB, the soldiers did not have to change the way in which they did their job." [Weiss 86 p. 95]

Thus, the voice of Huber echoes its warning that in order to be used and useful, the DSS must be compatible with the manager's dss. The system for a TAO will have to be flexible and adaptive to his changing environment. Waterman and Jenkins suggest that the user and the system may actually feed off of each other, improving each other's decision skills. "On the basis of rules provided by the analysts, the system will reach conclusions with which the analysts may disagree. In this case, the analysts will be compelled to reexamine the basis for their deductions, and this may lead to the formulation of new rules for the system." [Waterman & Jenkins 86 p. 97]

This iterative learning should also be applied to the design of the system's logic. Courbon et al. describe this as a "methodology based on the progressive design of a DSS, going through multiple as-short-as-possible cycles, in which successive versions of the systems under construction are utilized by the end-user." (cited in [Morton 88 p. 14]) Morton distinguishes this approach from prototyping "because the initial system could actually become the real system, not just a pilot test." [Morton 88 p. 11]

To design a system that allows continuous update, that adapts to changes in the problem, that supports rather than interferes with the "normal" way of doing things, that produces intermediate results of value, and that is compatible with the TAO's dss is a tall order. It requires a more thorough understanding of data available to the TAO, information required by him, and the jobs of the assistants who provide this information.

1. TAO's Principal Assistants

The TAO himself has a number of assistants to help him carry out his duties. They do this by keeping him informed of the various data which become available aboard the ship -- data which might help to narrow down the identity of the contact. These assistants range from the Officer of the Deck (OOD) on the bridge of the ship to the Electronic Warfare specialist (EW). These inputs are illustrated in Figure 3.

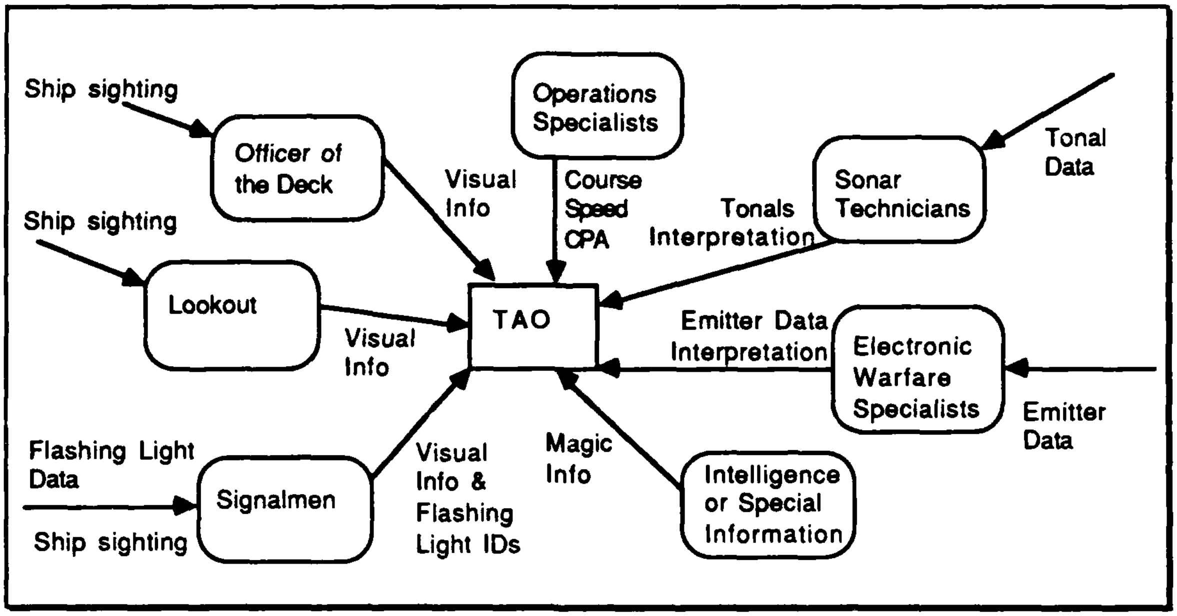

Figure 3. Information Inflow to the TAO

The Officer of the Deck is in charge of maneuvering the ship but his position allows him to see a number of things otherwise unavailable to the TAO.

The lookout has an even better view since he is frequently placed higher on the ship, thus extending his visual range. The lookout is often not experienced enough to know what he is looking at, but his raw data can still be helpful to those who can interpret what he reports.

The Signalmen on the signal bridge can send a flashing light message to other ships to ask them for their identities. This can be valuable even with Soviet ships since a standard communication procedure accepted by both sides allows for at least rudimentary communication to indicate one's intentions to avoid collisions. Signalmen are also trained in the art of visually identifying other men-of-war, as well as merchant ships and pleasure craft.

The Operations Specialists (OS) in the ship's Combat Information Center provide the radar tracking of contacts to determine their course and speed, closest point of approach, etc. This can be valuable in narrowing the field if a particular contact is observed proceeding at a speed faster than a class of ship is believed capable of or has a radar return indicating a larger aircraft than a hostile fighter.

The Sonar Technicians (ST) provide tracking on sonar and can similarly provide course/speed data and the narrowing of contacts' identities as well as certain tonal data which emanate from contacts. These "tonals" come from main feed pumps, reduction gears, etc. and are sometimes distinctive enough to identify a particular class of contact. Propeller blade rates also can provide identity data through speed of rotation and the actual count of the number of blades.

The Electronic Warfare specialists can passively listen to the electronic signals emanating from a particular platform and determine from the combination of signals what emitters a platform has and therefore what that platform might be. This guess is based on known data of which classes of ships, submarine, and aircraft carry that particular suite of emitters. Some of the EW's gear is automated and will determine from the pulse repetition frequency, jitter, pulse rate, etc. what the platform is while other less automated gear will merely present the parameters listed above to the ES and allow him to identify it from this data.

2. Further Complications

The potential danger of all of the supposedly helpful assistance the TAO is receiving above is that he is constantly interrupted by the various people who are informing him of some new tidbit of information to add to his growing collection. These interruptions cause his analytic train-of-thought to be broken and for information to be lost, forgotten, or worse yet, to be attributed to the wrong contact, actually worsening and further confusing the tactical picture. It is possible that better decisions would result from a tactical team consisting of the TAO and a TAO DSS to keep track of correlations and to help deduce answers. This relationship is illustrated in Figure 4.

This confusion coupled with the TAO's responsibility to brief the Commanding Officer on the tactical situation, to watch the Officer of the Deck's maneuvers to ensure the ship is in safe waters, to ensure the ship's weapons systems are unmasked, to manage the CIC team, and his responsibility to run exercises can further exacerbate the problem of the TAO's information glut and can cause information to never be correlated or used.

Even in a calm, ideal environment with all information available and all data flows perfect, there is a problem beyond that of merely correctly identifying neighboring contacts.

3. Determining Hostile Intent

The environment of the TAO is further complicated by the fact that even when he knows the identity of the various contacts, he is still unsure of their intentions. They may mean his ship harm or they may just be projecting their presence on the high seas and monitoring the U. S. ships.

To help the TAO through this dilemma, there exists a set of criteria which, when they are met, may determine that the contact has a so-called "hostile intent."

These criteria include such things as having the missile doors on a contact open (as viewed by a surveillance aircraft or a member of the ship's company) or radiating a friendly ship with a fire control radar. The hostile intent may be directed at other friendly forces (not the TAO's own ship), such as a friendly helicopter.

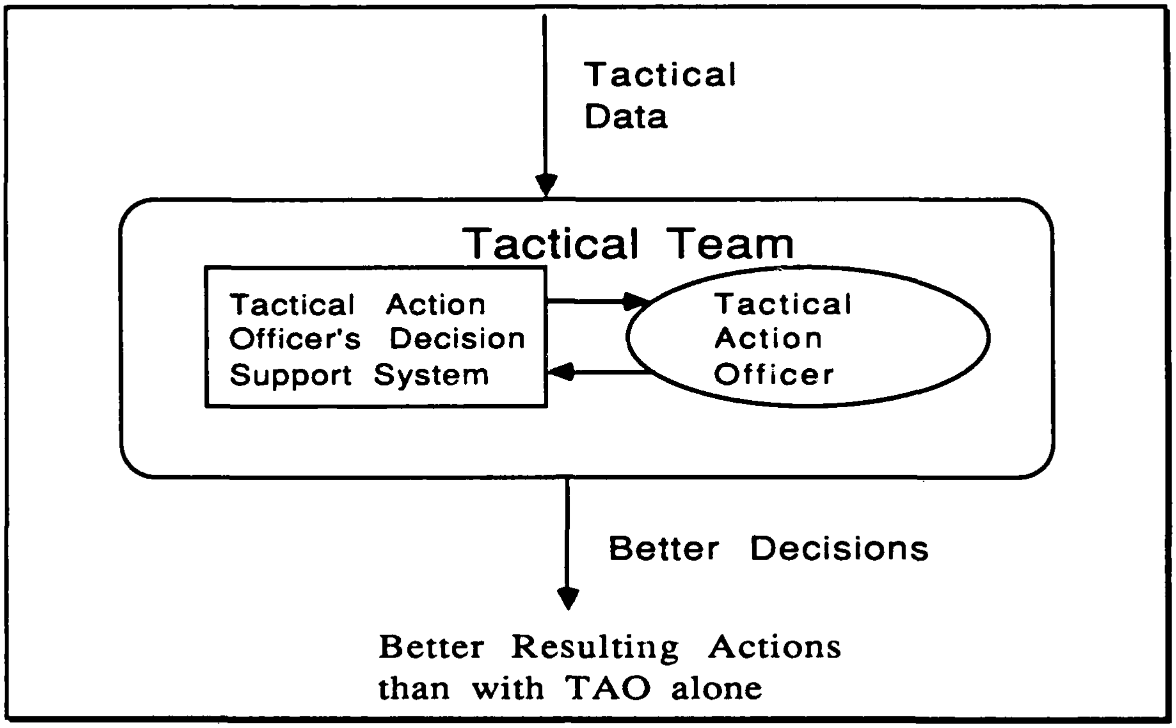

Figure 4. The TAO/ DSS Team

In these situations, a DSS could help by asking the TAO questions relative to a particular contact's status at the time to determine whether hostile intent is present in his actions. Yet another complication which comes into play is that the Rules of Engagement for a particular situation may be entirely different from those for the same situation in another ocean. These rules are created and invoked by the various fleet commanders under the direction of the National Command Authorities (the President and the Secretary of Defense). Those of the Persian Gulf are different from those of the Mediterranean because of known hostile intent in the Gulf. Here again the DSS could help the situation by knowing those rules and presenting the appropriate actions for the TAO to carry out for a given situation.

But, all of this is just conjecture if not backed up by interviews with real TAOs to determine what would be the most compatible with their collective dss, what would assist the "normal" way of examining problems, what information is most needed by the TAO and when, and what type of interface would be easiest, most effective, and fastest to use.

B. DESIGN OF THE RESEARCH APPROACH

In order to solicit this information effectively, careful design went into the specific research approach. Since most TAOs are not familiar with DSS in general or with the more specific aspects which this research was attempting to reach into, it was decided that a questionnaire was likely to confuse the respondents more than it would benefit the research. In light of this, the value of having a live interviewer present to explain what he was trying to get at was considered worth the extra scheduling problems and the extra time involved in conducting the interviews. This coupled with the tendency for more information and insight to come out during a spoken interview than in the environment of a respondent having to write this information down on a questionnaire clinched the decision.

The classic work of Sprague and Carlson describes four major areas for consideration in DSS design -- Representations, Operations, Memory Aids, and Control Mechanisms (ROMC). These four areas guided the design of the interview structure for elicitation of information from the future users -- the TAOs being interviewed. [Sprague & Carlson 82]

1. Representations

This element of the DSS is the way in which the information gleaned from the input data is presented to the TAO. Sprague and Carlson assert that, "Any activity in a decision-making environment takes place in the context of some conceptualization," [Sprague & Carlson 82 p. 102] and it is the representations which facilitate this conceptualization. The effort here was to extract from the TAOs interviewed the best way to show the information needed. This part of the interview revolved around the graphics, text, and video presentations. This is important as noted in the previous chapter because, if presented poorly, the information may not be used at all.

This issue was approached through the use of a mockup screen made prior to the interview and shown to the user for his critique and suggestions. This screen simulation is reproduced in Figure 5.

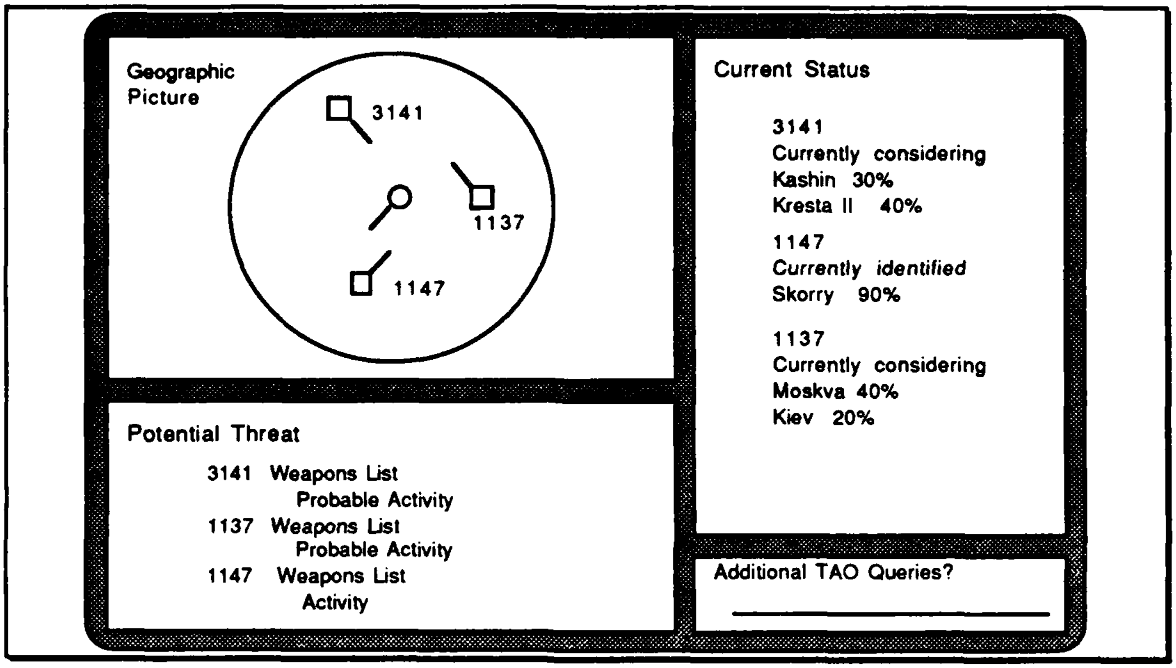

Figure 5. Sample Screen To Determine Proper Method For Representation

2. Operations

The Operations component involves the performance of the software and indeed the system as a whole from the user's perspective. Included here are the various capabilities of the system which the decision-maker can use. He could, for instance, use the system to ascertain the identity of the contact and also a recommended course of action to deal with a certain contact. This aspect of the DSS is critical because if the information is derived too slowly or the information gleaned is not the information needed, the system again will not be useful.

Some of this information was elicited from the TAOs through the use of a hypothetical tradeoff graph (reproduced here as Figure 6) illustrating the possible degree of certainty that the decision is correct, juxtaposed with the amount of time required to reach that level of confidence.

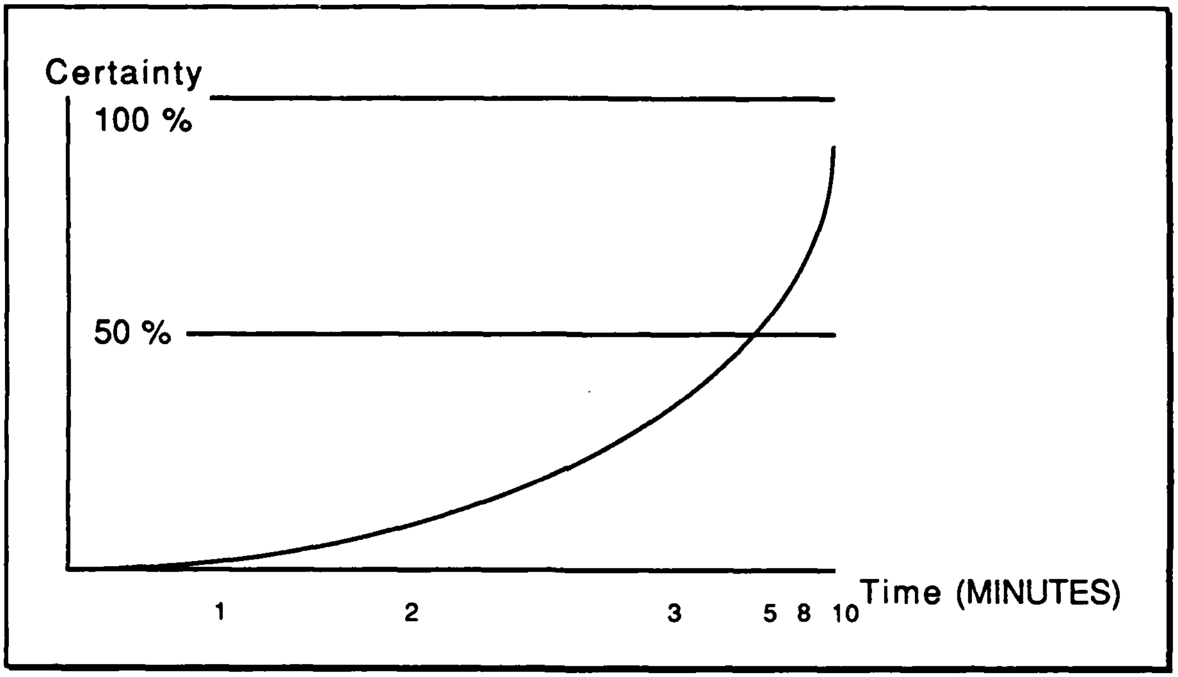

Figure 6. Time/Certainty Tradeoff

3. Memory Aids

This aspect of the DSS involves the method used to remind the TAO of the identity of a contact and other pertinent information. Sprague and Carlson point out that a decision can often be represented in terms of its presentation. [Sprague & Carlson 82] Here, the idea is to find the fastest, most effective method to remind the TAO with the least

least likelihood he might misinterpret what he is seeing. This could involve a change in symbology, a special way to flag a particular contact, text presentations, or audible signals.

One of the questions asked to determine the optimum method to remind the TAO was, "Should the information gleaned by the system through processing the input data be automatically presented to the TAO every so often; Or should the information determined by the system be presented to the TAO only when he queries the system for it?"

Answers to this question would reveal an appropriate storage format as well as important "operations" capabilities of the system.

4. Control Mechanisms

Usually consisting of option menus or another form of user-system dialog, this DSS component is aimed at finding the best way for the TAO to direct the efforts of his computer assistant. Sprague and Carlson state that this element of the paradigm is "intended to help decision makers use representations, operations, and memory to synthesize a decision-making process based on their individual styles, skills, and knowledge." [Sprague & Carlson 82 p. 107] It can take the form of a keyboard, a voice control module, a mouse (or track ball, discussed later), a light pen, or a touch screen. Here, ease of use and effectiveness of operation are key.

Goul and Tonge used this paradigm and allowed the user to choose within the limits of some of his Representations, Operations, Memory Aids, and Control Mechanisms. They state that "This has been shown to be effective in enhancing the expert's understanding of and direct involvement with the inference engine used in the system." [Goul & Tonge 87 p. 465]

One of the questions asked to discover the optimal method to be used for TAO control of the system was, "How often should the TAO be queried for new information?

Should he be queried at all or should he simply be able to enter information in the order he receives it and WHEN he receives it?"

This ROMC paradigm was used to develop the structure for the TAO interviews to be conducted (Appendix A). In fact, the interview structure was organized along the lines of the ROMC paradigm in order to channel the interviewees' thoughts into one area at a time.

There are areas where the distinct components become blurred, however. Where possible, these areas were used to guide the interviewees to the next topic. In some cases, this transition was avoided to permit a more separate examination of the topics at hand. Representations, for instance, was not joined with Control Mechanisms despite the common link between them - the user-system interface.

In other cases, much stronger links between areas were evident in interviews than had been anticipated. The Operations issue led more than a few interviewees into a discussion of Control Mechanisms.

Although this was set up as a structured interview process, these links were pursued rather than suppressed. It is, after all, the interviewees who know best what they want, and this freedom allowed several TAOs to generate new possibilities for the design of the system. These ideas are discussed in Chapter Four.

C. INTERVIEW DYNAMICS

The interviewees chosen were picked at random from among the Surface Warfare Officers in the student population of the Naval Postgraduate School with a preference for the more experienced officers. This thesis will therefore use the intuitive reasoning that more experience will give a better reading as to the value of a DSS in the TAO's environment. It will work from a starting assumption that the more information derived for a TAO from the data available to him, the better the tactical picture he will have. And the better the tactical picture, the better off he will be when the shooting war actually starts.

Interviews lasted from 30 minutes to 100 minutes depending on how much the interviewees had to say. The more experienced officers consistently had the longer interviews, and the two most senior interviewed both said that it is long overdue to have a system out there to help the TAO. Several officers got quite animated, and their excitement led to several of the ideas presented in Chapter 4. Not all interviews were conducted in complete privacy, and in three non-private interviews, Naval officer passersby added constructive comments to what they had overheard. Two of these comments proved beneficial in the evaluation of user-system interface possibilities.

D. SUMMARY

This is not the first attempt to assist military decision-makers through the use of DSS, but the TAO environment lacks any such help. That environment consists of numerous complications, arising from the complexity of determining identity and subsequently hostile intent. Although provided with assistants to help in this process, the TAO is still confronted with a difficult problem.

In the design of the interview structure, the Representations, Operations, Memory Aids, and Control Mechanisms paradigm was used to organize the interviews roughly along the lines of the design of an actual system. The interviews themselves generated a good deal of enthusiasm and valuable input for the research. The results of the interviews and the resulting design of the system are presented in Chapter IV.

IV. EVALUATION OF THE EFFICACY OF HOTDAM! (HART'S OPERATIONAL TACTICAL DECISION AIDING MICROCOMPUTER) FOR THE TAO ENVIRONMENT

Based on the TAO interviews conducted, the appropriateness of a Knowledge-Based DSS for the problem presented by the environment of the TAO was analyzed. Most TAOs questioned felt that such a system would be of significant benefit to them in the environment of the developing tactical situation for use in analytic form to:

- figure out what contacts are and
- remind the TAO what the team opinion regarding the identity of the contact is and
- recommend courses of action.

Since these were in fact the experts for whom the system was being designed, the "users," the assumptions made by the author about the need for such a system appear to have been accurate. A more specific breakdown of the interview results follows.

A. DEMOGRAPHICS

A total of fourteen TAOs were interviewed. Of those, two had prior enlisted service, and one is a reservist. All have stood watch as TAO, and all are U. S. naval officers. Seven officers were Lieutenants, four were Lieutenant Commanders, and three were Commanders. Two of the Commanders have already had command at sea.

The average years of commissioned service for the group was 10.32 (ranging from a low of 4.5 years to a high of 23 years). The average length of time since qualified as a

Surface Warfare Officer (SWO) was 7.8 years (with the low here being one year, and the high being 15). The true average may actually be higher than reported since formal SWN qualification was actually implemented only 15 years ago.

Levels of education ranged from bachelors degrees to "almost Ph.D." The major areas of study included: Ocean Engineering (1), Analytical Management (2), Information Systems (2), Marine Science (1), Nuclear Physics (1), Finance (1), English (1), History (1), Electrical Engineering (1), Communications (1), Economics (2), Political Science (2), Operations Analysis (1), Computer Science (1), Mechanical Engineering (1), and Oceanography (1).

Most interviewees characterized themselves as able to navigate around on computers pretty well (8), one listed his experience as extensive, three listed experience as minimal, and two claimed experience on one specific program only.

B. INPUTS FOR THE TAO DSS

Despite the wide diversity in level of experience on computers, years of experience as a TAO, educational background and majors, and the wide variety of ship types on which the interviewees had served, there was a general agreement about the need for a DSS to assist TAOs, the willingness to use such a system, and the importance of speed and of user interface.

All of the TAOs interviewed expressed a willingness to use a system to help narrow the identity of contacts closing their ships with the few (but almost unanimous) stipulations that it:

- work fast
- work effectively

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should be switchable to other categories or to all categories with a single action (such as a menu choice).

4. Chaining

All TAOs agreed that the system should also be able to work backwards from an educated guess (i.e., an intelligence report that a certain contact is in the area) until it hits something that refutes the evidence or until the TAO is satisfied that the contact is correctly identified.

5. Speed Versus Accuracy

Five TAOs preferred the system give them a fast answer rather than pursuing every possibility and coming up with the most accurate answer possible. Four preferred the most accurate answer only, and four preferred to receive the fastest answer first followed by a more accurate answer later. One suggested that both options be available, selectable by menu depending on the situation. This option seems a good choice since the opinions here were so split.

Shown the tradeoff graph of time versus certainty of identity shown as Figure 7, most declared a separate preference for the time/certainty pairing for air targets than for surface/subsurface targets due to the greater speed at which air scenarios develop. This means that the inference time required for the air contacts must be reduced or that inference time for both air and surface tracks must be improved. Half of the interviewees declared the choices on the scale unsatisfactory and stated that the performance represented was just too slow. One pointed out that this again is a situation-dependent performance issue. The remainder of the results are presented in Appendix B.

6. Non-Monotonic Versus Monotonic Reasoning

All interviewees indicated a desire to be allowed to change elements of data that had already been entered without being required to start the entire scenario over.

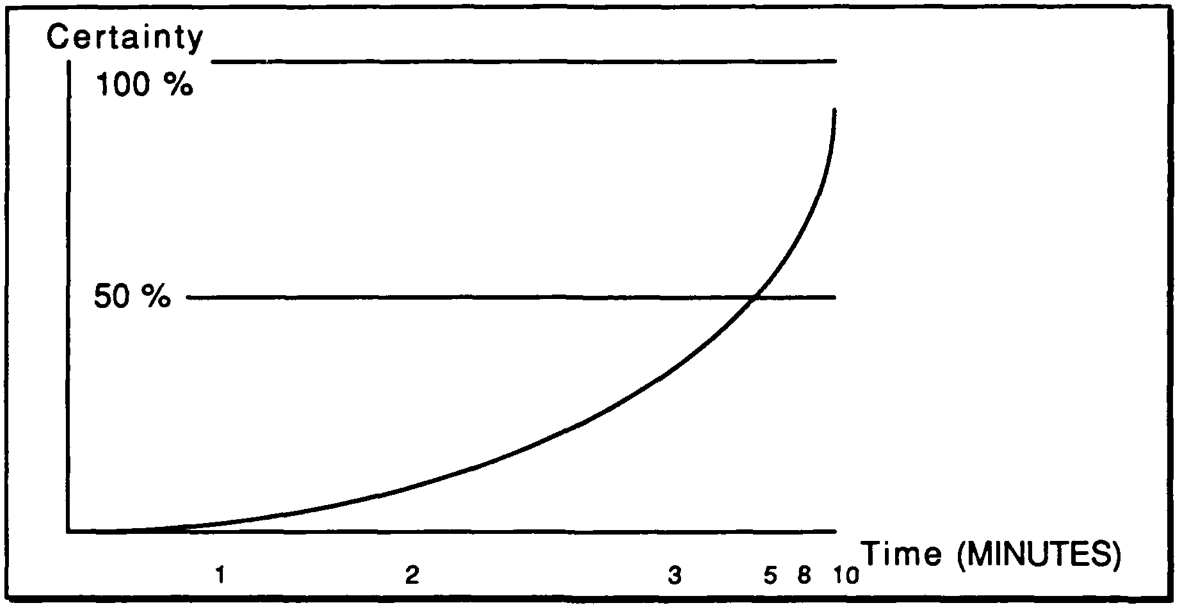


Figure 7. Time/Certainty Tradeoff

7. Platform Specific

Eleven respondents felt that it would be valuable to make the system platform-specific in order to exploit various sources of information that are available but frequently not used by a ship (i.e., size of a target extrapolated from detection range from one's own ship on a particular radar). The remaining three felt that this feature would add unnecessarily to the cost of a "generic" system. This may be a valid point in view of funding cuts already going into effect for the military. However, the value of the information attainable from exploiting the data already available on each class of ship is potentially tremendous. Such data might have prevented the downing of Iran Air flight 655, had the USS Vincennes been able to determine the size of that aircraft. In what has been called "one of the Navy's worst nightmares come true" [Matthews 88 p. 1], perhaps better interpretation of the available data and an unemotional evaluation of the situation (without the stress of the current gunboat battle in progress) could have prevented the misidentification and engagement. A retired Navy Captain has pointed out that "With the information he had in his hand and the time limit he was under, he did the right thing." [Matthews 88 p. 4] It may be possible someday to provide the TAO and CO of the ships we send into harm's way a better capability for the evaluation of the information they have to permit a better decision in a situation where his ship is "in imminent danger." [Matthews 88 p. 18] This could result in better defense of our ships while avoiding the tragic results of an incorrect interpretation of data.

8. Optimal Number of Tracks

As for the optimal number of contacts for the TAO/DSS team to handle together, the answers varied widely based on the past experience of the TAOs of the maximum number of contacts they had had to handle. Answers ranged from 5 to 256, but a realistic approach would be to not limit the number of contacts at all except due to hardware constraint or to the detriment of the actual software performance. The more the computer can keep track of, the less the TAO has to worry with. An absolute minimum should be around 100 tracks.

9. Man-Machine Interaction

Interviewees were about evenly split between preferences for a man-machine dialog featuring voice interaction (7) and one featuring a mouse or track ball (6). Some TAOs expressed a preference for more than one interface mode, resulting in votes for keyboard interface (2), light pen (1), touch screen (1), and function keys (1), as well. One TAO expressed a strong dislike for keyboard use, and one an extreme distaste for voice interface. The mouse or track ball is probably the best suited to the environment and functions to be performed by the TAO.

Pull-down menus, windows, and icons were preferred 12 to 1 over an MS-DOS command line format with one abstainer saying, "Only testing will tell" and the other that this was not applicable because of his preference for natural language interface. One answer was particularly telling, "MS-DOS would kill most TAOs," indicating that these users would probably find that environment so user-hostile that the system would go unused -- an unacceptable situation.

10. Learning the System

Most interviewees expressed a preference for having a live instructor to demonstrate the system come to each ship with the system (11 to 3), and most preferred a short instruction manual with examples (8) to a detailed one (2) or a short set of instructions with more detailed explanations in the back (4). All but one TAO thought instruction on such a system should be given at all TAO training facilities ashore, and 10 of those 13 thought hands-on training in laboratories was necessary, while the others felt a brief introduction would be sufficient.

11. Willingness to Use

If this system showed up on their ships, ten TAOs said they would take the time to learn to use it (the other 4 would be too busy), but eight interviewees said TAOs would become too dependent on such a system; the remaining six recognize a potential problem in that area but feel that drills and the TAO mentality would guard against this. These drills do tend to focus on just such failures, and most TAOs have been burned often enough to know that if such a system can fail, it will at the worst possible time. Thus, too much dependence on the system will probably be avoided.

All interviewees felt such a system would be tremendously helpful by replacing weapon system parameter lookups and platform weapons list lookups in Naval Warfare Publications (NWP), even if it fulfilled no other purpose.

12. Chauffeur

Twelve TAOs preferred to have a chauffeur to operate the system to minimize distraction of the TAO. One TAO suggested using Junior Officers (JO -- usually O-1 and O-2) as chauffeurs; this would accomplish the same purpose with the additional advantage of training the J.O.s. Eleven interviewees said Electronic Warfare specialists (EWs) were an inappropriate choice for chauffeur, while three felt they were a good choice if watched carefully. EWs are usually placed somewhere out of sight, frequently behind a curtain making the "watch carefully" option impracticable, but the fact that this was brought up illuminates another pertinent consideration. EWs have a reputation for being less than completely alert due to the fact that they are seated, their job in most cases requires attention only occasionally, and even then much of their gear is already so automated that no thought is required. If this reputation is founded, EWs are probably a poor choice.

13. Indication of Certainty

Since the system's degree of certainty is an important consideration to the TAO in a situation of contact identity, this should be presented to him. That is, it is crucial to the TAO to know how sure the system is of the identification displayed to him. If the system were only 10% certain, it would be unwise to rely solely on that identification. Normally referred to as a Confidence Factor, this degree of certainty can be presented in a variety of ways. Exactly half preferred a numerical percentage be presented to them, and half preferred a graphical display such as a thermometer graph. A combination of the two could be achieved.

Most TAOs (12) favored a TAO-initiated data input to the system with a system query only if 15 minutes or more pass with no update to a particular contact. The others preferred no system queries at all! It would seem prudent to have the system prompt the TAO after several minutes to remind him of the contact's existence, even if most input was initiated by the TAO or chauffeur. This could help prevent simple forgetfulness from becoming part of a potentially disastrous tactical scenario. Several suggested integrating the system into the ship's existing combat system, but one Lieutenant Commander made the valid and important point that this would eliminate the benefit of redundancy.

Most TAOs also expressed a need to be able to see why the system arrived at a particular answer -- what the trace of its logic was. This would improve confidence in the system and allow the TAO to pinpoint where it is that he disagrees.

C. DESIGN OF HOTDAM!

The TAOs interviewed provided valuable input on required system performance, user-system interface, services to be provided, modularization, methods of logic chaining, method of database search, the necessity to change data already entered, training capabilities, user's manual, and a need to review the logic trace the system followed to reach a conclusion. Based on this data and on the rigors and space constraints of the at-sea tactical environment, the HOTDAM! (Hart's Operational Tactical Decision Aiding Microcomputer!) system was designed to best fit all of these requirements.

1. Hardware

Mini- or Microcomputer-Based Personal computers have evolved into highly sophisticated systems capable of handling the rigors of Knowledge-Based applications. They are rugged, light-weight, inexpensive and readily available, allowing adaptation without the need for shipboard modification. The new generation of microprocessors (Intel 80386 and Motorola 68030) provide the power and speed needed to handle a Knowledge-Based DSS implementation. Should the memory requirements exceed the capacity of personal microcomputers (even with added memory), the system could be implemented on minicomputers with little added space requirements. The system could eventually be run on some of the Navy's existing combat systems computers if the system is ultimately tied into the system. Since the microcomputer choice is preferred, this setup is illustrated as sit-down consoles in Figure 8.

a. Keyboard Data Input and Mouse Control

In the dynamic environment of the Combat Information Center (CIC), the TAO needs to be free from traditional keyboard data entry for speed of input and to concentrate on the varied information presented. A voice recognition interface with large video display would alleviate the need to be seated at a computer terminal, providing improved flexibility. But, voice interface (at this writing) is frequently anything but user-friendly and highly unreliable.

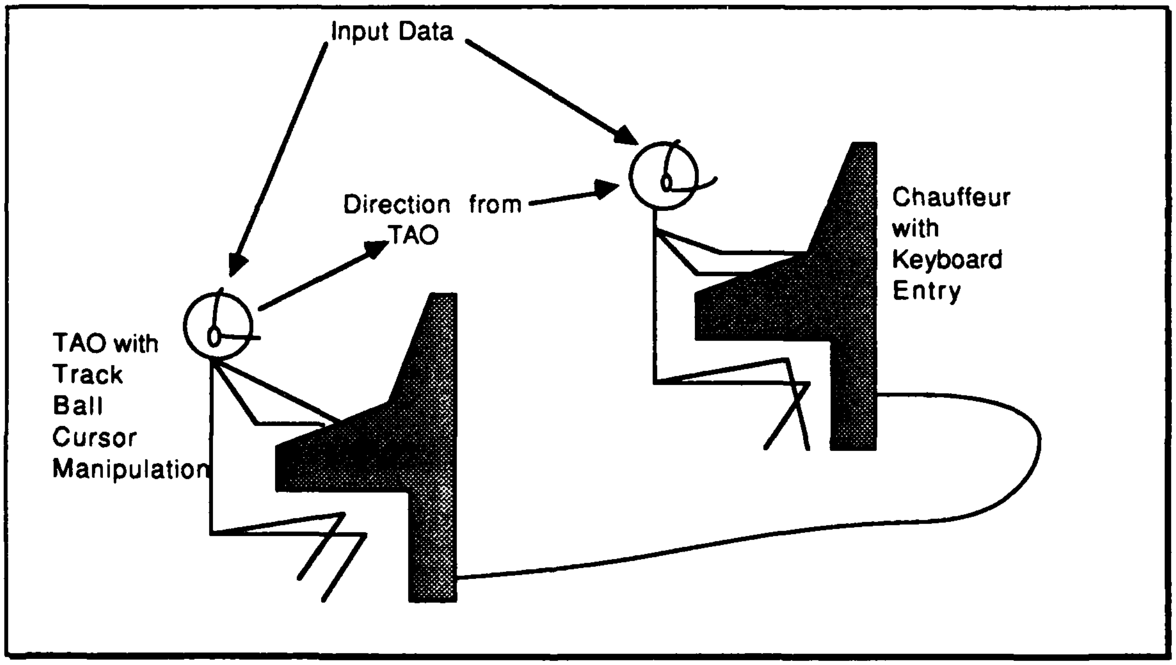


Figure 8. HOTDAM! in Action

Additionally, the TAO environment is probably an inappropriate place to use such an interface since the oft-experienced tension can change the TAO/chauffeur's voice enough to cause it to be not recognized by the system - a very undesirable result. Hence, keyboard entry by a chauffeur is the much more practical (and safer) way to go. A mouse or track ball should be used for the TAO's control of and interface with the system due to its speed and almost intuitive operation. A chauffeur would be recommended to free the TAO from the distraction of data input, but this should not be required since some TAOs really prefer to do it themselves (if they have time).

b. Cursor Manipulation

Much research has been done to determine the best and most efficient way to interact with a computer. Lohr even conducted specific work to determine the best interface for the tactical system. [Lohr 80] He favors an upside-down mouse or "track ball" because "downward force from the palm is required in addition to angular force, making this a very stable 'grip' generally immune to the effects of a moving platform," such as the pitching and rolling surface ship of the TAO's environment. He also discusses other interface methods and points out that there is an advantage to the use of light pens also because of their "familiar pointing action ('... want to pick that one')." But, in the final analysis, he says, "there is no single positioning device that is ideal for all applications, thus a general purpose tactical control system should be available with a variety of control devices." [Lohr 80 p. 26] For two reasons the choice for HOTDAM! is the track ball. First, it is already familiar to most TAOs since is is in current use aboard many ships for console manipulation. Second, the track ball has already proven satisfactory for shipboard use due to its general immunity to the inherent pitfalls of that environment.

c. High Resolution Color Graphics Display

As Benbasat et al. found in their gaming studies, graphics are generally more beneficial to the decision maker than text. [Benbasat et al. 81] To provide the "big picture" the system should display the tactical scenario much like the Naval Tactical Data

System (NTDS) with standard symbology. This pictorial summary allows the TAO to rapidly digest the situation in concert with system-generated recommendations without the need to learn new symbology. A flashing symbol could be used to attract attention should a hostile contact be identified, for example, and the color of contacts should be changed to indicate their identities (friendly, unknown, hostile). Choice of color here is important. As Lohr points out, "Blue is six times less noticeable than green and three times less noticeable than red." [Lohr 80 p. 27] So, if the goal is to have someone take particular note of a contact, green is the (almost counter-intuitive) color to display it in. It is important to note that making a contact more conspicuous can cause the dangerous side effect of confusion particularly if something is presented in a counter-intuitive color to that in which it is usually represented. Should this confusion turn out to be the result, the colors used should be the intuitive ones or the color issue might be abandoned altogether. Lohr's evaluation, however, was made with light contacts on a dark background and may not apply to the same colors with a light background. A further intuitive point to be made here is that a flashing contact would be more noticeable than any others. The real evaluation of efficacy should be tested on real TAOs in a close simulation of a true Combat Information Center in a tactical situation.

2. Software

The Knowledge-Based DSS is a hybrid creature, a blend of the best parts of both the Expert System and the DSS. As discussed in Chapter 2, there are many views about how exactly the various parts of such a system should interact to best assist the decision maker. The diagram presented in the discussion there was a blend from two other diagrams in an attempt to best present the system in light of the TAO's environment.

As the design of the system progressed after the interviews were complete, a number of alterations to the generic idea (and the diagram presented in Chapter 2) of the

Knowledge-Based DSS became necessary in order to incorporate the unanticipated needs of the TAO. Among these changes were the addition of a chauffeur and his associated keyboard interface, a relocation of the Justifier to a position immediately between the TAO interface and the Inference Engine, and the further specification that the TAO interface be one using Track Ball Manipulation of the cursor. This new design is presented in graphic form as Figure 9.

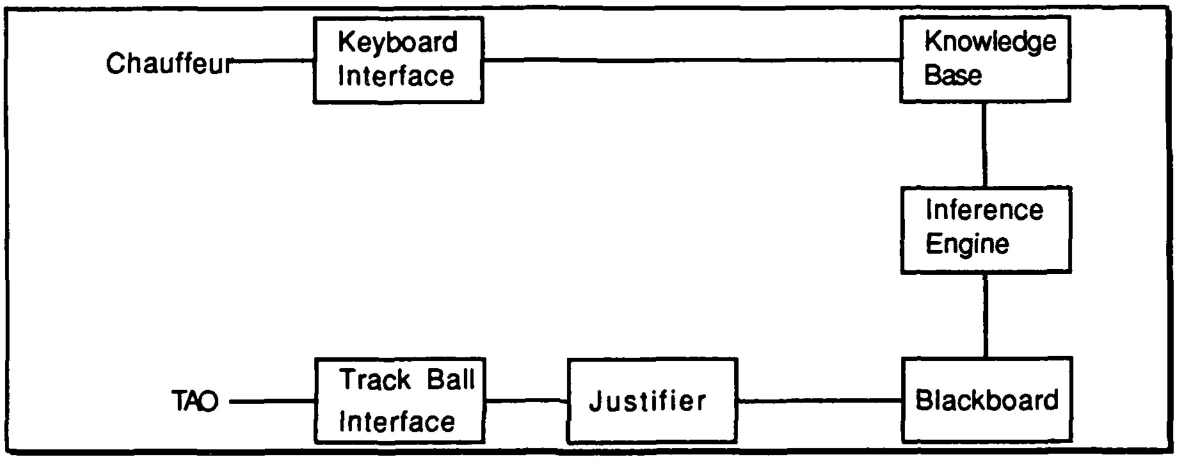


Figure 9. HOTDAM!, the TAO DSS

The Chauffeur is a weak link in this system -- his input will only be as fast as his typing speed, and his accuracy will only be as good as his understanding of the input data and the direction he receives from the TAO.

While it is recognized that this represents a quantum leap in the cost of such a system, it would be hard to place a value on the increased speed with which the system could provide an evaluation in a situation of an approaching, possibly hostile contact in time of doubt, confusion, and information overload. This assistance to the TAO could prove invaluable in the evaluation of the contact, thus preventing the engagement of a neutral contact while ensuring the proper actions are taken against a contact showing hostile intent.

The more specific software requirements of the HOTDAM! system are discussed in detail below and represented graphically in Figure 10.

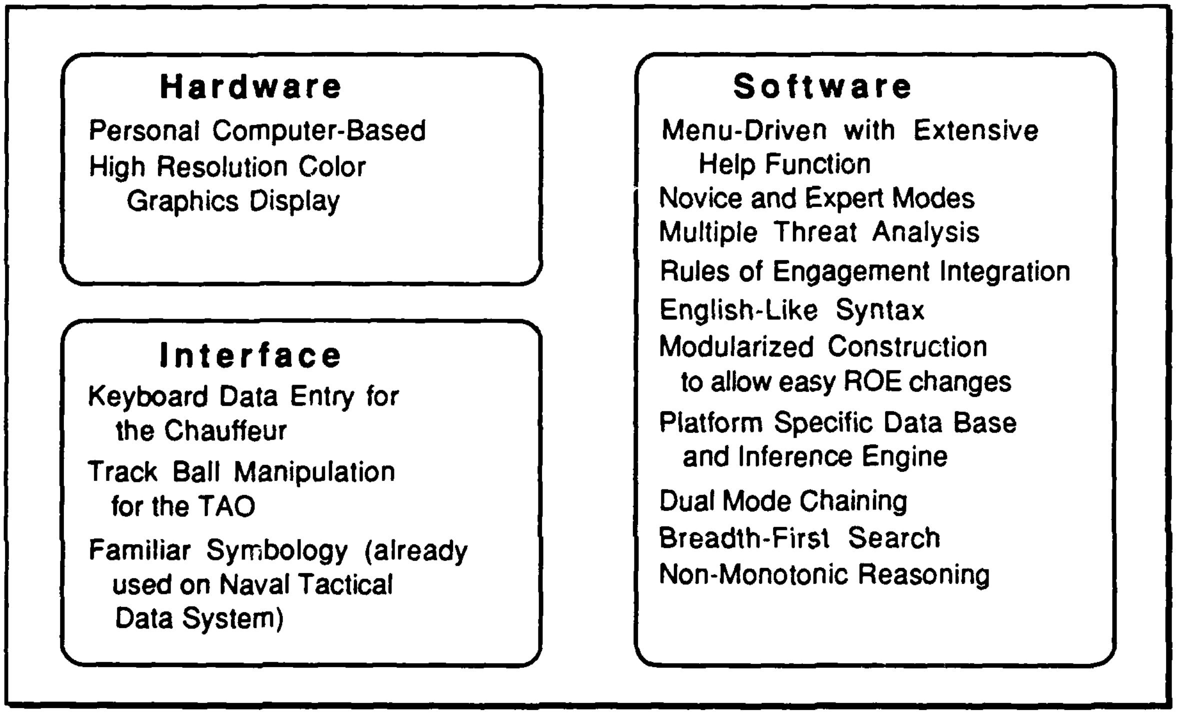


Figure 10. Proposed Design of HOTDAM!, the TAO DSS

a. Menu Driven with Extensive Help Function

The TAO needs direct, explicit dialog with the DSS for speed and accuracy of interaction. As Vedder and Mason experienced, to be successful, " It should be noted that should the funds be available to build one, an ideal system would be connected into the various sensors of the ship and to the existing combat system in order to significantly improve the input speed and accuracy of the data. A system used in a crisis must provide a terse, direct dialog. [Vedder 87] The TAO needs such dialog for speed and accuracy of interaction with the system. This is accomplished with multiple windows and icons where appropriate. An extensive HELP function provides a built-in tutor to guide the TAO-in-training.

b. Novice and Expert Modes

The inexperienced TAO needs guidance to adequately train on the ES; the veteran needs a streamlined system that enhances system operation by alleviating extraneous interface dialog. The dual-mode approach (achieved through a simple menu selection by the TAO) satisfies this requirement by giving the novice extensive on-line instruction while the expert is given minimal dialog for efficient system operation. The novice mode could be used not only to train TAOs in system use but also to train J.O.s in important tactical thinking.

c. Multiple Threat Analysis

As with the AEGIS weapon system, analysis and tracking of multiple targets is required to adequately fight the ship. Since the tactical DSS is not integrated with ship sensors and weapon systems, the program will be limited only by the memory constraints of the hardware. This is in order to improve the human information processing limitation of "seven (plus or minus two)", espoused by Miller. [Miller 56 p. 52] Since the TAO can keep track of about seven contacts by himself, the system will improve his capacity by remembering them for him and by reminding him of them through visual cues and changing symbols. Miller found that recoding can increase this capacity by allowing groupings to assist in this remembering process. In fact, the system could be used to recode for the TAO through such cues as symbol shape to allow better TAO processing.

d. Rules of Engagement (ROE) Integration

ROE are guidelines promulgated by higher authority that spell out under what circumstances we can legally engage a hostile adversary (e.g., return fire only when fired upon). To properly advise the TAO, the ROE in effect must be integrated into the inference engine. These rules can be modified, as needed, by trained personnel as the ship changes operating areas (i.e., Mediterranean, Atlantic, Pacific, Persian Gulf, etc.).

e. English-like Syntax

A fourth generation programming language (e.g., ROSIE from RAND) may be used to provide DSS code which promotes ease of software maintenance and user understanding.

f. Modularized Construction

By using a modular concept, the system software is capable of addition and deletion of platform-specific applications (i.e., surface warfare, airborne anti-submarine warfare, and subsurface warfare). This provides a standard shell with rule-base modules for various environments. Modularized construction also has the advantages that "technological advances can be easily accommodated" and that it "greatly aids in the ability to repair a system." [Lohr 80 p. 28]

g. Platform-Specific Data Base and Inference Engine

Each class of surface combatant has a unique suite of sensors and weapons systems. The DSS data and rule bases will be tailored to the specific class of ship to correctly infer weapons employment recommendations (e.g., weapons range versus target range). This will include data on electronic signal emission, acoustics, radar signatures, etc.

h. Dual Mode Chaining

Because tactical situations normally require construction of the conclusion from an extensive database of threats the system will use forward chaining. In situations where the TAO wishes to evaluate a non-system assessment (i.e., opinion of an experienced TAO or Intelligence Officer), backward chaining can be invoked, adding flexibility to the system. This could be accomplished by a single menu selection for each contact. Several systems exist today that have this capability.

i. Breadth-First Search

With the myriad threats facing our surface forces, error tolerance in target analysis must be extremely low. In support of this requirement, a breadth-first search will be used to consider all possible matches against data input.

j. Non-Monotonic Reasoning

The time-critical aspect of the seaborne tactical environment necessitates the ability to reverse incorrect assumptions. Use of non-monotonic reasoning in the inference engine will allow for this, eliminating the need to re-enter the entire data set when an error is discovered.

k. Man-Machine Interaction

In discussing the interface between a tactical system and its user, Lohr points out that "The interface must be easy to use, fast, and efficient." [Lohr 80 p. 25] Vice Admiral Gravely pointed out that flexibility is a certain advantage to a system like this. To make the system fit Huber's criterion of compatibility with the user's dss, the Integrated Information Display system, discussed in Chapter 3, can "be modified to reflect the operating style of an individual commander." [Gravely 83 p. 60]. Weiss points out the importance of "minimizing the amount of typing required," a system that "suggests the kinds of answers required" through a set of sample responses, the use of "standard symbology," the transparency of system logic," and "the ease of access to information." [Weiss 86 p. 95]

As just discussed, the system will use a breadth-first search to cover all probable target classifications. After preliminary administrative tasks (time, date, position, system mode, and target identification code update) the user is first presented with a menu prompting entry of target characteristic based on method of detection (e.g., Electronic Support Measures (ESM), radar, sonar, etc.).

One should be cautioned that system output may not result in a definitive target identification. Even after exhaustive database searches, it is possible that several platforms will satisfy input target characteristics. The result is a listing of possible target identifications for TAO evaluation.

3. Is it Possible to Implement Such a System Today?

Though numerous so-called Expert System Shells are on the market, many are appropriate for only "toy" problems. An Expert System Shell is a software package that allows "expertise" to be put into it and used without the extra time and difficulties associated with building the entire system from scratch. Most such systems allow the simple insertion of the rule base and inference strategies. Examination of those Expert System Shells known to exist narrowed the field to seventeen possibilities for the implementation of HOTDAM!.

Several of the companies approached expressed concern about corporate spies and were hesitant to discuss their systems with this researcher, citing "proprietary information." This was rather a surprising response since the questions asked were not those involving specific programming techniques but ones about whether their systems allow both forward and backward-chaining, whether or not they use non-monotonic reasoning, etc. Hence, some of the information about these systems had to be obtained through espionage -- in technical magazines!

The seventeen systems which made it through the initial screening and were further researched are presented in Appendix C, along with the list of those five systems which made it through the second screening process as finalists. The addresses of the corporate makers of these five finalists are also included in Appendix C.

Personal Consultant + was noteworthy for its ease of portability to other types of computers including mainframes, LISP workstations, IBM AT and compatibles, T I Explorer Workstations, IBM PS/2 Models 50, 60, and 80, and Compac Deskpro 386. It has an easily understood presentation of confidence factors, advanced graphics, and a good explanation facility. However, it had serious shortcomings in that it is not particularly friendly to users not already familiar with Expert Systems and seems to suffer from chronic out-of-memory errors when dealing with large databases of information (such as will be required by HOTDAM!).

Goldworks can brag of its ease of use, its explanation facility, its object orientation, and its certainty factors. But, it suffers from a lack of ability to perform knowledge-based reasoning without continual referral to DBase III^{+} files and seems better suited to knowledge acquisition and more flexible inferencing than the TAO's environment presents.

An overall winner was found in NEXPERT, which not only provides the non-monotonic reasoning, rule-based approach, and both forward and backward chaining but also allows for direct input from outside sensors should the HOTDAM! system ever be expanded to incorporate direct connection to the ship's combat system. Its object-oriented format fits nicely with the structure of the data to be included in the HOTDAM! system, and the multiple inheritance capability will allow for the easier structuring of the knowledge base.

Automatic goal generation will allow the system to pursue such goals as "Civilian Airliner," and when that goal is determined to be false to generate and pursue another follow-on goal. Its in-depth explanatory function is available at any point during a session. A "browsing" mechanism will allow a review of the data and would facilitate training.

Although the system runs on IBM AT or AT compatibles under Microsoft Windows operating environment or on the MicroVAX, its graphics and user interface are quite similar to those of the MacIntosh (and to the display represented in Figure 5).

A series of editors allows modification of rules, objects, classes, and properties should the occasion arise. This could facilitate the easy incorporation of changes to friendly or enemy weapons systems and to the Rules of Engagement.

Hence, it appears that the HOTDAM! system can be implemented through the existing Expert System Shell called NEXPERT. This will allow for an easier and faster resulting system, and provides for the further expansion of the system to include sensor input, if and when that enhancement comes to pass.

D. SUMMARY

This chapter has discussed the demographic data on the TAOs interviewed and has examined their inputs for the characteristics of HOTDAM!. It then explored the design of the system from hardware, software, inference engine, and interface points of view, discussing the benefits of the various choices made.

In order to create a system that is useful and usable for a TAO, it was necessary to look at the way a TAO makes decisions and whatever dss he uses to ensure compatibility and therefore usability. It is necessary to have a system rugged enough to stand up to shipboard life, a system with an optimal data input mode and an easy to use control mechanism.

The system must account for novices as well as experts and to allow analysis of multiple threats simultaneously. Inferences must be made in all the ways needed by a TAO, and the resulting recommendations must be in accordance with the effective Rules of Engagement. In short, the system must be designed to best fit the TAO's unique environment and information needs.

The resulting design of HOTDAM! optimizes the mix of the numerous criteria necessary to have the best Knowledge-Based DSS possible for the TAO. The design complete, further research was conducted to determine whether any Expert System shell on the market today could meet the requirements posed by HOTDAM!. Happily, there were enough qualifiers to permit a rather choosey comparison and selection of the extremely capable NEXPERT.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

This thesis has examined the fields of DSS, ES, Knowledge-Based DSS, and the previous efforts at crisis and emergency support by these two fields of study. It then examined the environment of the U. S. Navy's shipboard Tactical Action Officer to determine whether the TAO could be helped by DSS, ES, or Knowledge-Based DSS.

That environment is a complex one of multiple contacts closing the force, competing tasks, possible information overload, electronic warfare, smart weapons, and an enemy who is trying his best to deceive the TAO about his real identity and intentions. All of these complications must be taken into account, all possibilities must be explored, all options examined, and careful evaluation of the action to be taken made, all in an environment which inhibits these things. It is this environment that may be assisted by a microcomputer-based Decision Support System to keep track of some of this data for the TAO, to extract valuable information from the data, and to recommend courses of action to the TAO based on its evaluation of the situation.

In order to determine whether this would be a practical and realistic help to the TAO, an interview structure was developed to guide interviews of real TAOs to determine whether this was an appropriate solution to the TAO problem. The structure for the interviews was based on the Representations, Operations, Memory Aids, and Control Mechanisms paradigm of Sprague and Carlson in order to channel the discussion into these vital aspects of an effective decision aid. Fourteen TAOs of varying length of experience, time of qualification, and operational experience were interviewed to determine whether such a system would be of perceived value to the TAO faced with identifying unknown, potentially hostile contacts. The respondents identified the most needed assists the system could provide, the required information to be deduced, the necessary speed of operation, and the best interface method.

Based on the interviews conducted, the overwhelming view appears to be that a Knowledge-Based DSS would be a great help to TAOs. But there was a great deal of disagreement about exactly what help would be most beneficial to the TAO.

The small sample size may not have allowed enough screening to get a flavor for the majority of TAOs. However, the information gathered here does provide a valuable set of needs since those interviewed are quite experienced in the area of TAO operations. A follow-up set of interviews could be conducted with TAOs currently serving at sea and standing watch in the position on a day-to-day basis. These TAOs may come up with further valuable suggestions to improve the system discussed here.

Although more research may be required to accomplish the implementation of the system, this thesis establishes a good basis from which to work and some design criteria which appear relatively certain based on the general agreement about their inclusion. The following criteria must be included:

- Micro- or Minicomputer-Based
- Keyboard Data Input by a Chauffeur
- Track Ball Control by the TAO
- High Resolution Color Graphics Display
- Menu-Driven with Extensive Help Function
- Novice and Expert Modes
- Multiple Threat Analysis
- Rules of Engagement (ROE) Integration

- English-Like Syntax in the programming language
- Allow easy modification to ROE
- Modularized Construction
- Platform-Specific Rule Base and Inference Engine
- Dual Mode (Forward and Backward) Chaining
- Breadth-First Search
- Non-Monotonic Reasoning
- As User-Friendly an Interface as Possible.

B. CONCLUSIONS

Perhaps as important a result of this thesis as the specification of these criteria, though, is the determination from real TAOs that they unanimously felt that such a system would be a significant help to the TAO in resolving unidentified contacts in a non-combat environment. Knowledge-Based DSS show a great deal of promise for application to the TAO environment. Isett found that his mockup DSS significantly helped to improve the decision quality of the Air Force's equivalent of the TAO in crisis situations. [Isett 87] Results of experiments involving Knowledge-Based DSS do not always show that they help, however. Goul et al. found "no significant difference between the control group and the group using the DSS with a complete knowledge base" in their study of strategic planning. [Goul et al. 86 p. 82] The environment of the developing tactical scenario is neither that of crisis nor that of true strategic planning and will probably require something of a different approach.

C. RECOMMENDATIONS

Because TAOs will not always be able to explain what they need prior to implementation, a prototyping solution tested in-the-flesh by fleet TAOs is likely to be the most successful method of implementation. An iterative development allows the system to be honed to the razor's edge required by the TAOs of today's Navy. This prototype could be developed by students for trials in fleet exercises or inport drills in order to get a feel for how such a system would be evaluated under realistic conditions and show how such a system could be made better. Such a system could be developed using the Expert System shell NEXPERT, as determined in the final stage of this research. Naval Ocean Systems Command (NOSC) could then assume the watch in order to fully examine the work completed, make its evaluation and improvements, if any, and proceed with implementation.

A danger to be avoided in the implementation of HOTDAM! is the tendency of any bureaucracy to sometimes decide for a user what it is that the user needs and how best to provide the services required. In order to ensure the use and usefulness of a system like this, it is mandatory that the TAOs be consulted for their views at each step of the process leading to completion.

A terrible waste of money, effort, and lives could result from TAOs not using this system simply due to the fact that it does not provide what they really need. The only way to achieve this is through iterative, adaptive development. Iterative development, or prototyping, is supported in a number of the packages available for the development of Expert Systems and is specifically marketed for the Personal Consultant +, Goldworks, and NEXPERT. A possible further assurance against developing a system the TAO will not use would be to develop prototypes using each of these systems and allow TAOs to choose the one that most closely fits their needs. In doing this, though, care must be taken not to evaluate the wrong criteria. A benchmark test, for instance, tests the speed to perform a specific task, which is really not the most important factor in a developing scenario. A more appropriate test would be for the correctness of the solution regarding identity and recommended action and whether the information presented without excessive digging is the information really needed by the TAO.

The critical issue here is that a system designed to assist the TAO be appropriate for his environment and be capable of providing him the information he needs. The only way to accurately determine whether a design is good enough is to have fleet TAOs try it out in a realistic environment and let these end-users decide what it is that they need.

APPENDIX A

INTERVIEW STRUCTURE FOR TAO INTERVIEWS

DESCRIPTION: This appendix contains the questions and discussion points used for the structured interview technique to elicit the information for the analysis and design of the Decision Support System (DSS) for Tactical Action Officers (TAO). This structure is included to allow the user to view the actual questions and sequence of discussion areas used.

INTERVIEW STRUCTURE

What ship types and in what years have you served as a TAO?

FF-1052	________________
FFG-7	________________
Spruance DD	________________
Tin can	________________
Coontz DDG	________________
Kidd DDG	________________
Amphib	________________
Auxiliary	________________
CV/CVN	________________
CG/CGN	________________

How many years have you been commissioned?

How many years have you been a Surface Warfare Officer?

What, if any, combat experience do you have?

What is the level of your education?

Bachelors (Major)________Year_______

Masters (Major)________Year_______

Ph.D. (Major)________Year_______

How would you characterize your background on microcomputers (none, minimal, only on a specific program, can navigate around on them pretty well, extensive)?

How about other computers?

If a system were available that could help you narrow the possibilities about the identities of various contacts closing your ship (based on the information you or someone else enters into it), would you use it?

Do you think anyone else would?

How important a help would this be to you?

Of this list of information and services the system could provide to you, which would be the most valuable? The intent here is to have the subject rank the items in order of usefulness to him.

____Identity of the Contact

____A listing of the weapons each contact carries

____A notification when you are in a particular contact's weapons release range

____A threat ranking of the various possible contacts in the area

____A memory aid to provide feedback on what you and the computer together have determined a contact to be

____A reasoning tool for use in deciding on the identity for yourself

____An integrated package containing Rules of Engagement triggers and criteria for hostile intent

____A weapons employment advisor, to provide a suggestion about which weapon and how many of them would have the best probability of taking out a particular target

____A simple EW advisor since this data is acquired first and farthest from the contact (this would probably not provide a specific identity except in the case of unique emitters

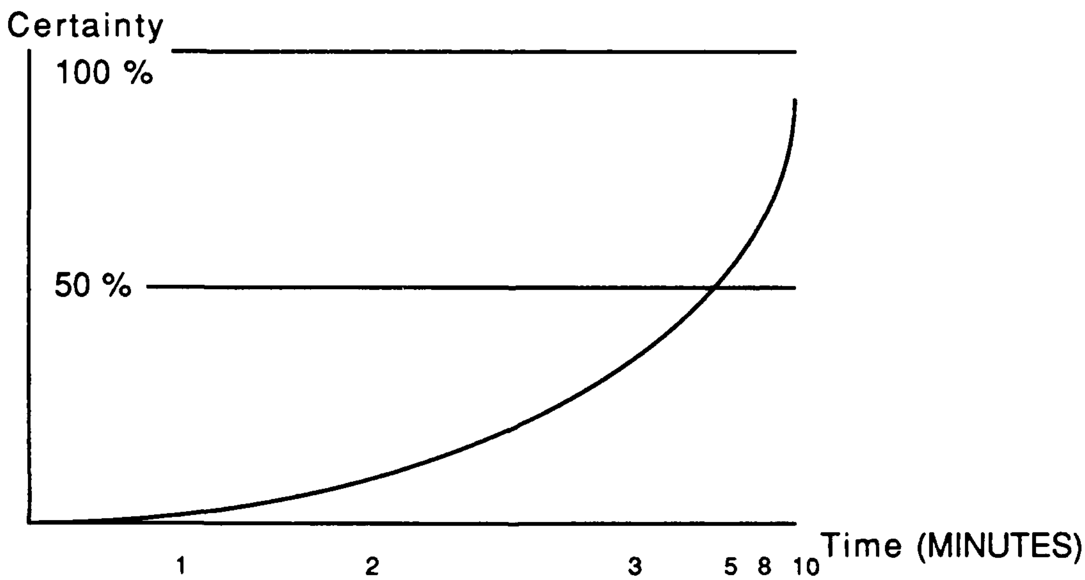
Should the system be modularized to allow viewing of only air targets, surface targets, etc.?

Or should all warfare areas always be available?

Should the system also have the capability to permit the TAO to start from an educated guess (i.e., an intel report), then prompt the TAO for further data to confirm or deny the contact identification?

Should the search allow for the pursuit of every possibility to prevent a false identification or should it permit the fastest possible conclusion? Imagine a typical identification scenario for an unknown ship.

Based on the following tradeoff chart, where would you be willing to have this system operate between certainty of the conclusion (in percent) and time to figure (in minutes)?



Should the system allow the used to change already entered data if it turns out to be wrong (without having to begin the whole process all over again) and proceed with a new set of rules?

For instance, if your EW information turned out to be a misidentification, do you want to be able to change it and leave the rest of the information the same and run the same contact?

Should the system be platform-specific to allow for the various characteristics of the different sensors (such as typical radar detection range) aboard the various friendly ships which will use such a system?

What is the optimal number of contacts for the system to hold and keep track of for the TAO and computer to work on together? Please keep in mind the tactical situations in which you found it most difficult to keep track of the developing situation.

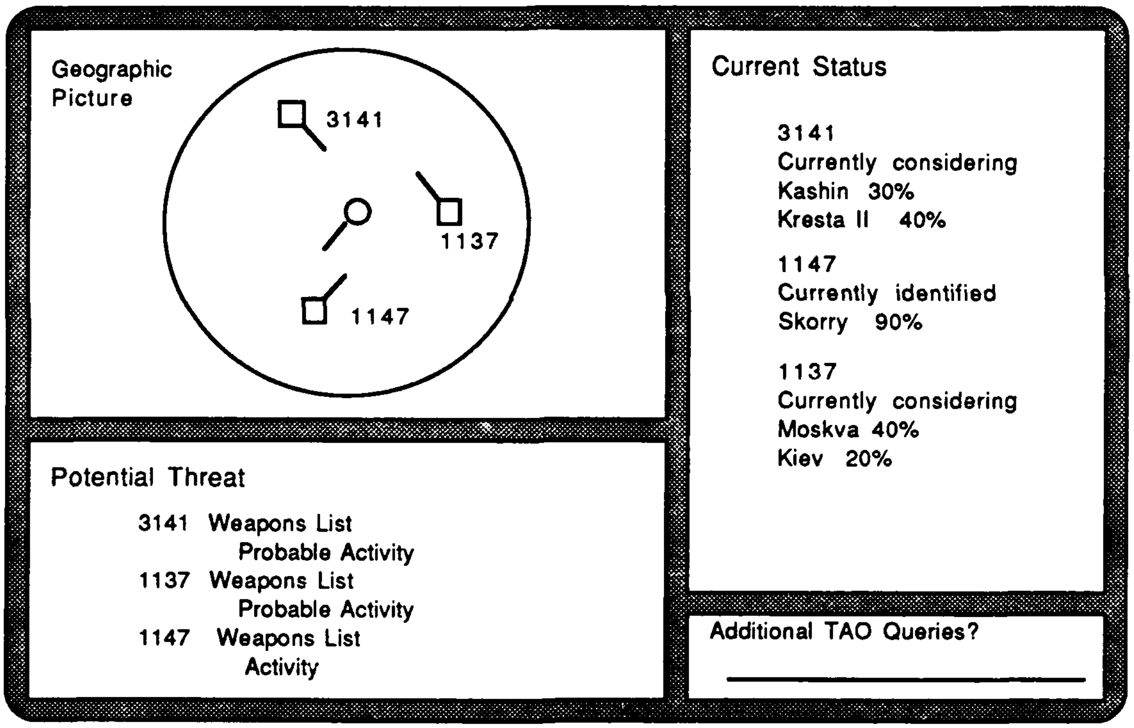
5 7 9 11 13 25 50 100

Why?

How would you as a TAO find it most beneficial to talk to your computer assistant?

Are pull-down menus, windows, and icons the answer, or will they be as intimidating as an MS-DOS-like text interface?

(Here the subject is shown the attached diagram of windows and a brief description of their use is given , i.e., double click on an icon to get further amplifying data)



How much of a User's Manual would you need to get started with this system (a simple explanation of the menus and a few examples of scenarios to run)?

How detailed an instruction set should come with the system?Should a real live instructor come to demonstrate and advise for a while with each such set?

Should instruction for such a system be given at Department Head School?

How much? (none [get it on the ship], brief introduction, hands-on practice)

If such a system showed up on your ship, would you invest the time to learn to use it?

Would TAOs become too dependent on such a system and be unable to function without it (in case it went down)?

Would its use be more similar to that of NTDS (if it's working great, and if not, operations go Mode IV)?

Would this system be a help in replacing NWP-lookups for determining which ships have a certain radar combination or a certain funnel or win configuration?

Should the system require a chauffeur to free the TAO from the interface problem altogether (other than talking to the chauffeur) and permit him to focus more thoroughly on the tactical problem at hand?

Would the EWs be more likely operators for this system than the TAO? (since they have the data first, they could consult this system and report the results to the TAO).

Should the information gleaned by the system through processing the input data be automatically presented to the TAO every so often? Or should the information determined by the system be presented to the TAO only when he queries the system for it?

Should the status display give a measure of progress toward a conclusion? (Here the subject is shown a series of thermometer sort of graphs, filling up as the identity becomes more certain.)

What are the critical ranges for such information about certainty?

0-25 %

30-40 %

45-60 %

65-75 %

80-90 %

95 % and above

What should be the sequence of questions asked of the TAO?

_____ electronic warfare

_____ radar detection

_____ visual

How often may the TAO be queried for new information?

Should he simply be able to enter information in the order he receives it and WHEN he receives it?

Should a form for each contact in question be presented on the screen (which would look somewhat like a fill-in-the-blank form) into which the TAO could enter whatever data he has for that contact?

Should this be in response to some action by the TAO or chauffeur (for instance, when he gets new data), or should it be initiated by the system after a certain amount of time since the generation of a new contact or the last update to the contact?

APPENDIX B

SUPPLEMENTAL RESULTS OF INTERVIEWS CONDUCTED

DESCRIPTION: This appendix contains the remainder of the interview results not discussed in the actual text of this thesis. These data are included to allow a complete review of the results by the reader. This permits an independent evaluation of the project.

VALUE TO THE TAO OF SERVICES PROVIDED

The data represented below is the number of incidents of a certain ranking for each of the services or information the TAOs were asked to prioritize in value of that particular service/information to them. The numbers to the right of the double line indicate the number of TAOs who assigned the service provided by the system the priority indicated in the leftmost column. For instance, four respondents indicated that the system's ability to provide the identity of the contact was highest priority (indicated by the 1 in the left column).

Priority (1-high 9-low)	Identity of Contact	Weapons Listing	Within Weapons Release Range	Threat Ranking	Memory Aid	Reasoning Tool	ROE Triggers/ Hostile Intent	Weapons Employ-ment Advisor	Simple EW Advisor
1	4	0	3	1	0	1	2	1	1
2	2	3	2	3	0	0	2	0	0
3	0	3	1	5	0	1	0	0	1
4	2	2	3	0	1	1	1	1	0
5	1	1	1	1	0	0	2	5	0
6	1	1	1	1	1	3	1	2	0
7	0	0	0	0	3	0	4	1	3
8	1	1	0	0	4	3	0	1	1
9	2	0	0	0	2	2	0	0	5

APPENDIX C

SEVENTEEN EXPERT SYSTEMS SHELLS INVESTIGATED AND THE FIVE FINALISTS

DESCRIPTION: The following seventeen names are the expert systems which made it through the initial screening and which were further investigated to determine the five finalists, which are listed below with their corporate makers and the addresses of the makers.

The seventeen systems which made it through the initial screening and were further researched are:

- XSYS by California Intelligence
- OPS5+ by Computer * Thought Corporation
- ESP Advisor by Expert Systems International
- Arity by Arity Corporation
- Expert Edge by Human Edge Software Co.
- Expert-Ease by Expert Systems Incorporated
- EXSYS by EXSYS, Inc.
- TIMM (The Intelligent Machine Model) by General Research
- Insight 2+ by Level Five Research, Inc.
- Guru by Micro Data Base Systems, Inc.

- Advisor by Ultimate Media
- Insight by Jeffrey Perrone and Associates, Inc.
- M.1 by Teknowledge, Inc.
- SuperExpert by Softsync, Inc.
- PC Scheme by Texas Instruments
- Personal Consultant+ by Texas Instruments
- Goldworks by Gold Hill Computers, Inc.
- NEXPERT by Neuron Data, Inc.

The five systems which checked out for having the ability to match the criteria determined for the design of HOTDAM! are:

- XSYS by California Intellige
  912 Powell St.
  Suite 8
  San Francisco, CA
  94108

- Personal Consultant+ by Texas Instruments
  P. O. Box 655012, Mail Station 57
  Dallas, TX
  75265

- M.1 by Teknowledge, Inc.
  525 University Ave.
  Palo Alto, CA
  94301

- Goldworks by Gold Hill Computers, Inc.
  163 Harvard St.
  Cambridge, MA
  02139

- NEXPERT by Neuron Data, Inc.
  444 High Street
  Palo Alto, CA
  94301

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