Technical Report
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DECISION AIDS FOR NAVAL AIR ASW

15 March 1980

Submitted to:
Human Factors Engineering Division
Naval Air Development Center
Warminster, PA 18974

and

Engineering Psychology Programs
Office of Naval Research
Arlington, VA 22217

Contract No. N00014-78-C-0743
Work Unit NR 199-003

Wayne W. Zachary

ANALYTICS
2500 MARYLAND ROAD, WILLOW GROVE, PA. 19090

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This report examines the applicability of a variety of decision aiding techniques to operation decision situations encountered in Naval Air Anti-Submarine Warfare (ASW). Decisions performed by the Tactical Coordinator (TACCO) in the three major Navy air ASW platforms -- P-3C, S-3A, and LAMPS MK-III -- are examined and synthesized into six decision making situations. These six situations are Lost Contact Reacquisition, Contact Classification/Verification, On-Station Search, Localization, Surveillance Tracking, and Attack Planning. They represent distinct decision making contexts in which specific → over

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) mission objectives are sought.

A method for prioritizing these decision situations for decision and construction is developed and applied. The prioritization methodology considers both the workload of the TACCO during a decision situation and the positional importance of a situation resulting from the sequential interdependencies of the situations in the ASW mission. The application of the methodology results in the prioritization indicated by the ordering of the decision situations as listed above.

A survey of numerous decision aids and a detailed analysis of 15 military decision aids results in the development of a six category taxonomy of decision aiding techniques. It is shown that while the aids surveyed and analyzed are not directly applicable per se to Naval Air ASW decision aiding, the individual techniques of which they are composed are general and can be applied independently and in combination to aid a variety of specific air ASW decision situations.

Possible combinations of techniques that could be applied to aid each of the decision situations are determined by matching the decision aiding techniques from the taxonomy to the detailed descriptions of the decision situations. The matching of techniques to situations is facilitated by the development of a descriptive framework for the decision situations. The categories in this framework chosen so as to uncover the aspects of the situations most amenable to decision aiding by the techniques in the taxonomy.

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EXECUTIVE SUMMARY

A variety of techniques to assist the military decision makers have been developed under the sponsorship of ONR, DARPA, and others. The objective of this effort has been to determine the applicability of these techniques to operational decision situations encountered in Naval Air Anti-Submarine Warfare (ASW). The environments in which the three major Navy ASW platforms (the P-3C, S-3A, and LAMPS MK III) operator was reviewed, and documentation on each of the platforms was analyzed. Primary attention was given to the Tactical Coordinator (TACCO), who is responsible for integrating all decisions made by other crew members into a tactical plan for the mission. A series of operator tasks associated with accomplishing specific mission function were identified and from them a set of situations that represent major decision aiding needs common to all three platforms were then synthesized. A method for prioritizing these decision situations for decision aid construction was developed and applied.

The analysis indicated the need for decision aids in six decision making situations that arise in the course of an air ASW mission. These situations are:

- Lost-Contact Reacquisition
- Contact Classification/Verification
- On-Station Search
- Localization
- Surveillance Tracking
- Attack Planning

The prioritization methodology developed included both the workload of the TACCO during a decision situation and the positional importance of a situation resulting from the sequential interdependencies of the situations in the ASW mission. The application of the methodology to the identified decision situations resulted in the prioritization indicated by the ordering of the decision situations shown above.

A survey of numerous decision aids and a detailed analysis of 15 military decision aids resulted in the development of a six category taxonomy of decision aiding techniques. It was found that while the aids surveyed and analyzed are not themselves directly applicable to Naval Air ASW decision aiding, the individual techniques of which they are composed are very general and could be applied independently and in combination to aid a variety of specific air ASW decision situations.

Possible combinations of techniques that could be applied to aid each of the decision situations were determined by matching the decision aiding techniques from the taxonomy to the detailed descriptions of the decision situations. The matching of techniques to situations was facilitated by the development of a descriptive framework for the decision situations. The categories in this framework were chosen so as to uncover the aspects of the situations that are most amenable to decision aiding by the techniques in the taxonomy.

This effort has resulted in five primary products:

(1) An *identification* and *prioritization* of current decision aiding needs in Naval Air ASW.

(2) A *framework* for decomposing and describing the decision problems central to each decision situation,

(3) A *taxonomy* of decision aiding techniques, based on the decision aiding functions performed by the various techniques,

(4) A *methodology* for matching decision aiding techniques with aspects of a decision situation as a means of determining the necessary elemsnts of a decision aid for the situation, and

(5) A *determination* of the decision aiding techniques applicable to aiding each of six Naval Air ASW decision situations.

The effort has also resulted in considerable clarification of the relationships among decisions, decision aids, and decision aiding techniques. *Decisions* were found to be strongly influenced by the context in which they must be made. Contextual constraints on decision making most often come in the form of tradeoffs among related decisions that must be made in order to allow some overall situational goal to be met. *Decision aids* were found to be very closely tied to specific problems as a result of these contextual considerations. Because the context of decision making necessarily changes from situation to situation, decision aids have a low level of generality. Decision aids were also found to consist of not one but rather many individual *decision aiding techniques* which, unlike the aids themselves, *do* reflect a high degree of generality. Thus, even though a specific decision might be of a highly general nature, its context places constraints on it which require a highly specific (i.e. non-general) decision aid. Similarly, the need for specificity in decision aids ties the highly general techniques of which a decision aid is composed into a restricted application framework. The incorporation of these relationships into the process of decision aid design present significant challenges to the decision aiding community. This effort indicates where the efforts of that community can best be directed for the benefit of Naval Air ASW.

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1. INTRODUCTION

The increasing speed and capabilities of digital computer systems, coupled with the increasing informational demands imposed on operators by complex control systems, has spurred intense interest in the development of decision aiding systems. In military systems, where available information varies from very incomplete and tenuous to complete and highly detailed, and where individual decisions have enormous consequences in life and property, such decision aiding systems are becoming imperative. In recognition of this need, ONR, DARPA, and others have sponsored a large number of efforts directed toward the development of viable decision aiding technologies. The objective of this effort was to determine where decision aiding is most needed in naval air ASW and which technologies or techniques are most capable of providing the needed decision aiding.

1.1 SCOPE

In order to meet this objective, it was necessary to establish some bounds for the study. First, the time frame of interest was restricted to the 1980-1985 period. Naval air systems that will be operational in this period are either currently operational or in a sufficiently final stage of the development cycle that concrete assessment of their capabilities and functions can be made. Second, only problems common to *all* naval air ASW platforms that would be operational in the 1980-1985 time frame were considered. This was done to aim the study at the overall or general decision aiding needs of the air ASW community in that time frame. Third, the focus of the study was placed on the decision making functions of the tactical coordinator (TACCO). While all members of air ASW crews have decision making roles, it is the explicit function of the TACCO to coordinate the decisions and efforts of the other crewmembers into tactical plans of action. Thus, the remainder of this report is concerned with the identification of decision aiding technologies that could be relevant to the construction of decision aids to assist the TACCO on all naval air ASW platforms that will be in operational use in the 1980-1985 time frame.

1.2 OVERVIEW

There are six sections in the remainder of this report. Section 2 discusses the various ASW platforms identified as relevant to the study, and from an analysis of the structure of a general ASW mission identifies six decision making situations for which the construction of decision aids is suggested. Section 3 reviews and analyzes existing decision aids and constructs a taxonomy of general decision aiding techniques. Section 4 provides more in-depth descriptions of the decision making situations identified in Section 2, along lines suggested by the taxonomy of decision aiding techniques. Section 5 matches the techniques from the taxonomy to the decision making situations to provide a "map" of the kinds of techniques that are applicable to decision aids for naval air ASW. Section 6 prioritizes the decision situations for decision aid construction. Finally, Section 7 offers conclusions and recommendations steming from the overall results of this study.

2. IDENTIFICATION OF AIR ASW DECISION SITUATIONS

This section presents analyses of naval air ASW platforms, operations and missions. These analyses served as the basis for the identification of six decision making situations, for which applicable decision aiding techniques are sought in later sections. Section 2.1 reviews the relevant platforms and operations. Section 2.2 reviews the missions these platforms undertake, and from them constructs a generalized or generic air ASW mission. In Section 2.3, the structure of this generic mission is related to decision making problems, and six key decision situations requiring decision aiding are identified. The individual decision functions which comprise these decision situations are discussed in Section 2.4, and the operator tasks which comprise each of the decision functions are discussed in Section 2.5.

2.1 ASW PLATFORMS AND OPERATIONS

Three air ASW platforms were identified as relevant to the time frame under study (1980-1985): the P-3C, and S-3A, and the LAMPS MK III. Of these, only the P-3C and S-3A are currently in the fleet, with the LAMPS MK III scheduled for operational use in the early 1980-85 period. An analysis was conducted of the equipment and capabilities of these three platforms, of the range of ASW operations currently undertaken by the fleet, and of the role of each of the platforms studied in these operations. There were two primary sources of detailed information on the individual platforms for these analyses: functional capabilities manuals, and Naval Air Training and Operation Procedure Standardization (NATOPS) manuals (References 11-13, 15, 16). Since the LAMPS MK III is not yet in the fleet, many of these documents were not available for it. The data for the LAMPS MK III platform were therefore taken from simulation studies, operational sequence diagrams, and various loading analyses, including timeline analysis and process flow analyses (Reference 14, 40-42, 63).

The results of the analysis are summarized in Appendix A. There were two principal findings from the analysis of platforms and operations:

(1) Although different equipment and nomenclature are used across the three platforms, their ASW capabilities are essentially similar. Primary differences lie in the capabilities of the air platforms themselves, with the P-3C being a long range land based platform, the S-3A being a medium range carrier-based platform, and the LAMPS MK III being a short range ship based platform.

(2) While the computational capabilities of the platforms differ, each currently possesses a large number of highly specific onboard decision aids. These aids are primarily directed toward the Tactical Coordinator or TACCO and assist him in such tasks as constructing acoustical sensor pattern, or estimating the position of targets.

The principal conclusion drawn from these findings was that the need for additional decision aids on these platforms was not at the highly specific level of the existing decision aids, but rather at a more general level, relating to that of coordinating multiple decisions to enhance overall mission achievement (see Appendix A for further details).

2.2 THE GENERIC AIR ASW MISSION

A second analysis was undertaken to detail the structure of the specific missions flown by the three platforms of interest. The goal of this analysis was to construct a profile of a generalized or generic ASW mission by uncovering the similarities among the missions flown by the various platforms. This generic mission profile could then be used to locate the points at which decision aiding was needed and the form in which it was needed.

At the most general level, all ASW missions were found to have one of two segmentary structures. In a hostile or "hot" environment, the mission segments are:

(1) Search for Contact

(2) Prosecute Contact

(3) Localize Target

(4) Attack Target

In a peacetime or "cold" environment, the mission segments are:

(1) Search for Contact

(2) Prosecute Contact

(3) Localize Target

(4) Track Target

The only difference between these two structures is that an attack may be placed in a hot environment, while the target will only be tracked in a cold environment.

The Search Segment is defined as the portion of the mission from the time the platform arrives on-station to the time a contact with a hostile target is gained. The Prosecute Segment is defined as the portion of the mission from the time the contact is gained to the time the contact is verified and classified. The Localize Segment is defined as the portion of the mission from the time contact is gained to the time the precise location, course, speed and possibly depth of the target are determined. The Attack Segment (present in hostile environments) is defined as the portion of the mission from the time the target is localized to the time an attack on it is placed. It is the period in which the criteria for an attack are gained, and a weapon is delivered toward the hostile target. Finally, the Tracking Segment (present in peacetime environments) is defined as the portion of the mission from the time the target is localized to the time the on-station portion of the mission ends. It is that period in which the surveillance is maintained on the target with regard to its position, course, depth, and speed.

In every segment after Search, the loss of the contact radically alters the mission flow in a way that is not reflected by the purely sequential structure given above. A separate but unintended segment called Lost Contact

Reacquisition, is begun when loss of contact occurs. This portion of the mission has as its goal the reestablishment of the preceding segment's initiating criterion. Although superficially similar to Search, Reacquisition has several significant differences in its deeper structure. Reacquisition begins with precise information on the target of interest, but the usefulness of this information decays as time increases. The Search Segment, by comparison, begins with little or no information on the target, but gains information about its possible locations as time progresses and the locations searched thus far prove empty. Thus, as Search proceeds the probability of success increases, while as Reacquisition proceeds, the probability of success decreases.

It is possible to construct a single generic mission-segment flow sequence which incorporates all of these contengencies. The two possible sequeces of the planned mission segments (the hot sequence which includes an Attack Segment and the cold sequence which includes a Tracking Segment) can be combined by having the Localize Segment followed by either the Attack Segment or the Tracking Segment. The unplanned Requisition Segment can be incorporated as an alternative outcome of the Localize, Tracking, and Attack Segments. The resulting structure of the Generic Air ASW Mission is shown in Figure 2-1. The mission segments are indicated by boxes, and possible unsuccessful segment outcomes which lead to no future segment are indicated by circles.

As indicated in Figure 2-1, each segment has two possible results based on the goals of that segment. When the segment goal is achieved, the result of the segment is the initiation of the next segment. When the segment goal is not achieved, the segment may continue indefinitely. For example, the Search Segment is terminated when a contact is obtained and will continue indefinitely until that goal is achieved. When it is achieved, the initiating criterion for the next segment, Prosecute, has been obtained and that segment begins.

Thus the transitions between mission segments are determined by the attainment of the goals or objective events which are specific to the individual

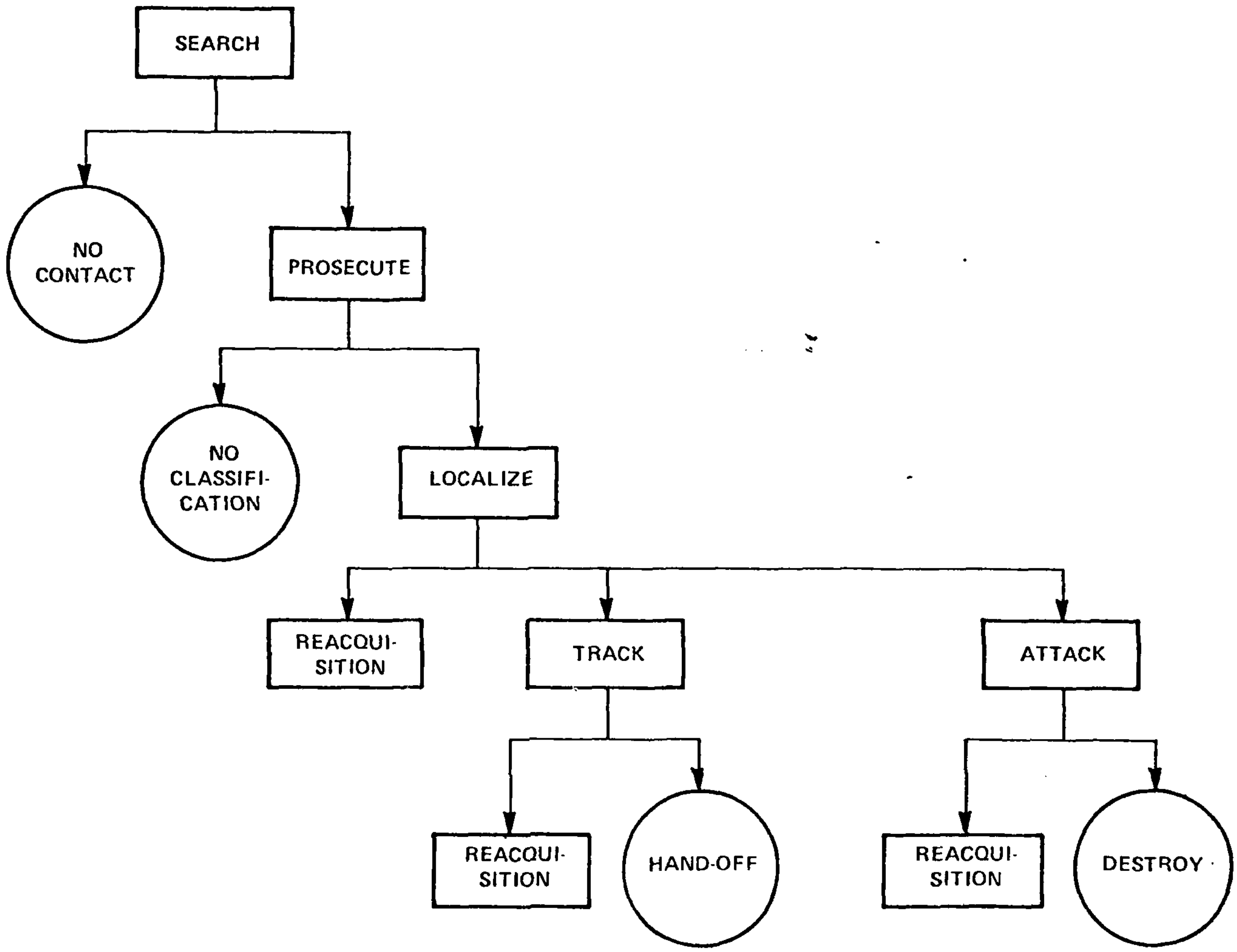

Figure 2-1. Generic Air ASW Mission Segment Flow

mission segments. For Search, the goal event is the gaining of a contact. The failure to achieve this event results in a continuation of the Search Segment. For Prosecution, the goal event is contact classification; failure to achieve this event results in continuation of that segment. Initiation of the Localize Segment, however, is not contingent upon the successful completion of the classification event, and thus can proceed in parallel with Prosecution. The goal event of the Localize Segment is the final localization of the target, but an additional segment-terminating event is also possible -- loss of the contact. Whereas the localization event would precipitate the start of the Attack or the Tracking Segments, loss of the contact precipitates the start of the Reacquisition Segment. The Tracking Segment has the goal event of surveillance tracking of the submarine. However, the attainment of this event does not end the segment, but instead allows it to continue. This segment can successfully end only with either a coordinated handoff of the target to a relief platform or the accomplishment of predetermined mission requirements (e.g. for the target to be localized to within a specified accuracy). An alterative event to the attainment of surveillance tracking is the loss of the contact. As in the Localize Segment, this event causes the start of the Reacquisition Segment. Finally, the Attack Segment has the goal event of the delivery of a weapon against the target. If the target is not destroyed by the weapon, another weapon may be delivered. However in order to deliver another weapon, the aircraft may have to return to the Localize Segment. But as in the Prosecute, Localize and Tracking Segments, the contact might be lost, resulting in the end of the Attack Segment and the initiation of the Reacquisition Segment.

The generic ASW mission can thus be thought of as a sequence of process which are terminated/separated by specific events. This process/event structure of the ASW mission is shown in Figure 2-2. Because it is not a planned part of the mission, the Reacquisition Segment, and all paths leading to it, are indicated by dashed lines. Mission segments in Figure 2-2 are indicated by boxes, events which terminate/separate mission segments are indicated by circles, and mission starting/ending events are indicated by diamonds.

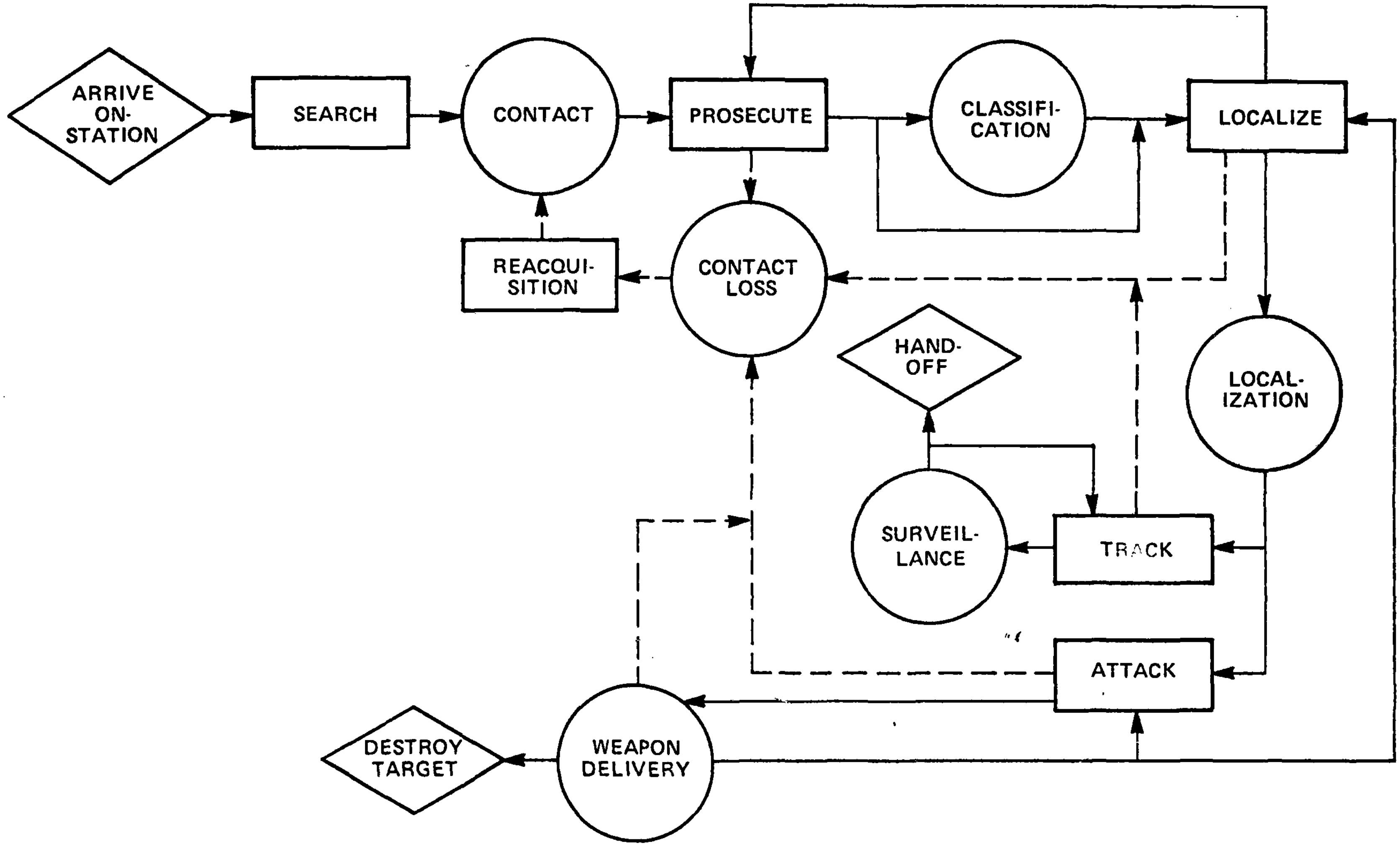

Figure 2-2. Mission Flow with Sequential Objectives and Alternatives

2.2.1 Context and Decision Making Problems

The mission structure indicated in Figure 2-2 is applicable to all the ASW platforms investigated. In order to locate the points in this generalized mission at which decision aiding was most needed, Fleet Exercise Reports, VP-TSC and CV-TSC Reports, Software Change Requests, and Program Trouble Reports were consulted (References 17-20). These documents identified operational problems encountered in the fleet and hence uncovered issues that were possibly not adequately addressed by existing equipment and procedures. As with the platform/operations analysis given in Section 2.1 and in Appendix A, data for the LAMPS MK III were taken from simulation and other analytical studies (References 14, 40-42, 63).

The review of Trouble Reports, etc., indicated that the problems encountered in operational settings dealt not with the general mission segments shown in Figures 2-1 and 2-2, but with highly detailed aspects of specific missions and specific equipment onboard the various platforms. One striking fact discovered in the review of operational problems was that similar problems (e.g., problems in equipment/stores management, or acoustical sensor pattern construction) occurred in different segments of the mission, but with different suggested solutions. Different mission segments required the performance of similar decision making functions, but to different ends. The presence of different goal events in each segment of the mission placed different demands on the TACCO as well as on the equipment (including existing decision aids) which he used, and thus required the same general decision to be made differently at different points in the mission.

When considered against the detailed decision composition of each of the mission segments (see Section 2.2.4), the issue came into clearer focus. Each segment requires many individual decision functions to be performed in order to achieve one objective event. But because the objective event changes from situation to situation, the manner in which these constituent decisions must be coordinated also changes. Certain decisions assume higher priority in some segments than others, and certain criteria become relevant to a decision in some parts of the mission and irrelevant in others. The key to identifying the kinds of decision aids needed was in the recognition that it was not the performance of the individual decision functions that posed problems, even though this was where the problems were reported. *Instead, it was the need to coordinate these decisions with other ones and relate them to some overall tactical plan for achieving the next goal event in the mission* that created the problems that were reported. Thus, the mission segments, as identified in Figure 2-2 with their goal events, do not merely subdivide the mission into temporal slices. They also provide decision making contexts or situations which define intermediate level problems in need of decision aiding. They are intermediate in that they are *more* detailed than the single high level problem of achieving the overall mission objective (destroy or track the submarine) but *less* detailed than the many low level problems of solving each individual decision function (e.g., determining the spacing for the next sonobuoy pattern) in the mission. These general decision making situations, rather than the individual decisions, were therefore selected as the basis for the analysis of decision aiding technologies in the remainder of the study.

2.3 AIR ASW DECISION SITUATIONS

A separate decision making situation was defined for each of the six mission segments identified in Figure 2-2. These were:

(1) *On-Station Search:* the selection, deployment, and coordination of sensors and sensor data to gain a contact with a hostile submarine,

(2) *Contact Classification/Verification:* the determination that a contact is valid and the classification of the contact,

(3) *Localization:* the selection, deployment and coordination of sensors and sensor data in order to determine the precise depth, course, speed and location of the hostile submarine,

(4) *Surveillance Tracking:* the selection, deployment and coordination of sensors and sensor data to maintain localized contact with a hostile submarine,

(5) *Attack Planning*: the analysis of sensor data, and target and weapon capabilities to determine the best time and location at which to place an attack on the hostile submarine, and the optimal weapon and setting to use, and

(6) *Lost Contact Reacquisition*: the utilization of previous track and historical data and the selection, deployment and coordination of sensors and sensor data to regain a contact with a hostile submarine, and determine its precise location, course, depth, and speed.

These six situations and the goal event toward which they direct decision making are listed in Table 2-1.

Table 2-1. ASW Decision Situations and Goal Events

DECISION SITUATION	GOAL EVENT
ON-STATION SEARCH	GAIN CONTACT WITH TARGET OF INTEREST
CONTACT CLASSIFICATION/VERIFICATION	IDENTIFY SOURCE OF CONTACT
LOCALIZATION	DETERMINE LOCATION, COURSE, SPEED AND DEPTH OF TARGET
SURVEILLANCE TRACKING	MAINTAIN LOCALIZED CONTACT WITH TARGET
ATTACK PLANNING	PLACE OPTIMAL ATTACK AGAINST HOSTILE TARGET
LOST CONTACT REACQUISITION	REGAIN AND LOCALIZE CONTACT WITH A LOST TARGET

2.4 DETAILED MISSION DECISION FLOW AND DECISION SITUATION COMPOSITION

The decision situation was selected as the unit of analysis because it relates many individual decision functions into a broad context for the achievement of an intermediate mission goal or event. It is thus important to identify the specific decision functions which comprise each of the six identified decision situations. To accomplish this, the mission segment flow shown in Figure

2-2 was reformulated in greater detail. Mission task functions which have a high cognitive workload for the TACCO and which also require an element of choice or selection on his part were identified as TACCO *decision functions*. The individual decision functions and their interrelationships are detailed in the mission decision flow structure shown in Figure 2-3. The rectangular boxes refer to on-platform decision functions performed by the TACCO or some other member of the air-platform crew. The ovals refer to the deployment of a specific kind of sensor and the hexagonal boxes refer to decision functions performed by the aircrew on the ground (prior to or after the mission) or to supporting functions performed by the VP-TSC or CV-TSC personnel on the ground. The individual functions identified in Figure 2-3 are discussed in the following paragraph.

Mission planning results in the determination of a search area for the mission, an estimate of the environmental (e.g., atmospheric and bathythermic) conditions in the search area and a set of equipment and stores to be used in the mission. Once on-station, the predetermined search area is obtained (search area obtension) an in-situ update of the estimated environmental conditions is undertaken and interpreted, and an initial sensor pattern for the search is constructed. This pattern will result in the deployment of acoustical and/or non-accoustical sensors. The sensors successfully deployed will then be monitored until one of four events happen. If no contact is made and no time remains on-station, the platform will return to base (if no relief platform is present) or will handoff to the relief platform (if a relief platform is present). If on-station time remains but the initial (or previous) sensor pattern has resulted in no contact and is of no further use (i.e., if it is felt that it cannot result in contact or if sonobuoys begin to expire), then the search may be extended into new areas. However, if a contact is detected, then the localization and classification portions of the mission will begin. The contact will be verified and classified. Localization tactics will be developed and applied to refine the estimates of the target's position, course, speed, and depth. These tactics will result in the deployment of active and/or passive acoustical sensors, as well as the utilization of other non-acoustical sensors.

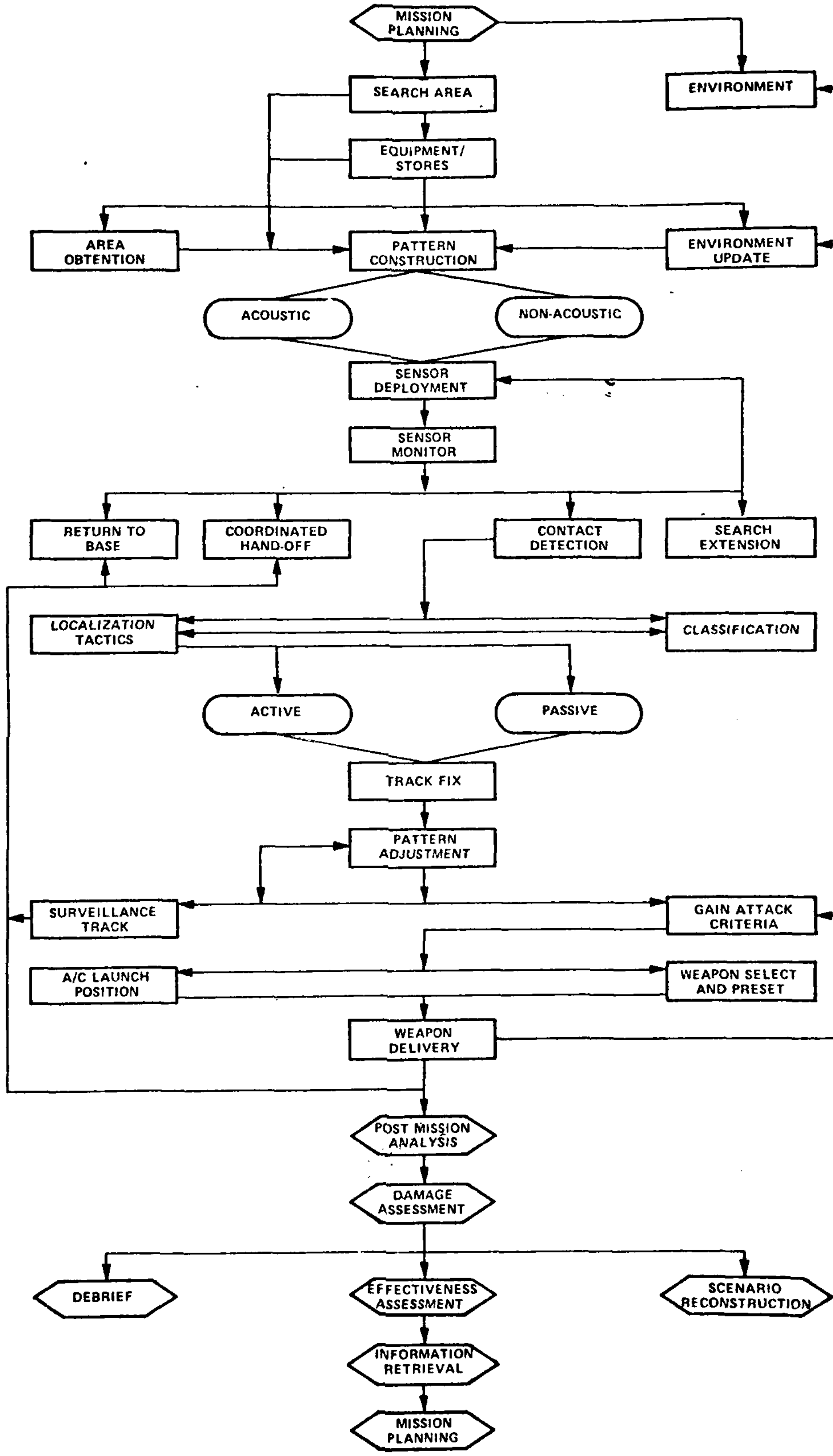

Figure 2-3. ASW Mission Decision Function Flow

If successful, these tactics will result in gaining more detailed information on the target. The sensor patterns will then be updated and adjusted until complete localization has been obtained. At this point, either surveillance tracking of the target or attack planning will commence. If no attack is to take place, the existing sensor patterns will be extended to maintain localized contact with the submarine until the on-station time is expired or the predetermined mission goal is achieved. At that time, the contact will be handed off if a relief platform is available or the ASW platform will simply return to base. If attack planning is undertaken, the information on the target's location, course, speed, and depth will be refined until they meet the criteria for an attack. Then, the optimal weapon and setting for the attack will be determined. Based on the weapons, weapon setting, the current aircraft and target positions and headings, the optimal location at which to drop the weapon will then be determined. If the attack is unsuccessful, the target movement will again be monitored until attack criteria are regained, at which time another attack will be placed. If the attack is successful, then the on-station activities against that target will be terminated. After the on-station portion of the mission, the damage inflicted on the target will be assessed, subsequent to the initial post mission analysis. The crew will be debriefed and the scenario of the prosecution and attack reconstructed. The effectiveness of the prosecution of the target will be evaluated, and this information will then be used as the basis for planning future missions.

Even though Figure 2-3 shows much more detail than Figure 2-2, it is still quite simplified. Many of the decision functions shown actually occur many times throughout the mission. The management of the equipment/stores, for example, or the consideration of in-situ environmental conditions, must take place throughout the mission. Also, Figure 2-3 proceeds as if every goal event in Figure 2-2 was achieved; paths representing failure to contact, failure to classify, or loss of contact are not shown. However, more detailed diagrams will not be presented for the simple reason that it would not result in the inclusion of a significant number of additional decision functions. For the most part, additional function boxes would not be required -- merely replications of ones already there and inclusion of additional arrows connecting them. The Lost Contact Reacquisition sequence, for example, consists of different combinations of decision functions already present in Figure 2.3. The primary purpose of Figure 2-3 is not to model every aspect of the air ASW mission, merely to show the decision functions which comprise the various decision situations, and to indicate some of their primary interrelationships.

The six decision situations identified above were reviewed to determine the individual decision functions of which each was comprised. The results of this analysis are shown in Table 2-2.

2.5 DECISION FUNCTIONS AND OPERATOR TASKS

The breakdown of each of the decision situations into a number of constituent decision functions provides the detailed logical composition of each decision situation. To provide a better picture of the decision functions from the operator's viewpoint, one final analysis of the generic mission was conducted. Each of the decision functions identified in Figure 2-3 was analyzed to determine the specific operator tasks required in order to complete it. Just as certain decision functions were found to occur in several decision situations, certain tasks were found to be required for many decision functions. The breakdown of the on-station decision functions (i.e., the rectangular boxes in Figure 2-3) according to their constituent operator tasks is shown in Table 2-3. Where a task is required by a decision function, an "x" is shown in the table. One explanatory note is required concerning the tasks listed in Table 2-3. Several of them, such as "Select Optimum Sensor Setting" may give the appearance of being decision functions themselves, but this is not the case. These tasks can be deterministically performed by standard procedures when adequate data are present and do not really embody an element of choice for the operator. These tasks are therefore really no more than computation or calculation operations. The tasks shown Table 2-3 were derived from Reference 64 (the Acoustic Performance Prediction (APP) System Informational Requirements). This document analyzed the ASW mission phases relevant to all three ASW aircraft considered here (P-3C, S-3A, and LAMPS MK III) and identified the decision functions performed in each mission phase for each platform.

Table 2-2. Constituent Decision Functions of Decision Situations

DECISION SITUATION	CONSTITUENT DECISION FUNCTIONS
ON-STATION SEARCH	SEARCH AREA ENVIRONMENT EQUIPMENT/STORES AREA OBTENTION PATTERN CONSTRUCTION ENVIRONMENT UPDATE SENSOR DEPLOYMENT SEARCH EXTENSION
CONTACT CLASSIFICATION/ VERIFICATION	SENSOR MONITOR CONTACT DETECTION CLASSIFICATION PATTERN ADJUSTMENT
LOCALIZATION	ENVIRONMENT EQUIPMENT/STORES ENVIRONMENT UPDATE LOCALIZATION TACTICS TRACK FIX PATTERN ADJUSTMENT
LOST CONTACT REACQUISITION	ENVIRONMENT EQUIPMENT/STORES ENVIRONMENT UPDATE SENSOR DEPLOYMENT SEARCH EXTENSION CLASSIFICATION TRACK FIX
SURVEILLANCE TRACKING	ENVIRONMENT EQUIPMENT/STORES ENVIRONMENT UPDATE SENSOR DEPLOYMENT SENSOR MONITOR TRACK FIX PATTERN ADJUSTMENT COORDINATED HAND-OFF
ATTACK PLANNING	ENVIRONMENT EQUIPMENT/STORES ENVIRONMENT UPDATE TRACK FIX GAIN ATTACK CRITERIA AIRCRAFT LAUNCH POSITION WEAPON SELECT AND PRESET WEAPON DELIVERY

Table 2-3. Operator Tasks Involved in ASW Decision Functions

OPERATOR TASKS \ DECISION FUNCTIONS	Search Area	Environment	Equipment/Stores	Area Obtention	Pattern Construction	Environment Update	Sensor Deployment	Sensor Monitor	Return-to-Base	Coordinated Hand-off	Contact Detection	Search Extension	Localization Tactics	Classification	Track Fix	Pattern Adjustment	Surveillance Track	Gain Attack Criteria	A/C Launch Position	Weapon Select and Preset	Weapon Delivery
Determine optimum flight routing	X			X																	
Determine enroute weather																					
Review predicted acoustic propagation	X	X			X	X	X	X				X	X			X	X			X	
Develop preflighted sonobuoy patterns	X	X			X	X	X	X				X	X		X	X	X	X			
Maintain stores inventory	X		X		X		X					X	X		X	X	X				
Develop preflight non-acoustic patterns	X	X			X		X	X				X	X			X	X	X			
Generate in-situ propagation loss					X	X	X	X			X	X	X		X	X	X	X		X	
Maintain non-acoustic sensor integration	X		X		X	X	X	X			X	X	X			X	X	X			
Maintain acoustic sensor integration	X		X		X	X	X	X			X	X	X			X	X	X			
Select optimum sensor setting	X				X	X	X	X			X	X	X		X	X	X				
Select optimum acoustic pattern	X		X		X	X		X				X	X		X	X	X	X			
Select optimum non-acoustic pattern	X		X		X	X		X				X	X		X	X	X	X			
Establish aircraft track				X	X		X		X	X		X	X			X	X		X		X
Activate sensors							X	X				X	X			X	X				
Monitor sensors according to plan							X	X				X	X	X	X	X	X	X			
Extract signals from noise											X			X	X			X			
Correlate signals to sources											X			X	X		X	X			
Perform target isolation											X			X	X		X	X			
Classify targets from signals											X			X	X			X			
Update in-situ environment					X		X	X				X	X		X	X		X		X	
Compare target signal with library											X			X			X				

Table 2-3. Operator Tasks Involved in ASW Decision Functions (Continued)

DECISION FUNCTIONS / OPERATOR TASKS	Search Area	Environment	Equipment/Stores	Area Obtention	Pattern Construction	Environment Update	Sensor Deployment	Sensor Monitor	Return-to-Base	Coordinated Hand-off	Contact Detection	Search Extension	Localization Tactics	Classification	Track Fix	Pattern Adjustment	Surveillance Track	Gain Attack Criteria	A/C Launch Position	Weapon Select and Preset	Weapon Delivery
Determine contact threat													X	X		X	X	X			
Determine contact evasion envelope													X	X	X	X	X	X			
Compute target range and bearing													X		X	X	X	X			
Recognize CPA													X	X	X	X	X	X			
Establish direct path/convergence zone											X	X	X		X	X					
Select new sonobuoy type					X		X					X	X		X	X	X	X			
Recognize DIFAR/ESM bearings											X		X		X	X	X	X			
Determine probability area for target					X		X					X	X		X	X	X	X			X
Establish target fix													X		X	X	X	X			X
Correlate bearings from target														X	X	X	X	X			
Display target position													X		X	X	X	X			X
Generate target course/speed													X	X	X	X	X	X		X	X
Determine target depth													X	X	X	X	X	X		X	X
Establish weapon setting																				X	X
Maintain weapon inventory																				X	X
Utilize TMA techniques													X	X	X	X	X	X			
Retain contact with target													X		X	X	X	X			X
Determine A/C restrictions					X		X	X				X	X			X	X	X	X		X
Determine weapon envelope																			X	X	X
Control weapon																					X

3. DECISION AIDS AND DECISION AIDING TECHNIQUES

The initial step in determining the decision aiding techniques that are relevant to aiding each of the six decision situations identified in Section 2 is the identification of the state-of-the-art decision aiding techniques themselves. To accomplish this, existing decision aids were reviewed and analyzed. This review, described in Sections 3.1 and 3.2 below, led to the identification of numerous decision aiding techniques, and a functional scheme for classifying them. The classification, or taxonomy, is described in Section 3.3. To allow the techniques identified to be compared with one another, nine critical dimensions were identified and the aids compared across them. This is discussed in Section 3.4. Finally, the ways in which the individual techniques relate to the decision making process are discussed in Section 3.5.

3.1 REVIEW OF DECISION AIDS

A variety of decision aids were identified and reviewed in order to determine the range, type and characteristics of current decision aiding technology. The aids studied were identified from several sources, including literature reviews of holdings in:

- Defense Documentation Center (DDC)
- National Technical Information Service (NTIS)
- Psychological Abstracts
- Management Citations

The bibliography presents a complete listing of the relevant decision aiding literature located through these services. The decision aiding systems reviewed range from those that deal with decision making in general to those that deal with specific military problems. Nearly 20 percent of the references cited relate specifically to ASW. Most of the decision aids were sponsored by the Office of Naval Research, the Naval Air Development Center, the Defense Advanced Research Projects Agency, or the Air Force.

In addition to the literature review, a number of decision aids developed for private industry were also consulted, as were surveys, overview papers, and reports on decision aiding, particularly Sinaiko (1977), and Glenn and Zachary (1979). From this body of literature, 15 decision aids which dealt with specific military problems were selected for detailed investigation. This was done to narrow the focus of the study to military decision-making. The decision problems addressed by each of the 15 decision aids studied are described in Table 3-1.

Table 3-1. Summary of Decision Aids Reviewed

DECISION AID	DEVELOPER	DECISION PROBLEM ADDRESSED
ADA (Adaptive Decision Aid)	Perceptronics, Inc.	Sonobuoy Pattern Selection in Air ASW Surveillance Tracking[1]
AHAB (Attacking Hardened Air Bases)	RAND Corporation	Determining Strike Force Composition in AAW
ASTDA (Air Strike Timing Decision Aid)	Analytics	Choosing Time to Launch Carrier-Based Air Strike
ASW Search Director	Calspan Corporation	Identifying Target Uncertainty Area in Air ASW
AZOI (Algorithm for Zone Optimization Investigation)	NADC	Developing Sonobuoy Pattern for Air ASW Search
DAISY (Decision Aiding Information System)	Wharton School, Univ. of Pennsylvania	Interface Decision Maker with Database(s), Specific Models and Decision Aids, and Predefine Decision Structures
Decision Structuring Aid	SRI International	Identifying Alternatives and Intervening Factors in Decision Problem Formulation
EWAR (Electronic Warfare Decision Aid)	Decision Science Associates	Constructing and Evaluating Task Force Emission Control (EMCON) Plans
Execution Aid	Decisions and Designs, Inc.	Determining Enemy Intent[1]
JUDGE (Judged Utility Decision Generator)	RAND Corporation	Allocating Aircraft for Nonpreplanned Close Air Support Missions
Options Selection Matrix	Grumman Aerospace Corporation	Selecting a Ship for Tattletail Mission[1]
Route Planner	Integrated Sciences Corporation	Selecting Air Ingress Route to Target through Multiple-Radar Detection Field
SOC (Strike Outcome Calculator)	SRI International	Constructing and Evaluating Carrier-Based Air-Strike Campaign Operation Plans
TASDA (Tactical ASW Decision Aid)	NADC	Developing Sonobuoy Pattern for Air ASW Search
WAND (Wharton Alerting Network Database)	Wharton School, Univ. of Pennsylvania	Continuous Monitoring of Dynamic Databases/ Datastreams for Anomalous Occurrences

[1] This is the specific problem for which the aid was developed; however, it is easily adapted to other similar problems.

Each of the aids in Table 3-1 is described below in terms of the main technological features it contains. The features are listed in order of their assumed importance to the usefulness of that aid. Within the description of each feature, certain key words/phrases which summarize that feature are italized.

3.1.1 Adaptive Decision Aid (ADA) -- Perceptronics

- Implicit and *adaptive measurement of* a decision maker's *(multi-attribute) utility function* through observations of actual decision making behavior.
- *Artificial intelligence* sequential pattern recognition *algorithm* for reconstructing the decision maker's utility functions.
- *Adaptive prediction* of the decision maker's next choice in a sequential decision task using an inferred multi-attribute utility model.

3.1.2 Attacking Hardened Air Bases (AHAB) -- Rand Corporation

- A *Monte-Carlo simulation model* of an air strike against a defended air base including air-to-ground and ground-to-air engagements incorporating both input uncertainty and process uncertainty (i.e., uncertainty inherent in the process) in predicting output uncertainty.
- A *multi-attribute utility model* based on the number of aircraft lost by both sides, the number of enemy hangars destroyed and the amount of time the enemy airfield runway is closed because of the strike.

3.1.3 Air Strike Timing Decision Aid (ASTDA) -- Analytics

- A *Monte-Carlo simulation model* of a complex air-to-air, air-to-ground, and ground-to-air engagement, incorporating both input uncertainty and process uncertainty in predicting output uncertainty.

- A *multi-attribute utility model* based on all the unit-specific losses incurred by both sides in the simulated engagement.

- *Graphic displays* of model output and inputs which indicate the *uncertainty* associated with each variable.

3.1.4 ASW Search Director -- Calspan Corporation

- A *probabilistic model* of the detection of a target in a passive sonobuoy field over time given an initial SOSUS datum.

- *Graphic display* presenting the uncertainty area of the target.

3.1.5 Algorithm for Zone Optimization Investigation (AZOI) -- Naval Air Development Center

- A statistically filtered *non-linear optimization algorithm* based on the Fibbonacci search method that determines the optimal spacing, orientation, and distance for a passive sonobuoy pattern.

- *Monte-Carlo simulation model* incorporating input uncertainty to estimate the probability of detection of a given threat.

3.1.6 Judged Utility Decision Generator (JUDGE) -- Rand Corporation

- A *dynamic programming algorithm* for predicting the cost of launching close air support sorties by minimizing the loss of future capabilities.

- A *nonlinear value model* which determines the utility of launching a number of sorties in response to a request for close air support.

- An *information processing algorithm* which schedules sorties by maximizing the overall differences between the benefit (value) of launching a sortie and the cost.

3.1.7 Decision Aiding Information System (DAISY) -- University of Pennsylvania

- A *multiple window display* format allowing simultaneous use of and communication with multiple decision aiding functions.

- *Data base* and *management* facilities for both relational and network data bases.

I

3.1.8 Decision Structuring Aid -- SRI International

- Natural language based *algorithm for eliciting decision tree structures.*

- *Algorithm* for combining decision branch probabilities and terminal node utilities and "rolling" them back up the tree *to determine the portion of the tree* that it would be most useful *to expand.*

3.1.9 Electronic Warfare Decision Aid (EWAR) -- Decision Science Corporation

- Flexible *management* of large volume of *information* on the task force, its emitters, and the EMCON plan(s).

- *Algorithms* that estimate the amount and type of information given away to the enemy by the task force EMCON plan.

- A *probablistic engagement model* which (assuming no input or process uncertainty) predicts the task force damage resulting from a user-defined type of enemy strike.

3.1.10 Execution Aid (DDI "Triangle" Aid) -- Decisions and Designs, Inc.

- Use of human judgment data and independent indicator variables in a *Bayesian updating* algorithm.

- *Graphic display techniques* based on a tripolar projection for indicating a course of action recommended by the aid or a state of the world inferred by the aid.

- *Multiattribute utility model* based on factors of weather, own readiness, and enemy readiness, with enemy intent as a parameter.

3.1.11 Option Selection Matrix -- Grumman Aerospace

- *Graphic display* of input information.

- An *information processing algorithm* for combining user-weighted problem considerations across alternatives into a rank-ordering of the desirability of each alternative.

3.1.12 Route Planner -- Integrated Sciences Corporation

- *Non-linear* and *dynamic programming optimization algorithms* which determine the local optimum of a user-suggested candidate route (i.e., the operator-aided optimization method).

- Use of *interactive color graphic methods* to enter/display route geography.

3.1.13 Strike Outcome Calculator (SOC) -- SRI International

- A *deterministic* air strike *campaign simulator* which models prolonged carrier-based air campaigns through a series of sub-process models, including deterministic models of carrier, airfield, and aircraft repair/resupply, launch/landing of aircraft, and air-to-air, air-to-ground, and ground-to-air engagements.

3.1.14 Tactical ASW Decision Aid (TASDA) -- Naval Air Development Center

- A *Monte-Carlo simulation model* of a single enemy target moving through a passive sonobuoy pattern, incorporating both input and process uncertainty to predict a variety of measures of effectiveness of the sonobuoy pattern.

3.1.15 Wharton Alerting Network Data Base (WAND) -- University of Pennsylvania

- User-defined *alerters which* passively *monitor* a dynamic *data base* for specified conditions.

3.1.16 Conclusions from Decision Aid Review

While it had been initially expected that existing aids could easily be modified and adapted to the six decision situations identified in Chapter 2, this proved not to be the case. Most of the aids reviewed are "hard wired" by the content of their models, algorithms, etc. to the specific problems they address. The few aids that are more general are really applicable only to general problems of a certain *type*, such as decision-tree structuring, or three-attribute inference problems. The review of these state-of-the art decision aids also pointed out that there is not a one-to-one correspondence between decision aids and decision aiding techniques. Each aid was found to incorporate a number of different techniques to achieve its goal. However a number of these constituent techniques were found in several of the aids, indicating that those techniques, in the abstract, might be quite general. This, coupled with the fact that the whole aids were *not* general, suggested that it is more appropriate to match the constituent *techniques* with the *situations* rather than attempt to match whole *aids* with decision *situations*.

One final conclusion was obtained from the review of the existing decision aids was that different techniques fulfilled similar functions in different decision aids. Both Monte-Carlo and deterministic simulations, for example, have been used to predict the outcomes of real-time processes. This suggested that there were actually substantially fewer *functional categories* of techniques than specific techniques. The different techniques in a functional category can be thought of as being functionally equivalent in the general case. The matching of techniques to situations will focus on these broader, functional categories, rather than on the individual techniques, to structure and simplify the matching task.

3.2 CATEGORIES OF DECISION-AIDING TECHNIQUES

The identification of the individual constituent decision aiding techniques described above resulted in the creation of a number of functional categories of decision aiding techniques.

Six specific functional categories of decision aiding techniques were identified:

(1) Outcome Calculators

(2) Value Models

(3) Data Control Techniques

(4) Analysis Techniques

(5) Display/Data Entry Techniques

(6) Human Judgment Amplifying/Refining Techniques

Each of these categories is discussed in greater detail below.

3.2.1 Outcome Calculators

Outcome calculators are algorithmic or mathematical models which calculate or predict the outcome of a real-world process, i.e., a situation which unfolds over real time. Outcome calculators are useful in problems where the decision maker has only partial or no control over the outcome of the process. These situations are common in ASW. For example, in an engagement, the decision maker controls the actions of his own forces, but cannot control those of the enemy; in search operations, the decision maker controls his search methods, but cannot control the evasive actions of the opponent. In such situations, outcome calculators may be used to predict the result of the process given a proposed course of action and an estimate or set of alternative estimates concerning the possible actions of the enemy.

Two independent features distinguish the four types of outcome calculators as shown in Table 3-2. The first is a deterministic/stochastic distinction. Outcome calculators which are *deterministic* produce fixed value outputs from fixed value inputs while *stochastic* outcome calculators produce distributions of outputs from distributions of inputs. The second feature is mechanical/analytic. *Analytic* outcome calculators model only the relationship between input and output, directly producing the latter from the former through a transfer function. Analytic calculators do not model the process itself. *Mechanical* outcome calculators model the step-by-step process through which the inputs are transformed into the outputs.

3.2.2 Value Models

Value or utility models are mappings from a description space of outcomes and subjective tastes of decision makers onto a unidimensional scale of value. In general, a value model may be thought of as a function of many variables, in which each of the independent variables represents some key attribute of a possible course of action. Since an action could be evaluated on any one of these attributes, each represents a potential decision criteria. The value model combines the different decision criteria into a single scale on which all possible courses of action can be evaluated. A value model may incorporate the subjective preferences of the decision maker or may simply operate as a rule for combining attributes.

3.2.5 Display/Data Entry Techniques

Data display and entry plays a critical role in all interactive computer systems and there is a large literature on the available technologies. However, a number of specialized display/entry techniques have been developed or given special application just for decision aiding systems. These are the techniques included under this category.

3.2.6 Human Judgment Amplifying/Refining

These are techniques which make use of both the human decision maker and computational algorithms to achieve a single result. The human provides subjective and/or intuition-based judgments to the algorithms, which then either refines their accuracy or amplifies their scope. The interaction between the algorithm and the man is most frequently iterative.

3.3 TAXONOMY OF DECISION-AIDING TECHNIQUES

The individual decision aiding techniques (shown in italics in Sections 3.1.1 to 3.1.15) were reviewed and assigned to one of the above six functional categories to create a taxonomy or classification of the state of the art decision aiding technique. In several cases, the techniques were subdivided into finer categories. For example, *optimization* techniques were assigned to the "analysis techniques" category of the taxonomy, but were subdivided into more precise categories such as *linear programming, nonlinear programming, dynamic programming,* etc. The completed taxonomy is shown in Table 3-3. Each of the separate techniques on the taxonomy is described in more detail in Appendix B. The taxonomy will serve as the basis for matching the individual techniques to the six ASW decision situations.

3.4 CHARACTERISTICS OF DECISION AIDING TECHNIQUES

Many of the techniques within each of the six categories in the taxonomy represent only different means to the same end. Techniques which are capable of producing analogous outputs from identical inputs are, at least from a systems point-of-view, equivalent. Stochastic processes, for example, may be modeled with either a Monte-Carlo simulation or a closed-form probabilistic type

Table 3-3. Taxonomy of Decision Aiding Techniques

1. OUTCOME CALCULATOR
   - 1.1 Closed Form Analytic Models
   - 1.2 Probabilistic Models
   - 1.3 Deterministic Simulations
     - 1.3.1 Mechanical
     - 1.3.2 Differential Equation
   - 1.4 Monte-Carlo Simulations

2. VALUE MODEL
   - 2.1 Multi-Attribute Utility Model (MAUM)
   - 2.2 Adaptively Constructed MAUM
   - 2.3 Direct Assignment of Utilities to Outcomes
   - 2.4 Risk-Incorporating Utility Models
   - 2.5 Non-Linear Utility Model

3. DATA CONTROL
   - 3.1 Automatic Data Aggregation
   - 3.2 Data Management Techniques

4. ANALYSIS
   - 4.1 Optimization Techniques
     - 4.1.1 Linear Programming
     - 4.1.2 Non-Linear Programming
     - 4.1.3 Dynamic Programming
     - 4.1.4 Fibbonaci Search
     - 4.1.5 Response Surface Methodology
   - 4.2 Artificial Intelligence Techniques
     - 4.2.1 Heuristic Search
     - 4.2.2 Bayesian Pattern Recognition
   - 4.3 Sensitivity Analysis
   - 4.4 Intra-Process Analysis
   - 4.5 Information Processing Algorithms
   - 4.6 Status Monitor and Alert
   - 4.7 Statistical Analysis
     - 4.7.1 Distribution Comparison
     - 4.7.2 Regression-Correlation
     - 4.7.3 Discriminant Analysis
     - 4.7.4 Bayesian Updating

5. DISPLAY/DATA ENTRY
   - 5.1 Display Graphics
   - 5.2 Interactive Graphics
   - 5.3 Windowing
   - 5.4 Speech Synthesis/Recognition
   - 5.5 Quickening

6. HUMAN JUDGMENT REFINEMENT/ AMPLIFICATION
   - 6.1 Operator-Aided Optimization
   - 6.2 Adaptive Predictions
   - 6.3 Bayesian Updating

of outcome calculator. The question then arises as to how specific techniques may be chosen for a specific problem from among these sets of equivalent techniques. There are two criteria upon which a technique may be selected. First and foremost is the applicability of the specific formal properties of the technique to the situation. In order to determine the technique's applicability, the data the technique will require must be weighed against those currently available within the decision situation. Second, the constraints of the situation must be weighed against the characteristics of the techniques. Each decision-making situation will contain certain constraints on the techniques to be used, such as limited computer power, need for rapid responses, etc., and these constraints may preclude the selection of certain techniques.

There are four general types of constraints which may limit the applicability of a technique: computer implementation, mathematical power, generality, and user interface. A number of dimensions or scales which exemplify each type of constraint were identified and applied to the techniques listed on Table 3-3. Three of the dimensions -- computational time, computational space and hardware/software independence -- relate to computer implementation constraints. Three other dimensions -- dependence on observable parameters, strength of underlying assumptions, and incorporability of uncertainty -- characterize the power of the mathematical models upon which the techniques rely. Two other dimensions -- new problem flexibility and incorporability of new factors -- describe technique flexibility and generality. A single dimension, transparency, was used to characterize the user interface associated with each of the techniques. Transparency refers to the ease with which a user can understand the procedures by which the technique produces its outputs from its inputs.

In order to indicate the relative advantages and disadvantages of each technique with regard to each type of constraint, the decision aiding techniques were evaluated and compared on these nine dimensions. Each dimension was subdivided by a dichotomized or trichtomized categorical scale.* While many of the

*The use of finer scale distinctions would require an impractical level of discrimination for the purposes of this study.

dimensions make reference to empirical values (e.g., less than 10 seconds run time, more than 100K core required) these values are only intended to provide some frame of comparison, and should not be taken as precise. The quantitative assessments were made by assuming a "typical" application of the technique in a "typical" computer. Truly typical applications of any method are rare, so the values given will certainly vary from specific instance to specific instance. However, this approach to technique characteration establishes a framework which can easily be adapted to any specific application on a particular computational system.

The scales used to measure each dimension are detailed below. The ratings of each of the techniques in Table 3-3 on each of these dimensions are shown in Table 3-4.

3.4.1 Computational Time Requirements

This dimension refers to the relative number of computations required by an application of the technique. Since on-platform decision aids are on-line and real-time, computational time is defined as the real-time response interval that is created by the execution of the method. Required computational time is categorized as:

- Fast (F) -- indicating a response interval of less than 10 seconds.
- Medium (M) -- indicating a response interval of greater than 10 but less than 60 seconds.
- Slow (s) -- indicating a response interval of more than 60 seconds.

3.4.2 Computational Space Requirements

This dimension identifies the amount of storage (core and/or disc) required in a typical application of the technique. Computational space requirements are categorized as:

- Small (δ) -- indicating less than 30,000 words of storage are required.

Table 3-4. Characteristics of Decision Aiding Techniques

		COMPUTATIONAL IMPLEMENTATION				POWER OF MODELS		TECHNIQUE GENERALITY		INTERFACE
		COMPUTATIONAL TIME REQUIREMENTS	COMPUTATIONAL SPACE REQUIREMENTS	HARDWARE/SOFTWARE INDEPENDENCE	DEPENDENCE ON OBSERVABLE PARAMETERS	STRENGTH OF ASSUMPTIONS	INCORPORABILITY OF UNCERTAINTY	NEW PROBLEM FLEXIBILITY	INCORPORABILITY OF ADDITIONAL FEATURES	TRANSPARENCY
OUTCOME CALCULATOR	CLOSED-FORM ANALYTIC MODEL	F	σ-μ	H	Y	s	N	N	N	N
	PROBABILISTIC MODEL	F-M	σ-μ	H	Y	s	Y	N	N	N
	DETERMINISTIC SIMULATION	F	σ	H	Y	s	N	N	N	N
	MONTE-CARLO SIMULATION MODEL	S	λ	H	Y	s	Y	N	N	N
VALUE MODEL	MULTI-ATTRIBUTE UTILITY MODEL (MAUM)	F	σ	H	N	vs	N	Y	Y	Y
	ADAPTIVELY CONSTRUCTED MAUM	F	μ	H	Y	vs	N	Y	Y	N
	DIRECT ASSIGNMENT	F	σ	H	NA	w	N	N	N	Y
	RISK INCORPORATING	F	σ	H	N	s	N	Y	Y	N
	NON-LINEAR	F	σ	H	N**	w	N	N	N	N
DATA CONTROL	AUTOMATIC AGGREGATION	F-M	μ-λ	L*	Y	s	Y	N	N	N
	INFORMATION MANAGEMENT	F-M	λ	L	NA	w	NA	Y	Y	Y
ANALYSIS	OPTIMIZATION	S	λ	H	NA	s	Y	Y	Y	N
	ARTIFICIAL INTELLIGENCE METHODS	M	λ	H	NA	w	Y	Y	Y	N
	SENSITIVITY ANALYSIS	S†	λ	H	NA	w	Y	N	N	Y
	INTRA-PROCESS	M	μ	H	NA	w	Y	N	N	Y
	INFORMATION PROCESSING ALGORITHMS	F-M	μ	H	NA	s	Y	N	N	N
	STATUS MONITOR AND ALERT	F	λ††	L	NA	w	N	Y	Y	Y
	STATISTICAL ANALYSIS	F-M	μ-λ	H	NA	s	Y	Y	N	N
DISPLAY/ DATA ENTRY	DISPLAY GRAPHICS	F-M	μ	L	NA	NA	NA	Y	NA	NA
	INTERACTIVE GRAPHICS	M	μ	L	NA	NA	NA	Y	NA	NA
	WINDOWING	F	σ	L	NA	NA	NA	Y	NA	NA
	SPEECH RECOGNITION/SYNTHESIS	M-S	σ	L	Y	w	NA	Y	N	Y
	QUICKENING	F	σ	H	Y	W	NA	Y	N	Y
HUMAN JUDGMENT REFINEMENT/ AMPLIFICATION	OPERATOR-AIDED OPTIMIZATION	S	λ-μ	H	NA	w	N	Y	Y	Y
	ADAPTIVE PREDICTION	F	μ	H	Y	s	N	Y	Y	Y
	BAYESIAN UPDATING	F	μ	H	N	vs	Y	Y	Y	N

KEY:

F	<	10 SEC.
M	=	10 - 60 SEC.
S	>	60 SEC.
Y	=	YES
N	=	NO
NA	=	NOT APPLICABLE
vs	=	VERY STRONG
s	=	STRONG
w	=	WEAK
H	=	HIGH
L	=	LOW
λ	>	100K CORE
μ	=	30 - 100K CORE
σ	=	< 30K CORE

† SENSITIVITY ANALYSIS IS NORMALLY CONDUCTED WITH MONTE-CARLO SIMULATION WHICH IS COMPUTATIONALLY SLOW. WHEN USED WITH FASTER ANALYTIC MODELS (I.E. CLOSED-FORM) IT IS CHARACTERIZED AS "F".

†† WHEN USED TO MONITOR DYNAMIC DATA BASES THE TECHNIQUE REQUIRES AS MUCH STORAGE AS THE DATA BASE AND IS CHARACTERIZED AS "L". WHEN USED TO MONITOR INPUT DATA STREAM, IT IS CHARACTERIZED AS "S".

* DATA FROM PHYSICAL DEVICES (SENSORS, ETC.) CHARACTERIZES THIS TECHNIQUE AS "L". DATA ENTERED BY HUMANS IS CHARACTERIZED AS "H".

** IF THE NON-LINEAR FUNCTION IS A COMBINATION OF SUBJECTIVE VALUES, IT IS CHARACTERIZED AS "N". IF A COMBINATION OF PHYSICAL VARIABLES, IT IS CHARACTERIZED AS "Y".

- Medium (μ) -- indicating more than 30,000 but less than 100,000 words of storage are required.
- Large (λ) -- indicating more than 100,000 words of storage are required.

3.4.3 Hardware/Software Independence

Some techniques require specialized pieces of hardware such as graphic display devices or particular software routines such as data base management systems in order to function. This dimension identifies whether a technique is independent of the hardware/software on which it is implemented. Hardware/software independence is measured as either:

- High (H) -- indicating the technique has high independence from the particular hardware/software on which it is implemented.
- Low (L) -- indicating the technique has low independence from the particular hardware/software on which it is implemented.

3.4.4 Dependence on Observable Parameters

Techniques which involve models or computational algorithms usually require that one or more parameter values be specified. In some cases, these parameter values may be derived from direct observation; in others, they may be based on subjective judgment. A model which depends on observable parameters is more verifiable than one that uses subjective parameters. This dimension identifies whether or not a technique depends on observable parameters. It is categorized as either:

- Yes (Y) -- indicating the technique can be made to depend on observable parameters only.
- No (N) -- indicating the technique cannot be made to depend on observable parameters only.
- Not Applicable (NA) -- techniques which require no parameters.

3.4.5 Strength of Assumptions

This dimension deals with the underlying assumptions which must be met if the technique is appropriately used. The strength of the underlying assumptions inversely indicates the number of real-world problems to which the technique may be applied; that is, the stronger the assumption, the more restricted the technique. Strength of assumptions is categorized as:

- Very strong (vs) -- indicating the assumptions on which the technique is based are rarely met.
- Strong (s) -- indicating the assumptions on which the technique is based are met frequently, but not a majority of the time.
- Weak (w) -- indicating the assumptions on which the technique is based are almost always met.
- Not Applicable (NA) -- techniques for which there are no underlying assumptions.

3.4.6 Incorporability of Uncertainty

This dimension refers to whether or not the technique can deal with explicit representations of uncertainty in either input, output or intervening variables. For display techniques, it refers to whether or not the technique can explicitly display or present uncertainty. Incorporability of uncertainty is categorized as:

- Yes (Y) -- indicating the technique can explicitly incorporate uncertainty.
- No (N) -- indicating the technique cannot explicitly incorporate uncertainty.
- Not Applicable (NA) -- techniques for which this dimension is not relevant.

3.4.7 New Problem Flexibility

Because each decision is unique in some respects, decision aids must be flexible over a range of similar problems. Some techniques are more easily transferred from one application to another. This dimension identifies whether or not an application of the technique can be transferred easily to a related problem: for example, from modeling a carrier-based air strike to modeling a land-based air strike. New problem flexibility is measured as either:

- Yes (Y) -- indicating an application of the technique is flexible with regard to new problems.

- No (N) -- indicating an application of the technique is not flexible with regard to new problems.

3.4.8 Incorporability of New Factors

A mathematical model may be found to exclude factors that are critical to an accurate representation of the process or relationships involved. The exclusion may be due to errors in original formulation or changes in the empirical process or relationship (e.g., new weapons systems and/or new platforms); but regardless of the cause, it may be necessary to incorporate additional factors into a completed model. This dimension identifies whether or not the technique allows new factors to be incorporated easily into a given application. Incorporability of new factors is measured as:

- Yes (Y) -- indicating new factors can be incorporated easily.

- No (N) -- indicating new factors cannot be incorporated easily.

- Not Applicable (NA) -- techniques for which this distinction is not relevant.

3.4.9 Transparency

This dimension refers to whether or not the inner workings of the technique are directly obsevable and/or easily understandable to a user. The transparency of techniques is a major concern to the user community and thus will be a key factor in the acceptance of decision aids by the user community. Transparency is measured as:

- Yes (Y) -- indicating the technique's operations are transparent.

- No (N) -- indicating the technique's operations are not transparent.

- Not Applicable (NA) -- techniques for which this dimension are not relevant.

3.5 AIDING TECHNIQUES AND THE DECISION PROCESS

The categories in the taxonomy shown in Table 3-3 group decision aiding techniques by the functions they serve in decision aids. The rating dimensions used in Table 3-4 assess the relative strengths and weaknesses of the techniques according to possible constraints imposed by a decision aiding situation. There is one final characterization of the techniques that can help facilitate matching them with the decision situations -- the identification of the part(s) of the decision process which they may aid.

Decision making is neither an instantaneous nor an invariant process. The decision process is typically accomplished in a series of steps or stages and different decision aiding techniques are relevant to aiding different parts of the decision process. A clearer picture of the possible use of each technique can be obtained by determining the various parts of the decision process which each technique addresses.

The decision making process can be broken into 6 phases. The first phase is *problem structuring*, in which the problem is defined and the alternatives and contigencies are identified. The second phase is *prediction*, in which the results of potential courses of action are estimated. The third phase is *valuation*, in which the possible courses of action and their potential outcomes are related to the decision maker's implicit and explicit preferences and goals. *Data handling*, the fourth phase, involves the manipulation, analysis, storage and retrieval of subjective and objective information. The fifth phase, *calculation*, is associated with the second and third phases and involves the numerical and logical manipulation of facts and relationships. The sixth and final phase, *reasoning*, involves the drawing of inferences, the use of heuristics, and the general organization of the way in which the problem is approached.

The relationship of each of the techniques in Table 3-3 to these six phases is shown in Table 3-5.

Table 3-5. Parts of the Decision Processes Aided

DECISION AUTOMATION TECHNIQUES	DECISION PROCESSING FUNCTIONS	PROBLEM STRUCTURE	PREDICTION	VALUATION	DATA HANDLING	CALCULATION	REASONING
OUTCOME CALCULATORS	CLOSED-FORM ANALYTIC MODEL		√		√	√	
	PROBABILISTIC MODEL		√		√	√	
	DETERMINISTIC SIMULATION		√		√	√	
	MONTE-CARLO SIMULATION MODEL		√		√	√	
VALUE MODELS	MULTI-ATTRIBUTE UTILITY MODEL (MAUM)			√		√	
	ADAPTIVELY CONTRUCTED MAUM			√			
	DIRECT ASSIGNMENT			√			
	RISK INCORPORATING			√		√	
	NON-LINEAR			√		√	
DATA CONTROL	AUTOMATIC DATA AGGREGATION		√	√			
	INFORMATION MANAGEMENT		√	√			
ANALYSIS	OPTIMIZATION TECHNIQUES		√	√			
	ARTIFICIAL INTELLIGENCE TECHNIQUES	√	√				
	SENSITIVITY ANALYSIS				√	√	√
	INTRA-PROCESS ANALYSIS		√	√		√	–
	INFORMATION PROCESSING ALGORITHMS	√	√	√	√	√	
	STATUS MONITOR AND ALERT				√	√	
	STATISTICAL ANALYSIS		√	√	√	√	√
DISPLAY/ DATA ENTRY	DISPLAY GRAPHICS	√			√	√	
	INTERACTIVE GRAPHICS	√			√		
	WINDOWING				√		
	SPEECH RECOGNITION/SYNTHESIS				√		
	QUICKENING		√			√	
JUDGMENT REFINEMENT/ AMPLIFICATION	OPERATOR-AIDED OPTIMIZATION					√	√
	ADAPTIVE PREDICTION		√	√	√	√	√
	BAYESIAN UPDATING		√		√	√	

4. DECISION SITUATION DESCRIPTIONS

Detailed descriptions of the six ASW decision situations identified in Chapter 2 are presented in this chapter as a preliminary to matching decision aiding techniques to the situations (Section 5). The matching of techniques to situations relies heavily on the specific content of each of the decision situations, and this necessitated the description of the six decision situations at a much higher level of detail than that provided in Section 2.

To insure that the same information was available for matching the decision aiding techniques with each decision situation, a highly-structured descriptive framework which could be applied uniformly to all the situations was required. The most commonly used framework is the decision-tree approach, where a decision is represented by a tree-structure in which terminal nodes are outcomes, branches are alternatives, and non-terminal nodes are choices among alternatives. The decision-tree approach, however, focuses on the analysis of well-defined *single* decisions, whereas the decision situations considered here are complex contexts in which *many* decision functions are coordinated to achieve some goal event. The decision-tree approach was therefore too restricted to be useful in describing the decision situations. It ultimately proved necessary to create a more generalized descriptive framework that could adequately treat a complex decision situation as its primary focus. This descriptive framework was constructed to meet three broad requirements:

- Be generalizable to all types of decision situations, not merely those involving Naval Air ASW,
- Be capable of describing 'multivariate' situations, i.e., those involving multiple input, multiple outputs, and multiple decisions, and

- Be directed toward facilitating the matching of decision aiding techniques with the decision situation being described.

The descriptive framework for presenting the decision situations works in conjunction with the decision aiding technique taxonomy presented in Section 3.3. The categories in the taxonomy represent groups of functionally equivalent techniques -- techniques which perform similar or analgous decision-aiding functions. The existance of these common functions across aids implied that there were common or general aspects of decision problems which were aided by all the techniques in a given category of the taxonomy. The decision framework was therefore constructed so as to identify the problem aspects with which each of the taxonomic categories is concerned. Descriptions generated by such a framework thus provide exactly the information needed to perform the matching task.

The descriptive framework that was applied to the six decision situations is discussed in the following section. The remainder of this section presents the six situation descriptions.

4.1 A DESCRIPTIVE FRAMEWORK FOR DECISION SITUATION CHARACTERIZATION

Six descriptive categories were applied to each of the decision situations identified in Section 2. These categories are best described in terms of the questions each category poses of the decision situation being described:

- *Underlying Process Involved* -- What is the process, if any, for which the decision maker is attempting to plan? What are the interactions with the enemy?
- *Value Criteria* -- On what kind of scale could a decision be evaluated? Are there one or more measures by which one choice can seem to be better than another?
- *Variables and Parameters* -- What are the inputs to the decision? What are the (fixed) parameters of the situation which affect the decision? What is the decision maker specifically trying to decide? What outputs (processed data) would be useful in making that decision?

- *Relevant Analyses* -- What kinds of analysis of the input and/or output data would help in making the decision?

- *Relevant Displays* -- What information should be displayed?

- *Required Human Judgments* -- Are there any judgmental assessments which the human must make? What are they? Can they be made by a computer?

These categories have obvious correspondences to the functional categories in the technique taxonomy defined in Section 4.3. The *underlying process* of a situation is that real-world action which outcome calculators attempt to model and predict. The *value criteria* are those decision-maker preferences which are formalized and modeled by the value models. The *variables and parameters* constitute the problem database which the data control techniques manage. The *relevant analyses* are those useful manipulations of the data that can be performed by the analysis techniques. The *relevant displays* are those data, required by the decision maker, which are presented or entered with the display/entry techniques. Finally, the *required human judgments* are those human inputs which may require further refinement or amplification by the human judgment refining/amplifying techniques.

To provide a general summary of each decision, two additional descriptors will be provided for each category, the *situational objective* and the situational *decision task dynamics*. As described in chapter 2, each decision situation is defined by some goal or objective event the TACCO is trying to achieve. By bringing about that event, the decision situation can be ended and another begun. The situational objective specifies this goal event.

The situational decision task dynamics refers to the way in which the constituent decision tasks in a decision situation are performed. Three general kinds of dynamics were defined:

- *Closed-Loop Iterative* -- Problems in which a single decision must be made repetitively in a short timeframe, for example, in discrete tracking or monitoring processes/tasks.

- *Sequential Contingent* -- Problems in which a number of different individual decisions must be made, once each in sequence.
- *Uni-or Multidimentional Independent* -- Problems in which one or several decisions must be made only once and without consideration to subsequent decisions.

Besides providing basic information about the decision situation, the task dynamics are of use in the matching task. Certain kinds of techniques are more applicable to decisions with certain task dynamics. For example, adaptive prediction and Bayesian updating techniques employ algorithms which iteratively converge on a solution, and thus are more applicable to "closed loop iterative" situations than to "multidimensional independent" situations. The impact of the task dynamics category is discussed more fully in Section 5.

While the decision situation descriptions in the following sections contain much more detail than the brief definitions given in Section 2, they are directed toward the matching in Section 5 below and are not intended to be encyclopedic. The absence of certain data should not be taken to indicate that they were overlooked and/or ignored, but only that a representative data sample is presented to illustrate the matching procedure required for this effort.

4.2 ON-STATION SEARCH

4.2.1 Situation Objectives and Task Dynamics

There are two objectives in this situation: first, to reduce in-situ spatial uncertainty and second, to improve the probability of gaining a contact. This is a closed-loop iterative situation in which some action is taken (i.e., sensors are deployed and monitored) and, unless something happens to end the situation (either obtaining contact or reaching the end of the on-station time), the procedure is repeated in a somewhat altered form to reflect new area, new sensors, etc.* The following description will consider a single iteration through this closed loop.

4.2.2 Underlying Process

The ASW platform is attempting to detect one or more targets moving in or through its (passive or active) sensor field by monitoring existing sensors or deploying new ones.

4.2.3 Value Criteria

There are two value criteria that can be used to judge how well the on-station search is proceeding. One is the probability of detecting the target in the next interval, t_1, of time, and the other is the probability that the target will be absent from the monitoring area at some future time, t_2. These two probabilities are not complementary as they might seem because there is also the probability that the target will be in the search area but will remain undetected.

4.2.4 Variables and Parameters

4.2.4.1 Inputs

There are basically two kinds of input variables -- those whose values are set before arriving on-station and those whose values are determined while on-station. Variables in the first category are the types and number of sensors available, initial estimates of propagation loss (PL) and bathythermal conditions (BT), and possible target position, course and velocity. While on-station, new PL and BT values will be determined, sensors will be deployed at specific locations and settings and sea-state and ambient noise will be observed. As sensors are deployed, the remaining stores (types and numbers of sensors) also becomes an input variable.

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*Actually, the process is slightly different in each iteration because as time passes and a target is not contacted, information as to where it is *not* located is gained. Therefore, the search area can be reduced on each iteration.

4.2.4.2 Parameters

The parameters of the situation are the capabilities of the sensor types available and the signatures of the various targets expected to be encountered.

4.2.4.3 Outputs

There are several output variables: the coverage area and coverage factor created by the present sensor deployment and ocean conditions, the best sensor monitoring pattern, the probability of detecting a target (over time) and the probability of no target being in the area (over time).

4.2.4.4 Decision Variables

Two decisions are made. One is a plan of action -- whether or not to deploy a new sensor or a new pattern, what the geometry, spacing, etc. should be if the decision is made to do so, what monitoring pattern will be used, and whether the current pattern is to be retained. The second decision is stores management, in which the deployment of new sensors is considered against the need to retain sensors for use later in the mission.

4.2.5 Relevant Analyses

Several different analyses are relevant to the situation. First, the currently deployed sensors could be automatically monitored for malfunctions or failures. Whenever failures occur which cause the coverage area or factor to be unfavorably altered, the TACCO would be alerted. For the deployment of new patterns or additional sensors in the present pattern, the best location for the new sensor(s) and the best time to deploy them could be determined. To aid in the stores management, the sensitivity of the probability of detection and probability of target absence to the number of sensors deployed could be computed.

4.2.6 Relevant Displays

One useful display would be the geometry (including location, orientation, spacing, and depth) and coverage area/factor provided by a sensor field, either the current one or a projected one. Another would list all the currently deployed sensors by type and setting and the type and numbers of the stores remaining.

4.2.7 Required Human Judgments

The judgment required of the TACCO would be the choice of the next sensor pattern to be deployed.

The description of the On-Station Search situation is summarized in tabular form in Table 4-1.

4.3 CLASSIFICATION

4.3.1 Situation Objectives and Task Dynamics

In the classification decision situation, a contact has been made with a target and the objective is to recognize and verify the signature of the target. The dynamics of this situation are sequential contingent in that the classification decision may take place in several stages.

4.3.2 Underlying Process Involved

Since the problem is essentially one of extracting the information needed to identify the target from the sensor readings, there are no time-dependent processes involved.

4.3.3 Value Criteria

There are two possible value criteria for the classification situation which relate to the two parts of the classification problem. First, the contact must be evaluated to determine whether it is a true or a false contact, so the first value criterion is the probability that the signal represents a true contact. Second, the actual signature of the target must be obtained and identified. As candidate classifications are made, the second criterion would be some measure of the confidence in the correctness of the classification.

Table 4-1. On-Station Search

Objective:

(1) Reduce in-situ uncertainty
(2) Improve Probability of Gaining Contact

Task Dynamics: Closed-Loop Iterative

Underlying Process Involved: Attempt to detect one or more targets moving in or through active/passive sensor field by continued monitoring of existing sensors or deployment of new ones.

Value Criteria:

(1) Probability of detecting a target over time
(2) Probability search area contains no target over time

Variables and Parameters:

Inputs

Propagation Loss
Bathythermal Conditions
Ambient Noise
Sea-State
Sensor Locations and Settings
Estimated Target Position
Estimated Target Course
Estimated Target Velocity
Estimated Target Depth
Stores Available
Time Remaining on Station

Parameters

Sensor Capabilities
Target Signatures

Outputs

Sensor Pattern
Coverage Area
Coverage Factor
Sensor Monitoring Information

Decision Variables

Plan of Action
Stores Management

Relevant Analyses:

(1) Monitoring of sensors for failure causing coverage lapse
(2) Optimization of coverage for new sensor or pattern
(3) Sensitivity analysis of coverage strength to number of sensors deployed

Relevant Displays:

(1) Sensor pattern and coverage area/factor
(2) Types and settings of sensors deployed
(3) Types and numbers of sensors remaining
(4) Optimized new pattern and time to deploy
(5) Sensor monitoring information

Required Human Judgments: New pattern geometry

4.3.4 Values and Parameters

4.3.4.1 Inputs

Many of the inputs to the classification decision are the same as for in-situ search. These are the PL, BT, and sea-state readings, and the sensor locations and their settings. The other inputs are the actual signals being received from the sensors which have the contact.

4.3.4.2 Parameters

As with the previous situation, the parameters are the signatures of the anticipated targets and the capabilities of the sensors, particularly their detection thresholds.

4.3.4.3 Outputs

The outputs that could assist in classification are the correlations between sensors having the contact, identification of which sensors have the contact, the signal excess, and all related frequencies and sound sources.

4.3.4.4 Decision Variables

There are two decisions to be made in the classification situation. First, whether the signal represents a true or a false contact. Second, for true contacts, the target emitting the signal must be classified and identified.

4.3.5 Relevant Analyses

One type of analysis relevant to classification is the statistical or mathematical comparison of the incoming signals with a "library" of known target signatures. Another is the calculation of correlations of the signals between the sensors, taking into account PL and BT conditions and the geometry of the pattern. A third is the identification of candidate or possible classifications as the classification analysis proceeds.

4.3.6 Relevant Displays

There are relatively few displays needed in this situation. One could be a display indicating which of the sensors were detecting a signal. Others could be a list of all the correlations between the detecting sensors, the values of all the output variables, a list of possible classifications and the confidence or probability of each being correct.

4.3.7 Required Human Judgments

The final acceptance of the contact classification must be made by the TACCO.

The description of the Classification decision situation is summarized in tabular form in Table 4-2.

4.4 LOCALIZATION

4.4.1 Situation Objectives and Task Dynamics

In the localization situation, a contact has been made, verified, and classified as a hostile submarine. In this situation, the objective is to isolate the targets (if there are multiple targets) and to determine the precise location, depth, course and speed of the most threatening target. The dynamics of this situation are closed-loop iterative, with the platform iteratively closing in on the target until its precise location, depth, course and speed have been accurately determined. (These four components will be collectively referred to as the target's Location, with a capital "L.") The following description will describe a single iteration through the loop.

4.4.2 Underlying Process Involved

The ASW platform is attempting to determine the precise Location of the target(s) by continued monitoring of existing sensors and/or deploying new-ones. The hostile submarine(s) may also be taking evasive action.

Table 4-2. Classification

Objective: Recognize, identify, and verify target signatures

Task Dynamics: Multidimensional Independent

Underlying Process Involved: None

Value Criteria:
(1) Probability of true contact
(2) Measure of confidence in correctness of classification

Variables and Parameters:

Inputs

Propagation Loss
Bathythermal Conditions
Ambient Noise
Signals from Sensors
Sensor Locations and Settings

Outputs

Correlation Between Sensors
Sensors Making Contact
Signal Excess
Related Frequencies and Sound Sources

Decision Variables

True or False Contact
Target Classification

Parameters

Expected Target Signatures
Sensor Capabilities

Relevant Analyses:
(1) Statistical/mathematical comparison of incoming signals with library of known target signatures
(2) Computation of signal correlation between sensors
(3) Identification of candidate classifications

Relevant Displays:
(1) Sensors receiving signals
(2) Correlated signatures
(3) Possible classifications
(4) All output variables

Required Human Judgments: Final acceptance of classification

4.4.3 Value Criteria

Since the target is localized by a convergent iterative procedure, the appropriate value criterion is one by which the degree of successful localization at the current time can be measured. A measure of localization as a function of uncertainty in the target's Location is needed.

4.4.4 Variables and Parameters

4.4.4.1 Inputs

Many of the input variables are the same as in the search and classification -- PL, BT, sea-state and ambient noise values. Other inputs are the types, locations, and settings of the sensors currently deployed, and the signals that these sensors are receiving. The estimated Location of the target and the uncertainty or possible error in the estimates are also inputs, as is the remaining time on-station.

4.4.4.2 Parameters

As in search and classification, both the sensor capabilities and the target signatures are parameters. However, since the target has now been classified, the known capabilities of the target (depth limitations, speed limitations, maneuvering limitations, and history of evasive measures encountered on previous missions) also become parameters of the situation.

4.4.4.3 Outputs

The output variables needed are the probability areas of the target at the present and at future times, the best monitoring sequence for the present sensors and the predicted location of the target over time.

4.4.4.4 Decision Variables

There are three decisions to be made. First, a plan of action must be determined in each iteration of the loop. This plan includes the decision to deploy additional sensors (or whole new patterns) or to continue to monitor the currrent sensors. A second decision concerns stores management, in which potential gain from deploying additional sensors is weighed against the need to retain sensors for future parts of the mission. Third, and most important, a determination of the precise Location of the target must be made.

4.4.5 Relevant Analyses

Several kinds of analyses are relevant to the localization situation. As with the search situation, it could be beneficial to have the currently deployed sensors monitored for failures, particularly those which would adversely affect the coverage in the area where the target is likely to be. The monitoring sequence could be optimized for presently deployed sensors; locations for new sensors and the time the new pattern should be deployed could also be optimized. Finally, to aid in the management of stores, the sensitivity of the coverage to the number of additional sensors deployed could be computed.

4.4.6 Relevant Displays

The relevant displays in localization situation are the location of all currently deployed sensors and the coverage area/factor that this pattern produces, the uncertainty area of the target, the type and setting of deployed sensors, the type and number of the sensors remaining, and the target's estimated position at future points in time.

4.4.7 Required Human Judgments

Several human judgments are required in this situation. First, if there are multiple hostile targets, the relative threat posed by each must be assessed to allow the most threatening target to be selected for localization, tracking and attack. This judgment must be made by the TACCO, as it is too complex and subjective for automation. As with the search situation, when new sensor patterns are to be laid, the basic pattern must be selected by the TACCO because of the wide range of possible choices. Finally, a human must decide when localization has ultimately been achieved.

The description of the Localization situation is summarized in tabular form in Table 4-3.

Table 4-3. Localization

Objectives:	(1) Isolate targets if multiple targets (2) Determine precise location, depth, course, and speed of target(s)
Task Dynamics:	Closed-Loop Iterative
Underlying Process Involved:	Attempt to determine precise location of one or more detected and classified targets by continued monitoring of existing sensors and/or deployment of new ones
Value Criterion:	Measure of localization of target as a function of uncertainty in location, course, speed, and depth

Variables and Parameters:

Inputs	Parameters
Progation Loss	Target Signatures
Bathythermal Conditions	Sensor Capabilities
Ambient Noise	Target Movement Properties
Sea-State	• Target Speed Limitations
Sensor Locations and Types	• Target Depth Limitations
Incoming Sensor Signals	• Target Maneuvering Limitations
Estimated Target Location	• Target History of Evasive Actions
Outputs	**Decision Variables**
Target Probability Areas	Plan of Action
Sensor Monitoring Information	Stores Management
Predicted Target Location	Determination of Target Location

Relevant Analyses:	(1) Monitoring of sensors for failures causing coverage lapse (2) Optimization of coverage area for new sensor or pattern (3) Optimization of monitoring sequence for current pattern (4) Calculation of target probability area and estimated location
Relevant Displays:	(1) Estimated position of target and probability area over time (2) Current sensor pattern and coverage area/factor (3) Types and settings of current sensors (4) Types and numbers of stores remaining (5) Sensor monitoring information (6) New pattern position and time to deploy
Required Human Judgments:	(1) Assessment of target threat if multiple threats (2) Geometry of new sensor pattern (3) Determination of localization

4.5 LOST CONTACT REACQUISITION

4.5.1 Situation Objective and Task Dynamics

This situation occurs when contact with a target is made but then lost. The target may have been classified before the contact was lost. The objective in this situation is to regain contact with, and reclassify, the lost target. The dynamics of this situation are different from the preceding situations, as different actions are required depending on the time elapsed since the signal was lost. Thus, this is a sequential contingent type of problem.

4.5.2 Underlying Process Involved

The platform is attempting to detect a specific target moving away from the point where contact was lost, through the continued monitoring of the existing sensors or the deployment of additional ones. The target may be taking evasive action.

4.5.3 Value Criteria

Since target reacquisition is an all-or-nothing procedure, the value criteria must measure the degree to which reacquisition can be expected at some future time, rather than the degree of reacquisition. A measure of the reduction in the area of uncertainty of the lost target is therefore appropriate. This criterion is a function of the time elapsed since the target was lost, the target's capabilities and the ASW platform's detection capabilities (i.e., the types, settings and locations of sensors, the propagation conditions, etc).

4.5.4 Variables and Parameters

4.5.4.1 Inputs

The basic environmental variables are again important inputs (the PL, the BT, ambient noise and sea-state) as are the sensor locations, settings and types. The contact that the platform had with the target is also an input. The on-station history of the target's movements and the target's estimated position speed, course and depth when it was lost are particularly critical inputs.

Other inputs are the stores remaining, the time remaining on-station and the time since the contact was lost.

4.5.4.2 Parameters

The sensor capabilities and target signatures are again basic parameters. As in the previous two situations, the target capabilities -- its speed, depth, maneuvering limitations -- and its history of evasive actions on previous missions are also parameters.

4.5.4.3 Outputs

The basic outputs needed in this situation are the uncertainty area and predicted location of the lost target at the present and at future times and the best sequence of monitoring presently deployed sensors.

4.5.4.4 Decision Variables

There are again two basic decisions being made in the reacquisition situation. First, a plan of action (consisting of decisions of whether or not to deploy new sensors, when, where and what to deploy and how to best monitor existing sensors) must be constructed. Second, the tradeoff between deploying sensors and retaining them for later in the mission must be assessed.

4.5.5 Relevant Analyses

As in all mission situations which involve searching or tracking, one analysis that is relevant is the monitoring of existing sensors for failures which can adversely affect the coverage in the part of the search area of greatest interest. Two other analyses are similar to, but slightly different from, those described in the other situations. The deployment of new sensors or sensor patterns could be optimized with regard to both locations and time of deployment, given the past history of the contact with the lost target. Similarly, the target's present the future location and area of uncertainty could be predicted, given the history of the contact with the lost target.

4.5.6 Relevant Displays

The basic displays that are relevant are the locations and coverage area/factor provided by the presently deployed sensors, the probability area of the lost target and its predicted present and future location, the types and settings of currently deployed sensors, the types and numbers of sensors remaining, and the locations and time of deployment of additional sensors.

4.5.7 Required Human Judgments

As in other situations, it is probably necessary for the human to choose the pattern geometry to be used if an entirely new pattern is to be deployed.

The description of the Lost Contact Reacquisition situation is summarized in tabular form in Table 4-4.

4.6 SURVEILLANCE TRACKING

4.6.1 Situation Objective and Task Dynamics

In the Surveillance Tracking situation, the target has been contacted, identified, and localized. The objective now is to maintain the continuity of the track. The dynamics of this situation are similar to the on-station search and localization situations, as the platform repeatedly deploys new sensors to extend the surveillance field along the path of the target. This is therefore a closed-loop iterative type of situation. The following description will consider a single iteration through this loop.

4.6.2 Underlying Process Involved

The platform is attempting to maintain the continuity of the track by continued monitoring of existing sensors and deploying new ones along the course of the target, which may be taking evasive action. The future location of the target must be predicted by inferring the course, depth and speed of the target from present and past sensor readings and historical data on the target.

Table 4-4. Lost Contact Reacquisition

Objective:	Regain contact with lost target
Task Dynamics:	Sequential Contingent
Underlying Process Involved:	Attempt to relocate target moving away from position of last contact through continued monitoring of present sensors or deploying of new ones
Value Criterion:	Measure of reduction in the area of uncertainty of lost target

Variables and Parameters:

Inputs

- Propagation Loss
- Bathythermal Conditions
- Sea-State
- Ambient Noise
- History of Contact with Lost Target
- Estimated Target Location, Course, Depth and Speed at Time of Contact Loss
- Stores Remaining
- Time Remaining On-Station
- Time Since Contact Lost

Decision Variables

- Plan of Action
- Stores Management

Parameters

- Sensor Capabilities
- Target Signatures
- Target Movement Properties
  - Target Speed Limitations
  - Target Depth Limitations
  - Target Maneuvering Limitations
  - Target History of Evasive Action *from Previous Mission*

Outputs

- Target Uncertainty Area
- Predicted Target Position
- Sensor Monitoring Information

Relevant Analyses:

(1) Monitoring of existing sensors for failures causing coverage lapse
(2) Optimization of new sensor locations and deployment times, *given history of contact*
(3) Prediction of target location and uncertainty area over time, given history of contact

Relevant Displays:

(1) Sensor locations and coverage area/factor
(2) Predicted position and probability area of lost target over time
(3) Type and settings of currently deployed sensors
(4) Type and number of stores remaining
(5) Locations and time of deployment of additional sensors

Required Human Judgments: New pattern geometries

4.6.3 Value Criteria

Since the failure to maintain the track results in a loss of the contact, the track must be completely maintained. There is therefore no value measure of the degree of success in the surveillance track situation.

4.6.4 Variables and Parameters

4.6.4.1 Inputs

The basic environmental variables continue to be important input variables (BT, PL, ambient noise, sea-state), as does the history of the contact with the targets (its present estimated location, course, depth, speed and past movements). Other input variables are the locations, types, and settings of the sensors currently deployed, the stores remaining, and time remaining on-station.

4.6.4.2 Parameters

The basic parameters are the same as in other situations -- sensor capabilities and target signatures. Other parameters refer to the specific target being tracked -- its speed, depth, maneuvering limitations and history of evasive action on previous missions.

4.6.4.3 Outputs

The output variables needed are the predicted position of the target over time, the best method of monitoring existing sensors and the geometry, orientation, spacing and depth of new sensor patterns to be deployed along the target's course over time.

4.6.4.4 Decision Variables

There are again two basic decisions being made. One concerns the plan of action (where to place the next sensors so as to maintain the track). The other concerns the management of stores (how to tradeoff the benefit of deploying sensors now against the need to reserve them for later in the mission).

4.6.5 Relevant Analyses

As in the other closed-loop iterative situations, the existing sensors could be monitored for failures that would adversely affect the coverage area in the vicinity of the target. Another analysis that is relevant is the optimization of the location (and setting and depth) of the next sensor pattern along the target's predicted path.

4.6.6 Relevant Displays

The displays relevant in this situation are the locations and depth of all the currently deployed sensors, the types and settings of the deployed sensors, the stores remaining, and the predicted position with an area of uncertainty of the target at present and future times. The display of possible new sensor patterns is also relevant.

4.6.7 Required Human Judgments

As in previous situations, it will probably be necessary for the human initially to select the geometry of new sensor patterns to be deployed.

The description of the Surveillance Tracking decision situation is summarized in tabular form in Table 4-5.

4.7 ATTACK PLANNING

4.7.1 Situation Objective and Task Dynamics

At some point in the Surveillance Tracking decision situation, a decision may be made to launch an attack on the hostile submarine, giving rise to the attack planning situation. In this situation, the objective is simply to determine the best possible plan of attack against the target. The dynamics of the situation are multi-dimensional independent, with each different aspect of the attack plan constituting a different dimension of the decision.

Table 4-5. Surveillance Tracking

Objective: Maintain continuity of target track

Task Dynamics: Closed-Loop Iterative

Underlying Process Involved: Prediction of future location of target from inferred course and speed, estimated present location, and sensor responses.

Value Criterion: None

Variables and Paramters:

Inputs

- Propagation Loss
- Bathythermal Conditions
- Ambient Noise
- Estimated Target Location, Course, Speed, Depth
- On-Station History of Contact with Target
- Stores Available
- Sensor Positions, Type, Setting
- Time Remaining On-Station

Decision Variables

- Plan of Action (next pattern)
- Stores Management

Parameters

- Sensor Capabilities
- Target Signature
- Target Movement Properties
  - Target Speed Limitations
  - Target Depth Limitations
  - Target Maneuvering Limitations
  - Target History of Evasive Actions

Outputs

- Sensor Monitoring Information
- Predicted Target Position
- Location, Depth, Setting of Future Sensors

Relevant Analyses:

(1) Optimization of next pattern
(2) Monitoring of existing sensors for failures causing coverage lapse

Relevant Displays:

(1) Location and depth of present sensors
(2) Types and settings of present sensors
(3) Predicted position and uncertainty area of target
(4) Stores remaining
(5) Possible new sensor patterns

Required Human Judgments: New pattern geometry

4.7.2 Underlying Process Involved

The process involved is the attack that the platform intends to launch against the target. Unlike the other situations, this process does not take place within the decision situation, but after it.

4.7.3 Value Criteria

The success of the attack is measured in terms of the damage inflicted on the submarine. In the planning stage, the attack plan will be chosen that promises to inflict the greatest damage on the target, so the value criterion to be used is some (unidimensional) scale of damage. However, damage can be inflicted on any or all of the target's various systems (e.g., weapons systems, maneuvering systems, life support systems, etc.) independently of each other. Therefore, the damage scale must take into account, and combine, the amounts of damage inflicted on each of the relevant systems of the target.

4.7.4 Variables and Parameters

4.7.4.1 Inputs

The basic environmental conditions are again input variables (PL, BT, ambient noise, sea-state), although in this case their impact is primarily on the attack conditions and only to a lesser extent on the sensor detection capabilities. Other input variables concern the target and the ASW platform. In the former case, the estimated position, course, speed and depth are needed, and in the latter case, the present speed, location and course are needed. In addition, the locations, settings and types of deployed sensors and the stores remaining are input variables, along with the weapon loadings of the aircraft.

4.7.4.2 Parameters

In addition to the basic parameters of sensor capabilities and target operating limitations, two additional types of parameters are needed -- the charcteristics of the weapons that can be used in the attack and the vulnerability of the target to each of these weapons.

4.7.4.3 Outputs

There are two groups of output variables -- one dealing with the actual attack and one dealing with sensor placement. Included in the first group are the weapon release, the location, the weapon entry location, the speed of the aircraft at the time of the weapon release and the angle of the weapon. The estimated damage to the target's various systems is also included here. In the second group are the location, type and setting of additional buoys to be deployed. The placement of additional buoys in the attack planing situation may be primarily for monitoring the results of the attack rather than for further tracking of the target.

4.7.4.4 Decision Variables

There are two decision variables; (1) the determination of an attack plan, which requires decisions of when to attack, where to attack and with what weapons to attack, and (2) weapon-stores management, which is analogous to sensor-stores management.

4.7.5 Relevant Analyses

One type of analysis that is obviously relevant here is the optimization of the attack plan in terms of the value criterion scale of target damage. A second type of analysis that could be useful is a sensitivity analysis of the estimated target damage resulting from a planned attack to the uncertainty in the location of the target and to the performance characteristics of the weapons used.

4.7.6 Relevant Displays

Several of the displays that are relevant in this situation are similar to those discussed in the previous situations: the location and depth of additional sensors to be deployed, the settings and type of currently deployed sensors, and the sensor stores remaining. Two additional displays are relevant; (1) a display of the geography of the attack, including the location, motion and altitude of the aircraft at the point of weapons release, the angle of release and the point of entry of the weapon, as well as the target location, and (2) a display of the weapons stores remaining.

4.7.7 Required Human Judgments

The TACCO will be required to determine the point at which attack criteria have been gained and an attack may be placed.

The description of the Attack Planning situation is summarized in tabular form in Table 4-6.

Table 4-6. Attack Planning

Objective: Determine the optimal plan of attacking the target

Task Dynamics: Multidimensional Independent

Underlying Process Involved: Attack of airborne ASW platform on hostile submarine

Value Criterion: Combined (unidimensional) scale of damage to target

Variables and Parameters:

Inputs

- Propagation Loss
- Bathythermal Conditions
- Ambient Noise
- Sea-State
- Estimated Target Position and Area of Uncertainty
- Estimated Target Location, Speed, Course and Depth
- Aircraft Speed, Location, and Course (present)
- Locations and Settings of Deployed Sensors
- Aircraft Weapons Loadings

Decision Variables

- Plan of Attack
- Weapon Stores Management

Parameters

- Target Movement Properties
  - Target Speed Limitations
  - Target Depth Limitations
  - Target Maneuvering Limitations
  - Target History of Evasive Actions on Previous Missions
- Target Signature
- Sensor Capabilities
- Weapons Characteristics
- Aircraft Operating Characteristics

Outputs

- Aircraft Location at Weapons Release
- Aircraft Speed and Course at Weapons Release
- Location of Weapon Entry
- Angle of Weapon Entry
- Estimated Damage to Target Systems
- Location, Type, Setting of Additional Sensors

Relevant Analyses:

(1) Optimization of attack plan on value criterion scale
(2) Sensitivity analysis of target damage to uncertainty in target location and weapon characteristics

Relevant Displays:

(1) Geography of attack
(2) Location and depth of additional sensors
(3) Types and settings of deployed sensors
(4) Sensor stores remaining
(5) Weapon stores remaining

Required Human Judgment: Determination of gain of attack criteria

5. MATCHING DECISION AIDING TECHNIQUES WITH DECISION SITUATIONS

In this section, techniques from the decision aiding taxonomy developed in Section 3 will be matched to the six ASW decision situations identified in Section 2 and described in Section 4. This matching will take a very general form, i.e., associating one or several kinds of techniques with broad aspects of the situations, rather than a very specific form, i.e., associating one specific technique with every individual aspect of each situation. There are two reasons for this.

First, a very detailed matching would be inappropriate to the scope of the present research. There are many points in the matching of aiding techniques with decision situations where the selection of one technique over another will depend on the results of experimentation and on implementation concerns. Such choices are more properly design decisions for an actual decision aid, and should be made only at the time the aid is designed and developed. Where possible, however, the criteria for making these design decisions are stated.

Second, the level of detail in the matching task that can be achieved without resorting to subjective judgment varies greatly from one part of the taxonomy to another. At the most general level in the taxonomy (i.e., the six broad categories of techniques), it is possible to draw firm conclusions as to the need for and applicability of techniques of each type. For example, it is possible to conclude that some type of outcome calculator is needed or that a technique which incorporates human judgment is required. For some of these six categories, it is possible to make even finer level distinctions with the same degree of certainty, while for others, it is not. It may be possible, for example, to decide that a graphic display technique is needed as opposed to a digital display, but it may not be possible to choose which type of outcome calculator is most appropriate. Particularly in those parts of the taxonomy where application of a technique involves extensive modeling (outcome calculators, analysis features, value models), the choice among essentially equivalent methods simply cannot be made on the basis of differences among the techniques alone. Modeling is still as much an art as it is a science and the choice of a model type depends as much on the preferences and capabilities of the modeler as do the choices of the factors to be included and excluded in the model, the level of detail used in the model, and so on. When any of a variety of techniques could be applied to the same aspect of one of the decision situations, they will all be discussed.

5.1 HOW THE MATCHING IS DONE

The categories used in the situation descriptions in Section 4 and in the taxonomy of techniques in Section 3 are directly comparable, facilitating the matching process. Outcome calculators model and predict the results of the real-world processes associated with a decision selection. Thus the relevance of the various outcome calculators can be determined by comparing the processes underlying the situation with the capabilities and characteristics of the various types of outcome calculators. A value model quantifies and represents the value criteria of a decision situation. Thus the relevance of the various value models can be determined by comparing the value criteria of the situation with the capabilities and characteristics of the various types of value models. Data control techniques manipulate and manage the data involved with a decision situation, so the relevance of the various data control techniques to a decision situation can be determined by comparing the variables and parameters associated with the situation with the capabilities and characteristics of the various data control techniques. Analytic techniques provide analytical data manipulations, so the relevance of the various analytic techniques to the decision situation can be determined by comparing the analyses that are relevant to that decision situation with the capabilities and characteristics of the various analysis techniques. Display/entry techniques format, present and accept information for and from the user. Thus the relevance of the various display/entry techniques can be determined by comparing the display requirments for the decision situation with the capabilities and characteristics of the various display/entry techniques. Finally, human judgment refining/amplifying techniques enhance the judgments required from the man, so the relevance of these techniques to a decision problem can be determined by comparing the human judgments required in each decision situation with the capabilities and charcteristics of the various human judgment refining/amplifying techniques.

The matching was accomplished by considering all the techniques in each category of the taxonomy against the corresponding aspect of each decision situation, and identifying the most appropriate techniques for that situation. The matching results are shown in matrix form in Table 5-1. Techniques (the columns) that were found applicable to a decision situation (the rows) are indicated by a check. Some techniques were found to be definitely applicable to given situation and others possibly applicable. Matchings which are not definite are indicated by circled checks, while those which are definite are indicated by uncircled checks.

There are two ways in which the information in Table 5-1 can be presented and discussed. First, the range of applicable techniques from each category in the taxonomy could be determined by examining each descriptive category across all the situations (i.e., by examining the columns). For example, by considering the underlying processes involved in each of the decision situations, the types of outcome calculators needed for Naval Air ASW decision aids can be determined. Second, by examining all the descriptive categories for each situation (i.e., by examining the rows) the techniques appropriate to each situation can be determined. For example, by considering all the techniques matched to the Lost Contact Reacquisition situation, the basic components of a decision aid for that situation can be determined. Both approaches are taken below, because they provide complementary perspectives. The range of applicable aiding techniques (the first approach) is discussed in Section 5.2. The general correspondences between the techniques and the ASW mission are presented in that section, along with general conclusions as to the specific techniques that are

Table 5-1. Decision Situations Matched with Decision Aiding Techniques

	DECISION AIDING TECHNIQUES: OUTCOME CALCULATORS				VALUE MODELS					DATA CONTROL		ANALYSIS							DISPLAY/DATA ENTRY					HUMAN JUDGMENT REFINEMENT/AMPLIFICATION		
DECISION SITUATION	CLOSED FORM ANALYTIC MODELS	PROBABILISTIC MODELS	DETERMINISTIC SIMULATIONS	MONTE-CARLO SIMULATIONS	MULTI-ATTRIBUTE UTILITY MODEL (MAUM)	ADAPTIVELY CONSTRUCTED MAUM	DIRECT ASSIGNMENT OF UTILITIES	RISK-INCORPORATING UTILITY MODELS	NON-LINEAR UTILITY MODELS	AUTOMATIC DATA AGGREGATION	DATA MANAGEMENT TECHNIQUES	OPTIMIZATION TECHNIQUES	ARTIFICIAL INTELLIGENCE TECHNIQUES	SENSITIVITY ANALYSIS	INTRA-PROCESS ANALYSIS	INFORMATION PROCESSING ALGORITHMS	STATUS MONITOR AND ALERT	STATISTICAL ANALYSIS	DISPLAY GRAPHICS	INTERACTIVE GRAPHICS	WINDOWING	SPEECH SYNTHESIS/RECOGNITION	QUICKENING	OPERATOR-AIDED OPTIMIZATION	ADAPTIVE PREDICTIONS	BAYESIAN UPDATING
ON-STATION SEARCH		(✓)		(✓)	✓				✓			(✓)		✓			✓		✓	✓	(✓)			(✓)	(✓)	(✓)
CONTACT CLASSIFICATION/ VERIFICATION					(✓)			(✓)	✓	✓	✓		(✓)			(✓)		(✓)	✓		✓					✓
LOCALIZATION		(✓)		(✓)	(✓)				(✓)	✓		(✓)		✓		✓	✓		✓	✓	(✓)			(✓)	(✓)	(✓)
SURVEILLANCE TRACKING		(✓)		(✓)						✓	✓	(✓)					✓		✓	✓	(✓)			(✓)	(✓)	(✓)
ATTACK PLANNING	(✓)	(✓)	(✓)	(✓)	✓							(✓)		✓					✓		✓			(✓)		(✓)
LOST CONTACT REACQUISITION		(✓)		(✓)					✓			(✓)				✓	✓		✓	✓	(✓)			(✓)	(✓)	(✓)

relevant to several or all of the decision situations. In addition to providing an overview, this discussion will serve to avoid a great deal of redundancy in the following Section 5.3, where the techniques relevant to each individual decision situation (the second approach) are discussed.

5.2 APPLICABLE TECHNIQUES

5.2.1 Outcome Calculators

All of the decision situations but one (Classification) involve a dynamic real-world process. Similarities among these processes suggests that there are two general processes involved, a *search/detection* process and an *attack/destruction* process. The construction of a separate outcome calculator for each of these two processes is appropriate.

The search/detection process is associated with the On-Station Search, localization, Surveillance Tracking and Lost Contact Reacquisition situations. It relates to the ASW platform's function of detecting and/or determining the location of the target in its surveillance area. The primary difference among situations with respect to this process is in the amount of available information concerning the target. At one extreme, there may be no information on the target's possible location (in the On-Station Search situation); at the other extreme, the target's precise location, depth, course, and speed may be known (in the Surveillance Tracking situation). An outcome calculator for the search/detection process would predict or estimate the result of the detection and/or localization effort over time, given an actual or proposed sensor field, and the range of locations and movements of target. The outcomes being predicted would be the probability that a target would be detected (over time) by 1 to n sensors and the probability that a target in the surveillance field would pass out of the sensor field undetected (again, over time). Given the need for probabilistic outcomes, either a probabilistic model or a Monte-Carlo simulation model outcome calculator would be appropriate, but it is not possible to say which of these two is preferable.

The attack/destruction process would be used in the Attack Planning situation to model the ASW platform's attack on the hostile target and the results of that attack. Given a proposed or actual attack plan and an estimated target location, depth, speed and course, the model would predict both the primary outcomes (the damage resulting to each of the target's systems) and the secondary outcomes (the detectable impact of the damage on the environment, such as presence of oil slicks, changes in acoustical emissions, etc.). The outcome calculator for this process would model the process either deterministically or stochastically, either in closed form or through simulation, so it is not possible to state which of the four types of outcome calculators would be most appropriate for this process.

5.2.2 Value Models

Although all of the situations but one (Surveillance Tracking) have identifiable value criteria, there is no single type of value model that is appropriate to all the situations or all the criteria. The value models appropriate to each situation are discussed in Section 5.3.

5.2.3 Data Control

Little is needed in the way of novel data control techniques in any of the situations. However, existing data control techniques can be employed to considerable benefit in seeral of the situations. It will be necessary to maintain a data base (containing such information as target signatures, movement limitations of possible targets, and histories of target movements recorded on previous missions) to be used by the decision aids for the various situations. The decision maker would interface only indirectly with this database via some sort of interactive query system, but the database itself would interface with the various aids directly, via conventional database management techniques. While it is possible that some of the inputs may require some degree of aggregation (or disaggregation, such as separating out individual frequency portions of incoming sensor signals), standard techniques also can be applied to achieve these ends, eliminating the need for specialized aggregation methods.

5.2.4 Analysis

Nearly all of the analysis techniques listed in the taxonomy are relevant to one or more of the six situations, but two of them, sensitivity and optimization analysis, deserve comment. Both of these methods would be applied in conjunction with one or both of the outcome calculators, rather than by themselves. Sensitivity analysis would exercise an outcome calculator to determine the precise impact of various input variables on each of the output variables. Optimization analysis would be used to determine the configuration of input values which optimizes some function of the output values. Therefore, the applicability of these methods must be considered when choosing outcome calculator types.

5.2.5 Display/Data Entry

All of the situations require the display of some spatial information, in most cases involving relative sensor locations, coverage area, and/or target locations and uncertainty areas. It is well documented that human operators can assimilate such information much more readily from a graphic or spatial type of display (such as the depiction of locations on a map) than from an alphanumeric type of display (such as a listing of the coordinates of the locations only). Graphic display techniques will be needed in all of the seven situations. Furthermore, in all but one of the situations (Classification), the TACCO will be required to enter information on the location of new sensors, and the entry of spatial information is similarly facilitated by the use of spatial or graphic entry techniques. Interactive graphics are therefore needed in five of the decision situations. There is a potential need for the simultaneous independent display of different information, but the extent of this need can only be determined through an experimental evaluation of specific platform and operator task requirements. Windowing is therefore only potentially needed in each of the aid situations.

5.2.6 Human Judgment Refining/Amplifying Techniques

Because these techniques are so different from one another, they must be considered individually.

5.2.6.1 Operator Aided Optimization

Operator aided optimization (OAO) produces a similar result to fully-automatic optimization and involves a similar procedure, so in situations where optimization is applicable, OAO is also applicable. The difference between the two techniques is that while automatic optimization uses only explicit computational techniques, OAO incorporates the intuitive problem solving capabilities of a human operator into the optimization process. Several studies have shown that OAO proceeds much more rapidly than automatic optimization, particularly when the solution surface of the problem is both "hilly" (multimodal) and nonlinear. In classical linear programming formulations, (i.e. where the solution surface is monomodal) the human cannot add much to the automatic approach. Although it can often produce optimal solutions faster, OAO places demands on the decision maker's attention that automatic optimization does not, and this must also be taken into consideration when deciding whether OAO is the most appropriate method.

5.2.6.2 Adaptive Prediction

Adaptive prediction is not analogous to any of the analysis techniques in the taxonomy; its closest analog is the strict application of a multi-attribute utility model (MAUM). In fact, the adaptive prediction technique is directed toward making the decision maker's performance completely consistent with his underlying MAUM and the expected utility hypothesis. By observing the choices of the decision maker and inferring his MAUM function, adaptive prediction relies on the essential correctness of the decision maker's implicit mental model of the process or procedure involved. To the extent that he has an accurate model of the process, this technique can improve his decision making performance, but to the extent that he has a fundamentally inaccurate mental model, the technique can actually make his performance worse. A decision maker who exhibits an unrealistic perference (or aversion) to using certain tactics or resources may well be better off behaving inconsistently with his underlying utility function, (as the literature on behavioral decision making indicates most people do anyway). The adaptive prediction technique, however, may force such a decision maker to behave totally consistantly with his utility function, and thus degrade his performance. The adaptive prediction technique is applicable in situations where an outcome calculator and value model could be used in combination to help a decision maker select among alternatives. But because the technique itself requires operational training, it can be used only in situations with closed-loop iterative task dynamics. Choosing between the adaptive prediction and the outcome calculator/value model approaches depends on whether all human decision makers in this situation can be expected to possess well-formed accurate mental models of the relevant underlying process.

5.2.6.3 Bayesian Updating

Bayesian updating (in cases where the likelihood ratios are subjective assessments made by a human) is also a technique which relies on the decision maker's implicit mental model of the situation. Unlike the adaptive prediction method which must be "trained" through the observation of actual decisions, the Bayesian updating method requires no training. Instead, the decision maker (or some other person) must supply two types of subjective information before the actual decision situation is encountered -- likelihood ratios and prior distribution(s). As with the adaptive prediction method, a value model may be used to suggest one specific alternative based on the posterior distributions, but unlike the adaptive prediction model, the value model need not be constrained to a MAUM form.* The implicit mental process or procedure model of the decision maker is used in the process of deriving and making consistent the likelihood ratios, which are used to transform the prior distributions into the posterior ones. As a very general technique, Bayesian updating is applicable to any situation where information processing algorithms or outcome calculators are required. The Bayesian updating method is preferable to the outcome calculator approach when the implicit information processing or process models of the decision maker are superior to any possible outcome calculator or computational

*The value model used by DDI, for example, to suggest courses of action from the posterior distributions was a MAUM but that choice was not required by the Bayesian inference procedure. The adaptive prediction method is constrained to the MAUM because of the type of pattern recognizer used.

algorithm, or when the computational facilities required by these explicit models are not available.

5.3 APPLICABLE TECHNIQUES BY SITUATION

In this section, the techniques or groups of techniques which are applicable to each of the six situations are identified. The manner of presentation is designed to coincide closely to the format of the decision situation descriptions in Section 4.

5.3.1 *On-Station Search*

On-Station Search consists of implementing the search plan developed in the mission planning segment. Its objective is to gain target contact. This is done by reducing the ocean area of uncertainty by the deployment of selective sensor pattern/suites. This situation is essentially a closed-loop iterative deployment and monitoring operation, where the decision strategy must deal with in-situ plan of action, pattern adjustment associated with the probability of detecting a target over elapsed time, and consideration of the probability of no target in the search area over time.

5.3.1.1 Outcome Calculators

An outcome calculator that predicts the results of the search/detection process is needed in this situation. Because the value criteria for this situation are probabilistic, the calculator must provide probabilistic outputs, indicating that either a probabilistic or Monte-Carlo outcome calculator is needed.

5.3.1.2 Value Models

The value criteria defined for On-Station Search are both probabilities relating to the presence or absence of the target as the search area over time. These probabilities can be used directly as a utility or value function for the situation. Since these probabilities are both complex combinations of many other variables, the value model required to calculate them will be non-linear. A multiattribute utility model which combines these two probabilities into a single measure may also be used.

5.3.1.3 Data Control

No data control techniques are needed in this situation.

5.3.1.4 Analysis

The situation description identified three relevant analyses for this situation. Either automatic optimization or operator-aided optimization techniques are needed to optimize sensor patterns. The optimization must be conducted using the same value measure as used in the value model, to insure that consistant value criteria are met. The optimization should be conducted in conjunction with the search/detection outcome calculator and the nonlinear value model in order to identify the optimal pattern according to the stated value criteria for the situation. The techniques of alerting could be used to provide the needed transparent* checking of the deployed sensors for critical failures or new signals. The technique of sensitivity analysis could be used to determine the sensitivity of the value criteria to the number of sensors deployed. The technique would be used in conjunction with the search/detection outcome calculator and the nonlinear value model.

5.3.1.5 Display/Data Entry

As discussed above, the spatial displays (of pattern geometry, sensor locations, coverage area, etc.) would be best presented using graphic display techniques. The entry of spatial information (principally the designation of new sensor location) would similarly be best done using interactive graphic techniques. Other information would be best entered/displayed using alphanumeric techniques, possibly in conjunction with a windowing technique.

5.3.1.6 Human Judgment Techniques

Since (automatic) optimization is applicable to this situation, operator-aided optimization could also be used in its stead. As discussed

*The checking procedure is conducted automatically while the TACCO engages in other actions. Any condition detected by the computer which may warrant the attention of the TACCO is then displayed to him. The checking proceeds continually out of the 'sight' of the TACCO, and is thus transparent to him. He is aware of it only when it brings some fact to his attention.

above, the adaptive prediction and Bayesian updating techniques can be used in place of the (probabilistic or Monte-Carlo) outcome calculator and the (nonlinear) value model, although the Bayesian approach would require some reformulation from its standard presentation to consider two dimonsional probabitity functions.

5.3.2 Classification

This is a critical step in the on-board action sequence because it serves to verify that genuine contact has been made (target has been isolated from background) and to determine the type of target contacted. Target type is ascertained from a complex analysis of contact signature characteristics and matched to a library of signature types. Determination of target type sets the stage for subsequent localization and track functions.

5.3.2.1 Outcome Calculators

As there is no process involved with the Classification situation, no outcome calculator of any type is needed.

5.3.2.2 Value Models

Each of the two relevant value criteria must be modeled separately. The first criteria (probability that the contact is a true contact) can be directly used as a value or utility function. Since this probability will be some complex function of the situational input variables, the value model used to generate it will, in all likelihood, be nonlinear. The second criteria (target identification) is not a probability but a composite measure of the confidence in the correctness of the classification. Since the classification must ultimately be made (or at least accepted) by the TACCO, his attitude toward the riskiness of misclassification is an important parameter. This suggests that a risk-incorporating utility model is relevant. Alternatively, if risk is not deemed relevant, then this second value criteria could be modeled by a simpler multi-attribute model (MAUM).

5.3.2.3 Data Control

There is a significant need for data aggregation methods that collate and process multiple sensor returns. In addition to preparing these aggregated returns for inspection by the TACCO, the aggregation process should also combine them in a manner compatible with later analytic requirements.

5.3.2.4 Analysis

Three different analyses are listed as being relevant to this situation. Two of them -- the comparison of incoming signals with a pre-stored set of expected target signals and the determination of candidate (or final) classifications -- can be accomplished by any of a variety of analytic techniques. Statistical techniques could be used to make the comparison, or artificial intelligence techniques (particularly pattern recognition/classification methods) could be used. Alternatively, numerical information processing algorithms such as a Fourier analysis could be applied. All of these techniques are potentially applicable to the Classification situation. The third relevant analysis -- determining the correlations between the sensors receiving signals -- could be best accomplished by standard statistical methods in conjunction with an information processing algorithm which allows the propagation loss and bathythermographic conditions to be considered in the computations.

5.3.2.5 Display/Data Entry

Most of the displays relevant to this situation could be presented through conventional or windowed alphanumeric display techniques, except for display of sensor locations and signal correlations which would be best depicted in a graphic display.

5.3.2.6 Human Judgment Techniques

The judgment required of the TACCO is the final selection of a classification from among the candidate classifications. The technique of Bayesian updating could be employed to refine the sequential reduction of the candidate classifications by allowing the TACCO to use experienced-based selections to update the statistically derived probability distribution of alternatives.

5.3.3 Localization

The objective of Localization is to confine the target geographically. The precision with which the source is localized determines the probability with which the weapons can be successfully delivered.

5.3.3.1 Outcome Calculators

Since this situation involves the same search/detection process as the on-station search situation, the same two types of outcome calculators are relevant: probabilistic and Monte-Carlo models.

5.3.3.2 Value Models

The value criterion for this situation is a function of several variables: uncertainty in target location, course, depth and speed. If these factors are considered to be independent of each other, then the value criterion can be modeled with a simple multi-attribute utiity model. If they are not considered to be independent, then a nonlinear utility model must be used.

5.3.3.3 Data Control

Effective use of sensor data involves extensive data aggregation procedures. As with the Classification situation, multiple sensor returns should be aggregated automatically.

5.3.3.4 Analysis

Both of the optimization procedures identified in the situation description (optimization of sensor monitoring sequence/pattern and optimization of new sensor patterns) can be achieved by either automatic optimization or by operator-aided optimization. An alerting technique could be applied to achieve the required transparent checking of the deployed sensors for critical failures or for new signals. Sensitivity analysis could be applied to the outcome calculator to yield the relevant data on the relationships between the value criteria and the numbers of additional sensors deployed and an information processing algorithm could be used to calculate the target's uncertainty area and estimated location.

5.3.3.5 Display/Data Entry

The special displays required in this situation are best presented through graphic display methods. The entry of spatial information (new sensor locations) is facilitated by interactive graphics. Other relevant information can be displayed with alphanumeric methods. Windowing could provide multiple simultaneous access to the alphanumeric displays.

5.3.3.6 Human Judgment Techniques

Since automatic optimization is applicable to this technique, operator-aided optimization is also. As an alternative to the use of an outcome calculator and value model, either the adaptive prediction technique or the Bayesian updating method could be used.

5.3.4 Lost Contact Reacquisition

The difference between Lost Contact Reacquisition and the initial search situation is that in the Reacquisition situation the target's last-position, its type, course and speed are known. Reacquisition strategies, therefore, are based upon known target parameters which include maneuverability, diversionary tactics and avoidance/deception capabilities.

5.3.4.1 Outcome Calculators

The search/detection process is involved in this situation also, with the platform attempting to re-establish the lost contact. As with the other situations in which the search/detection process is involved, both the Monte-Carlo simulation and probabilistic model outcome calculators are applicable.

5.3.4.2 Value Models

The value criterion for this situation is a combination of the factors which contribute to reduction in target uncertainty area over time -- the time since loss, the target movement capabilities and the sensor field detection capabilities. It is unlikely that these factors can be combined in a linear additive manner (since the latter two factors are themselves multivariate), indicating that a nonlinear value model will be required.

5.3.4.3 Data Control

No specialized data control techniques are needed beyond those already provided by the platforms of interest.

5.3.4.4 Analysis

Three relevant analyses were identified for the Lost Contact Reacquisition situation. The technique of alerting could be used to provide the transparent checking of deployed sensors for critical failures or for new signals. The needed optimization of new sensor patterns could be achieved either through automatic optimization or through operator-aided optimization. An information processing algorithm could be used to calculate the target's uncertainty area and its estimated location.

5.3.4.5 Display/Data Entry

The display of spatial information, such as uncertainty areas or sensor locations, is best accomplished through graphic display techniques. The entry of spatial information such as new sensor locations is best done through interactive graphics. All other information can be displayed/entered using alphanumeric techniques, possibly with windowing.

5.3.4.6 Human Judgment Techniques

The operator-aided optimization technique is applicable in place of fully automatic optimization as described above. As alternatives to the use of an outcome calculator, either Bayesian updating or adaptive prediction techniques could be used.

5.3.5 <u>Surveillance Tracking</u>

The objective of Surveillance Tracking is to establish an anticipated target course so that sensor fields can be laid out ahead of the target. The amount of information available consists of instantaneous last-position, target type, course, speed and perhaps route objective data. The major unknown in surveillance tracking is the propagation conditions within the sensor fields to be laid down.

5.3.5.1 Outcome Calculators

Since the search/detection process is involved in this situation, the same two outcome calculators (i.e., Monte-Carlo simulation and probabilistic models) are applicable to this situation as to the other situations involving this process.

5.3.5.2 Value Models

As described in Section 4, Surveillance Tracking can be thought of as an all-or-nothing binary operation, with no value measure of "degree of tracking" possible. Because of this, no value model is required for the Surveillance Tracking situation.

5.3.5.3 Data Control

Both data aggregation and information management are required to manipulate the data relevant to surveillance track decision strategies.

5.3.5.4 Analysis

Only two types of analyses were identified as relevant to the Surveillance Tracking situation. The required transparent checking of deployed sensors for critical failures on new signals could be accomplished with alerting techniques. The optimization of new sensor patterns could be done with either fully automatic optimization or operator-aided optimization.

5.3.5.5 Display/Data Entry

The entry and display of spatial information would best be accomplished with graphic display/entry methods. Other information could be displayed entered using standard alphanumeric methods, possibly enhanced by a windowed alphanumeric display.

5.3.5.6 Human Judgment Techniques

Operator-aided optimization is applicable as an alternative means of optimization of new sensor patterns. Either Bayesian updating or adaptive prediction methods could be employed in place of an outcome calculator and value model for the search/detection process.

5.3.6 <u>Attack Planning</u>

Attack Planning is concerned with optimizing weapons delivery with respect to weapons capabilities and target type. Attack Planning is highly constrained by the time available.

5.3.6.1 Outcome Calculators

The process involved in this situation is the attack/destruction process. To predict the results of this process, some form of outcome calculator is needed but the precise type cannot be determined. Either a closed-form analytic model, probabilistic model, deterministic simulation or a Monte-Carlo simulation outcome calculator could be used.

5.3.6.2 Value Models

The value criteria specified in the situation description is a function of damage estimates to several different systems on the target. These different values can be most easily combined into a single value with a multi-attribute utility model.

5.3.6.3 Data Control

No special data control methods are required in this situation.

5.3.6.4 Analysis

The required optimization of the attack plan against the value criterion would be accomplished through either an automatic optimization or an operator-aided optimization method. The techniques of sensitivity analysis could be used to determine the sensitivity of the value criteria to the uncertainty in the location of the target.

5.3.6.5 Display/Data Entry

The display of the attack geography and geometry and of the displayed sensor locations will require graphic display techniques. The other displays (remaining weapons, remaining stores, and settings/depths of deployed sensors) can be presented with standard alphanumeric techniques. Windowing could be used to provide simultaneous access to these displays.

5.3.6.6 Human Judgment Techniques

The technique of Bayesian updating could be used as an alternative to some form of outcome calculator. Because the task dynamics of this situation are not closed-loop iterative, the adaptive prediction technique is not applicable. Operator-aided optimization could be used in place of automatic optimization to optimize the attack plan on the value criterion.

6. DECISION SITUATION PRIORITIZATION FOR DECISION AID DESIGN

Subdividing the air ASW mission into six distinct decision situations and matching decision aiding techniques with these decision situations provides a firm basis for the design and implementation of decision aids for naval air ASW. But while a number of decision aiding techniques have been identified above as applicable to each of the six decision situations, no assessment has thus far been made of the relative need or priority for the construction of decision aids for each situation. It is intuitively clear that the need for a decision aid (or aids) is not equal for each situation; some must have a higher priority than others. This section presents a preliminary scheme for prioritizing the decision situations and outlines an approach for a more sophisticated method for prioritization.

Section 6.1 discusses the key issues and difficulties posed by the prioritization task. Sections 6.2 and 6.3 detail the construction of the scale that was used to prioritize the decision situations and the results of the prioritization. Section 6.4 presents an overview of an alternate prioritization and validation methodology.

6.1 ISSUES AND PROBLEMS IN DECISION SITUATION PRIORITIZATION

The prioritization of the decision situations requires the construction of a figure-of-merit specifying their priority for decision aid development and the evaluation of each of the six ASW decision situations along that scale. Two key issues require resolution before the figure-of-merit can be defined. The first issue is the identification of the factors that contribute to priority. Clearly, many different factors may affect the priority of a situation: the importance of the situation to mission achievement, the relative workload of the TACCO during the situation, the speed with which decisions must be made in the situations, the possible negative consequences of incorrect decisions in the situation, and so on. Thus, decision aid priority is multi-dimensional, in that there are many independent factors or dimensions which contribute to it. Before a figure-of-merit could be defined, all the relevant factors had to be ascertained. Attempts to identify the factors relevant to prioritization led to three conclusions:

(1) That the list of possible contributing factors could be expanded nearly indefinitely,

(2) Although a few were obviously crucial, there was no simple method to determine which of the remainder were actually relevant to prioritzation, and

(3) Combining the individual factors into a single figure-of-merit presented a significant problem in itself, no matter which or how many factors were selected.

As a result, it was decided to reduce the number of factors to be considered in the figure-of-merit to the two which were clearly crucial to priority: the *positional importance* of the situation to the achievement of the overall mission objective, and the *relevant workload* of the TACCO during each of the decision situations. It is not claimed that these two factors are the only ones relevant to decision situation prioritization. They are merely the only ones which it was felt could be included within the scope of the current effort.

Positional importance of a situation refers to the interrelationships among the situations imposed by the sequential nature of the air ASW mission. A key ramification of the definition of the decision situations on the basis of goal events (see Section 2.2.2) is that the execution of the later situations is totally dependent on the successful completion of the earlier ones. Attack Planning, for example, cannot begin (much less be successful) unless contact is made, the contact is classified, and the contact is localized. On-Station Search, on the other hand, does not require the successful completion of any other decision situation because it is the first situation to occur. Thus, earlier situations have greater impact on the mission than the later situations because they affect all subsequent parts of the mission.

Operator workload was considered to be crucial because a principal, if not *the* principal, goal of air-platform decision aiding is to reduce and simplify the operator's decision making workload. The heavier the workload of the TACCO in a decision situation, the more a decision aid is needed for that situation.

A second issue in the construction of a figure-of-merit was the measurement of each of the identified contributing factors. Neither of the two factors given above have obvious or simple quantitative measurement scales. Yet, in order to define a figure-of-merit, such quantitative scales are required.

As with the identification of the relevant factors, it was clear that the measurement of the two chosen factors was a formidable problem that could not be thoroughly resolved within the scope of the current effort. The measurement of workload, for example, is one of the most widely studied issues in human factors engineering, yet no standard measurement method exists. Positional importance, on the other hand, has been given virtually no attention in the past, but appeared to be itself a combination of as many different factors as priority.

There were two possible approaches that could be taken to measurement of these two factors. One was an analytic or external approach in which measurement formulae were developed from an analysis of the platform and missions, and then applied to existing data. The other was an experimental or internal approach in which empirical measurements were made of the opinions and/or performance of actual experienced ASW personnel. The external approach was selected because it was considered desirable to develop, to the extent possible, an objective measure and methodology that could potentially be of value in the analysis of other decision aiding situations. The development of an experimental method, the location of suitable subjects and facilities, and the collection and analyses of the necessary data required by the internal approach would have been too sizeable an undertaking for the current effort.

6.2 THE FIGURE-OF-MERIT CALCULATION

The first step in calculating the figure-of-merit was to determine the way in which the two factors, positional importance and operator workload, would be combined. Both contribute positively to priority. Greater importance and greater workload both lead to higher priorities for a given decision situation, whereas a low workload or a low positional importance give a decision situation a low priority. Thus, a multiplicative combination rule was defined, as follows:

$$P_i = PI_i \times OW_i \tag{1}$$

where P_i is the priority of situation i, PI_i is the positional importance of the situation i, and OW_i is the operator workload of situation i.

The second step was to assign values to the PI_i and OW_i. This required the use of some strong simplifying assumptions. Without the use of these assumptions, the task would have quickly become intractable. The first assumption was that operator workload could be represented by only two factors -- the number of required operator tasks in a situation and the amount of time available to perform these tasks. The individual operator tasks (Section 2.5 and Table 2-3) associated with each decision function (Section 2.4 and Figure 2-2) were used as the basis for assessing operator workload. Since there was no basis for differentiating between each of the tasks, it was assumed that they could be treated as equivalently. Thus, the number of required tasks for decision situation i (NT_i) was defined as:

$$NT_i = \sum_{j \in DS_i} \sum_{t \in T} F_j(t) \tag{2}$$

where DS_i is decision situation i, T is the set of all operator tasks, and $F_j(t)$ is a function that is equal to 1, if task t is required for function j, and equal to 0, if it is not. Equation (2) simply says that NT_i is equal to the sum of all the tasks required for all the constituent decision functions in decision situation i. The calculation of the NT values for each of the six decision situations is summarized in Table 6-1.

The amount of time available for each decision situation was measured as the relative percentage of the on-station portion of the mission consumed by each decision situation. Since only the on-station search situation will arise in every mission, the determination of these relative time factors required the construction of several scenarios. In particular, the following mission scenarios were considered:

- No contact was made.
- Contact was made but not classified or localized.
- Contact was made, classified and localized but then lost.
- Contact was made, classified and localized and an attack was placed.
- Contact was made, classified, localized and tracked.
- Contact was made, classified, localized, tracked, and lost.
- Contact was made, classified and localized, an attack was attempted but the contact was lost.

A Delphi panel, consisting of Analytics' ASW analysts, then constructed estimates of the percent of the mission that would be devoted to each decision situation in each scenario. These relative time (RT) values were then averaged across the scenarios, to produce the values shown in Table 6-2.*

*Because each situation did not arise in every scenario, the values do not total to 100%.

Table 6-1. Calculation of Number of Operator Tasks for Decision Situations

DECISION SITUATION	CONSTITUENT DECISION FUNCTION	NUMBER OF ASSOCIATED OPERATOR TASKS $\Sigma F_j(t)$	TOTAL SITUATIONAL TASK SCORE (NT)
ON-STATION SEARCH	SEARCH AREA	10	76
	ENVIRONMENT	3	
	EQUIPMENT/STORES	5	
	AREA OBTENTION	2	
	PATTERN CONSTRUCTION	15	
	ENVIRONMENT UPDATE	8	
	SENSOR DEPLOYMENT	15	
	SEARCH EXTENSION	18	
CONTACT CLASSIFICATION/ VERIFICATION	SENSOR MONITOR	13	67
	CONTACT DETECTION	11	
	CLASSIFICATION	13	
	PATTERN ADJUSTMENT	30	
LOCALIZATION	ENVIRONMENT	3	101
	EQUIPMENT/STORES	5	
	ENVIRONMENT UPDATE	8	
	LOCALIZATION TACTICS	29	
	TRACK FIX	26	
	PATTERN ADJUSTMENT	30	
SURVEILLANCE TRACKING	ENVIRONMENT	3	131
	EQUIPMENT/STORES	5	
	ENVIRONMENT UPDATE	8	
	SENSOR DEPLOYMENT	15	
	SENSOR MONITOR	13	
	TRACK FIX	26	
	PATTERN ADJUSTMENT	30	
	SURVEILLANCE TRACK	31	
ATTACK PLANNING	ENVIRONMENT	3	93
	EQUIPMENT/STORES	5	
	ENVIRONMENT UPDATE	8	
	TRACK FIX	26	
	GAIN ATTACK CRITERIA	28	
	AIRCRAFT LAUNCH POSITION	3	
	WEAPON SELECT AND PRESET	8	
	WEAPON DELIVERY	12	
LOST CONTACT REACQUISITION	ENVIRONMENT	3	88
	EQUIPMENT/STORES	5	
	ENVIRONMENT UPDATE	8	
	SENSOR DEPLOYMENT	15	
	SEARCH EXTENSION	18	
	CLASSIFICATION	13	
	TRACK FIX	26	

Table 6-2. Decision Situation Relative-Time Factors

SITUATION	RELATIVE-TIME VALUE (RT)
ON-STATION SEARCH	53.0
CONTACT CLASSIFICATION/ VERIFICATION	14.6
LOCALIZATION	21.2
SURVEILLANCE TRACKING	13.6
ATTACK PLANNING	11.0
LOST CONTACT REACQUISITION	8.9

RT and NT were then combined into a measure of OW_i (operator workload in decision situation i) by dividing RT by NT, yielding the number of tasks per unit of time. Thus,

$$OW_i = \frac{RT_i}{NT_i} \tag{3}$$

Values for the positional importance, (PI), of each situation were determined by considering the sequential structure of the ASW mission, as discussed in Section 2.2. Since the mission was divided into segments, each of which had two possible outcomes, (the tree-like structure shown in Figure 2-1) and since no basis existed for differentiating the relative frequency with which each branch in the tree was taken, it was assumed that each segment had an equal probability of both outcomes being obtained. The PI of a situation, therefore, was defined as the probability of the branch leading into it being taken. For Lost-Contact Reacquisition, the only situation with more than one branch leading to it, PI was defined as the sum of the probabilities of all the branches. Figure 6-1 shows the assignment of weights to the branches of the mission structure tree, and Table 6-3 shows the PI values assigned to the various decision situations.

Table 6-3. Situational Positional Importance Values

DECISION SITUATION	POSITIONAL IMPORTANCE VALUE (PI)
ON-STATION SEARCH	1.000
CONTACT CLASSIFICATION/ VERIFICATION	.500
LOCALIZATION	.250
SURVEILLANCE TRACKING	.083
ATTACK PLANNING	.083
LOST CONTACT REACQUISITION	.337

6.3 DECISION SITUATION FIGURE-OF-MERIT VALUES

By substituting equation (3) into equation (1), the following computational formula was derived for the situational figure-of-merit:

$$\text{Figure-of-Merit(situation i)} = PI_i \left(\frac{RT_i}{NT_i} \right)$$

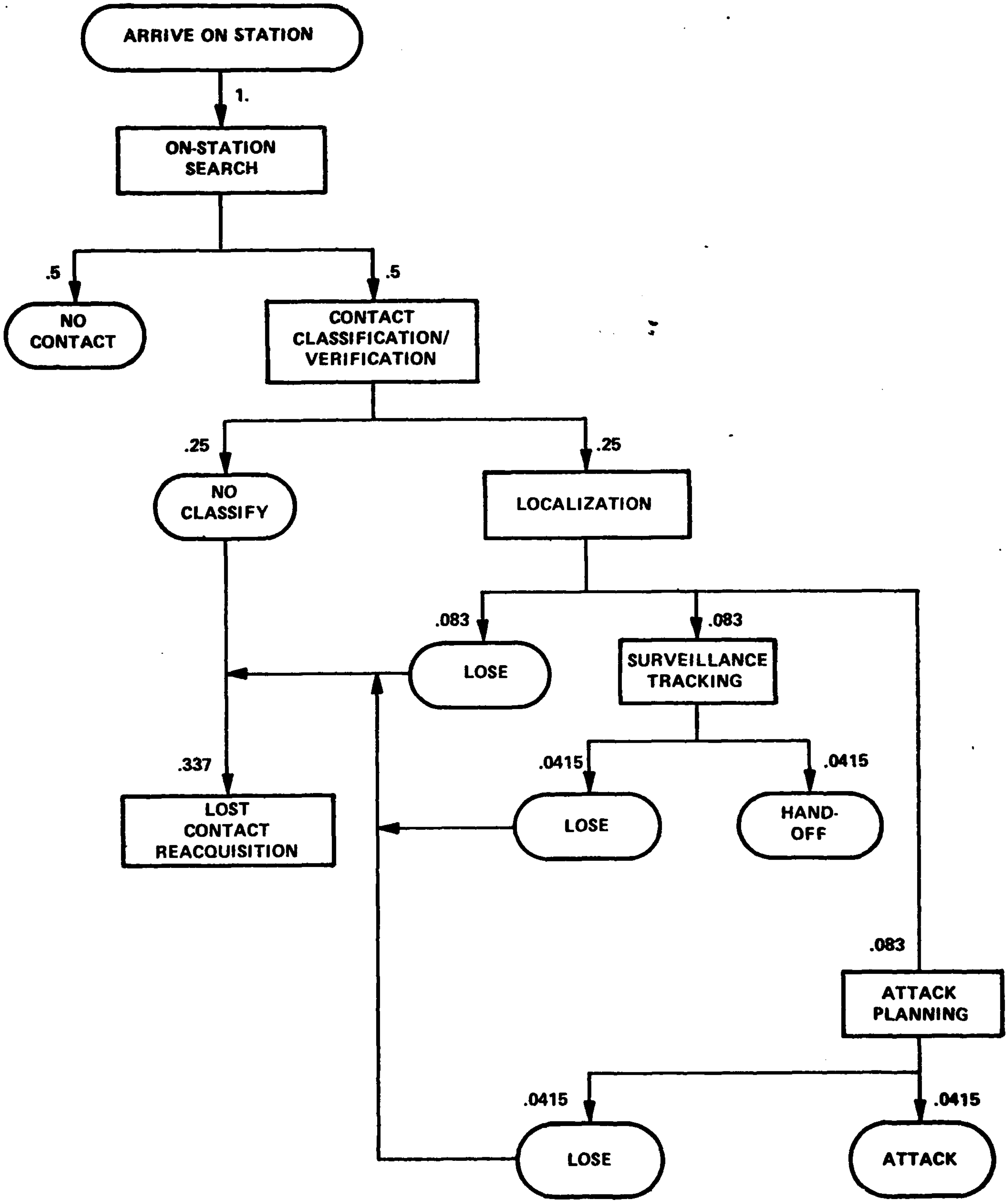

Figure 6-1. Mission Structure Tree with Branch Probabilities

The values for the PI_i, NT_i, RT_i, P_i, and the figure-of-merit for all the decision situations are summarized in Table 6-4. Based on of these values, the final prioritization of the decision situations, in order of decreasing priority, is:

(1) Lost Contact Reacquisition

(2) Contact Classification/Verification

(3) On-Station Search

(4) Localization

(5) Surveillance Tracking

(6) Attack Planning

These results are pictured in Figure 6-2.

Table 6-4. Decision Situation Figure-of-Merit Calculations

DECISION SITUATION	$\Sigma\Sigma F_j(t)$	RT	PI	FIGURE-OF-MERIT
ON-STATION SEARCH	76	53.0	1.000	1.430
CONTACT CLASSIFICATION/ VERIFICATION	67	14.6	.500	2.290
LOCALIZATION	101	21.2	.250	1.190
SURVEILLANCE TRACKING	131	13.6	.083	.803
ATTACK PLANNING	93	11.0	.083	.701
LOST CONTACT REACQUISITION	88	8.9	.337	3.320

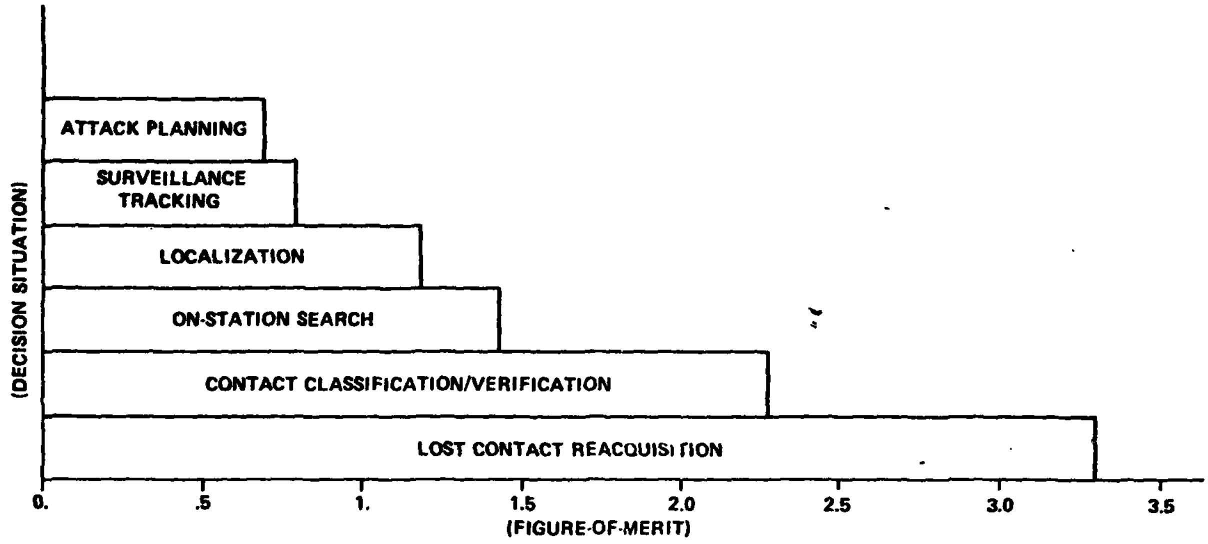

Figure 6-2. Decision Situation Figure-of-Merit Rankings

6.4 ALTERNATE APPROACHES TO PRIORITIZATION

The prioritization methodology described above, although workable, does have a number of shortcomings. First, the number of factors relevant to prioritization is almost certainly greater than two, and the use of only two probably caused certain important relationships to be missed. Second, the number and strength of the assumptions required to measure positional importance and operator workload detract from the validity of the results. In particular, the operator tasks are not all equivalent, nor are the probabilities of each alternate outcome of each mission segment equal. Third, except for determining the relative time values shown in Table 6-2, no attempt was made to incorporate the knowledge, experience, and intuition of operational ASW personnel into the analysis.[1]

[1] An attempt was made to validate the prioritization with ASW personnel from the P-3C, S-3A, and LAMPS MK III project offices at NADC. The small sample size (4), however, prevented any meaningful interpretation of the results.

To correct these shortcomings, an alternate and more sophisticated methodology for prioritizing the decision situations is needed. A brief discussion of such a proposed methodology is presented below.

The basic philosophy of the methodology is that a prioritization should incorporate the viewpoint of experienced ASW personnel and should explicitly treat priority as a multidimensional measure. This methodology has two broad steps -- the derivation of the relevant dimensions and the construction of a priority scale which combines these dimensions. The first step uses a psychometric technique called Multi-Dimensional Scaling (MDS). Experienced ASW personnel are asked to make judgments about the basic similarities and differences among the decision situations and constituent decision functions. These data are then preprocessed to create a numerical measure of dissimilarity among decision functions, after which MDS is used to extract the independent dimensions which underlie the original judgments. Because the judgments are unlikely to possess interval measurement properties, MDS utilizes only the ordinal properties of the similarity measure. Each of the dimensions detected by the MDS procedure represents a distinct factor, upon which some or all of the personnel interviewed based their judgments. Together, the dimensions represent all the factors that are relevant to ASW decision making according to the subject ASW population.

The second step of the methodology uses the technique of unfolding analysis to relate the dimensions to judgments concerning the ranked importance of each of the constituent decision functions in the overall ASW mission. Unfolding analysis determines the form of the function which best models the importance rankings as a combination of the dimensions identified in the first step and then constructs the function. This combination function will be a priority function for the decision functions which constitute the decision situations. The priority of the decision situations can then be calculated by summing the priorities of each constituent decision function and dividing by the number of constituent functions, to normalize the scores.

This methodology solves the factor identification problem of the present prioritization by empirically determining the relevant dimensions. Because it is not a purely analytic approach, this methodology is able to eliminate the need for numerous simplifying assumptions and hence solves the second problem with the current prioritization. Because it is based on data from experienced ASW personnel, it also solves the third problem (conformance with expert opinion) as well.

7. CONCLUSIONS AND RECOMMENDATIONS

This effort has resulted in:

(1) The identification and prioritization of six Naval Air ASW decision situations,

(2) A structural approach to decomposing and describing the decision problem central to each decision situation,

(3) A taxonomy of decision aiding techniques, based on the decision aiding functions performed by the various techniques,

(4) A methodology for matching decision aiding techniques with aspects of a decision situation as a means of determining the necessary elements of a decision aid for the situation, and

(5) An outline of the decision aiding techniques applicable to aiding each of six Naval Air ASW decision situations.

In the course of the study, it was found that the *decision situation* -- the decision making context in which many individual decision functions have to be coordinated in order to achieve some mission objective -- is a more useful construct for identifying potential decision aiding areas than is the individual decision function. Air ASW consists of an almost unending stream of decision functions, many of which are already aided by some form of on-board decision aid. It is in the areas of coordinating and making tradeoffs among these decision functions that decision aiding is most needed.

It was also found that, contrary to expectations, existing decision aids are composed of not one but many constituent decision aiding techniques and have a low level of generality. The content of the models, equations, etc. used by the existing aids restricted them to the narrow problems for which they were developed. The individual decision aiding techniques of which they were composed, on the other hand, were found to be quite general and adaptable to a wide variety of aids and subjects. All of the large number of decision aiding techniques identified were found to fall into one of six functional categories and a taxonomy of the techniques was developed from these categories (Table 3-3). The matching of these decision aiding techniques to decision situations was facilitated by the use of six categories for decision situation description, each of which identified an aspect of the problem that can be aided by techniques from one category of the taxonomy. The descriptive categories and their related category of techniques are:

(1) Underlying process (modeled by outcome calculators).

(2) Value criteria (modeled by value models)

(3) Variables and parameters (managed by data control methods).

(4) Relevant analyses (provided by analysis techniques).

(5) Relevant displays (presented by display/data entry techniques).

(6) Required human judgments (enhanced by human judgment refining/amplifying techniques).

Matching the taxonomy against the decision situations (Table 5-1), indicated not only which techniques are appropriate to each decision situation, but also the emphasis that should be placed on developing aid components for Naval Air ASW decision aids. In particular, the development of a sophisticated probabilistic or Monte-Carlo outcome calculator for the search/detection process should be stressed, since this process underlies four of the six decision situations.

The task of prioritizing the decision situations for decision aid construction was found to be significantly more complex than had been anticipated. Difficulties were encountered in identifying and limiting the number of relevant factors to be considered in the prioritization, in measuring and combining the individual contributing factors, and in maintaining a balance between analytic and experimental considerations in factor measurement. Although a prioritization was achieved (Figure 6-2), the large number of assumptions required and the restricted number of factors considered left the issue of its validity unresolved. A multidimensional scaling approach to constructing a priority scale from these dimensions is suggested as a means of validating the approach used here.

Finally, this effort has outlined the general techniques that should be applied to the development of decision aids for specific Naval Air ASW decision situations. It has indicated what such techniques would require in terms of computational power, how general and adaptable to new situations they would be, and how acceptable to user populations they would be (Table 3-4). The next step should be to develop both structural and functional specifications for decision aids for some or all of the decision situations. Such an effort would prove the feasibility of using the analysis methodology developed here to structure the decision aid development process, both for Naval Air ASW and for other operational purposes as well.

A. NAVAL AIR ASW PLATFORMS

There are three primary Naval air ASW platforms -- the P-3C, the S-3A, and the LAMPS MK III -- which will be the cornerstones of the Navy's ASW capability through at least 1985, the timeframe established for this study. This appendix contains a brief review and comparison of the missions and capabilities of those three platforms.

A.1 PLATFORM SENSOR EQUIPMENT COMPARISONS

There are numerous similarities in equipment and equipment capabilities among the P-3C, S-3A, and LAMPS MK III platforms. Although the equipment nomenclature may vary among platforms, the functions and utilization of the equipment are comparable. Table A-1 summarizes the P-3C, S-3A, and LAMPS MK III mission profiles and equipment installation for a typical ASW mission. Numerical data are supplied in Table A-1 where appropriate; an "x" indicates the presence of the indicated capability; a blank indicates the absence of the indicated capability.

The P-3C and S-3A aircraft are designed to conduct ASW search and prosecution utilizing only the equipment and personnel onboard the aircraft. The LAMPS MK III is designed to relay all information (tactical and sensor) to its base ship where the information is processed for use by the LAMPS MK III crew. However, the LAMPS MK III is capable of operating independently of its base ship in a reduced processing capability mode.

All three platforms have radar, Magnetic Anomaly Detection (MAD), and passive Electronic Support Measurement (ESM) equipment. The P-3C and S-3A process and display radar, MAD, and ESM data onboard. The LAMPS MK III

Table A-1. Air ASW Platform Comparisons

	P-3C	S-3A	LAMPS MK III
TOTAL FLIGHT TIME (HRS)	12	6	3.5
OPERATING RADIUS (NM)	1000	400	100
ON-STATION TIME (HRS)	4-6	3-4	2
ACOUSTIC PROCESSING CAPABILITY	X	X	X
MAD CAPABILITY	X	X	X
PASSIVE ESM CAPABILITY	X	X	X
RADAR CAPABILITY	X	X	X
FLIR CAPABILITY	X	X	
SONOBUOYS (NUMBER CAPABLE OF CARRYING)	84	59	25
TORPEDOES (NUMBER CAPABLE OF CARRYING)	8	4	2

processes and displays MAD and ESM data onboard, but normally transmits the radar data to the base ship for processing and use in decision making.

The P-3C and S-3A are equipped with Forward Looking Infrared (FLIR) sensors for use in the ASW mission. The equipment is normally used only when there is a possibility that the submarine is exposed (e.g., is charging its batteries or cruising on the surface). The LAMPS MK III is not equipped with FLIR equipment.

All three platforms are capable of carrying and processing data from passive and active sonobuoys. The passive sonobuoys which are available for use by the platforms include LOFAR and DIFAR sonobuoys, while the active sonobuoys include range only, CASS and DICASS sonobuoys. The LOFAR sonobuoys are used for omnidirectional search, while the DIFAR sonobuoys can be used for both omnidirectional and directional search. The CASS and DICASS sonobuoys are command activated when initiated by the operator. The CASS sonobuoys provide ranging information while the DICASS sonobuoys provide both range and bearing information.

A.2 ASW MISSIONS

There are three basic types of ASW missions which can be performed by the airborne ASW platforms: independent ASW, task force defense ASW, and coordinated ASW. The purpose of each of these missions is the same -- to search for and track/attack enemy submarines. The difference between each of these missions is the number and type of platforms involved and the overall operational control of the platforms.

Independent ASW consists of individual platforms performing ASW search without the assistance of other forces. This mission is normally performed in known hostile submarine operating areas and submarine transit lanes. The purpose of these missions is to search, detect and track the enemy submarine to an accuracy that would allow an attack to be made if authorized. Independent ASW consists of multiple sorties, where one platform relieves another and continues in the prosecution of the target. During peacetime, these missions will normally continue until the submarine has been localized to within weapon attack accuracy. This mission is normally performed by P-3C aircraft and controlled by a land-based tactical support center or VP-TSC.

Task force defense ASW involves the search, localization, track and/or attack of hostile submarines in the vicinity of the task force. Each unit involved in this mission will perform the search, prosecution and/or attack. Although all three air platforms can perform this mission, the areas of search for each platform differs. Task force defense ASW search areas are defined by radii about the center of the task force. The inner ASW zone consists of all areas within a 100 nm radius of the task force. The middle ASW zone consists of all areas between 100 nm and 300 nm radius of the task force. The outer zone consists of all the areas beyond 300 nm radius of the task force.

Typical utilization of aircraft for task force defense ASW has the LAMPS MK III operating in the inner ASW zone, S-3A in the middle ASW zone, and P-3C in the outer ASW zone. The P-3C and S-3A aircraft operate under the control of the task force ASW commander who is normally resident in the aircraft carrier tactical support center (CV-TSC). The LAMPS MK III aircraft operates under the control of the base ship. The base ship and the CV-TSC coordinate all operations. Task force defense ASW occurs whenever there are hostile submarines in the vicinity of the task force. However, it is not necessary to have all three platform types simultaneously involved in the mission.

Coordinated ASW is normally performed in the vicinity of a task force and involves multiple platforms prosecuting a common target. These missions involve the ASW aircraft, surface ship and submarines collectively searching for and prosecuting hostile targets. They can be designated in a manner which has all units performing similar tasks (e.g., search) or similar unit types (e.g., ship) performing one mission phase and other unit types (e.g., aircraft) performing other mission phases. Whenever multiple units are involved in the coordinated ASW mission, one unit will act as controller and will direct all other units involved in the individual target search/prosecution.

A.3 P-3C OPERATIONS

The P-3C is capable of performing independent ASW, task force defense ASW, and coordinated ASW. For all missions, the P-3C will receive its mission briefing at the VP-TSC. When conducting task force defense ASW and coordinated ASW, the flight crew may have to receive an updated briefing when it checks into the area of the task force. When performing independent ASW and task force defense ASW, the P-3C flight crew normally operates in an autonomous manner with exception of receiving updated target intelligence information. During coordinated ASW, the P-3C operates closely with the other forces involved and therefore must respond to more extensive information than during the other ASW missions.

The P-3C's reaction time to an immediate threat is increased since it is a land-based aircraft. The average time between notification of launch and arrival on-station for the P-3C is between six and seven hours. This includes three hours for briefing and preflight and three to four hours for transit. Because of this time delay and the autonomous nature of P-3C operations, a great emphasis must be placed upon mission briefing and updated intelligence.

The transit time involved with P-3C operations, especially during independent ASW missions where the aircraft must remain covert, results in the two subsequent flights not being able to obtain data at their brief from previous flights. If contact is gained early in the on-station time, that data may not be available for briefing until it is over eight hours old. Some of this information can be passed to the relief aircraft via coordinated hand-offs, which will require the P-3C crew to be able to alter its tactics given sufficent information.

A.4 S-3A OPERATIONS

The S-3A normally performs task force defense ASW and coordinated ASW relating to the task force to which it is assigned. In the task force defense ASW mission, the S-3A is mainly responsible for search between 100 and 300 nm from the task force. All mission briefings are conducted by the CV-TSC onboard the S-3A's aircraft carrier and can be updated during flight if authorized.

The S-3A can be considered a relatively quick response platform since its normal transit time is between one and one and on-half hours. Since the S-3A is a quick reaction platform, it must be capable of altering procedures and tactics as initial information is updated. The S-3A will normally operate in a dependent manner relying on updated information from the CV-TSC. Since the S-3A operates in close proximity to the task force and is dependent upon the CV-TSC, information gained from each flight can be supplied to the subsequent flight without major time delays.

A.5 LAMPS MK III OPERATIONS

The LAMPS concept states that the LAMPS MK III helicopter acts as an extension of its base ship. This results in the LAMPS system being capable of performing task force defense ASW and coordinated ASW, with the LAMPS MK III helicopter participating as needed to the overall system. The LAMPS MK III helicopter conducts coordinated ASW on a continuous basis with its base ship.

Although the LAMPS MK III helicopter is capable of operating independent of its base ship, the base ship is designed to perform all processing of tactical and sensor data. This results in the base ship being required to determine what the helicopter should perform throughout the ASW mission. The base ship not only receives information from the helicopter, but also obtains data from its own sensors for use in correlation of target location.

A.6 AIRCRAFT DECISION AIDS

Both the P-3 and S-3A aircraft have a number of simple decision aids onboard for use by the aircrew. The LAMPS MK-III software operating program will also contain a number of low-level decision aids. Examples of decision aids which are either available in the P-3C or S-3A or are intended for incorporation into the LAMPS MK-III include: sonobuoy pattern construction; target movement prediction; stores/weapons inventory maintainence; target probability contour generation; active sensor range estimation; and fly-to-point and steering command development for the pilot. The majority of the existing or planned decision aids are used by the tactical coordinator (TACCO) to satisfy very specific functions (e.g. predicting the target's position at the current time or a future time). Although there can be some correlation between the output of one decision aid and the employment of another decision aid, they have been developed to operate independently of each other.

Current decision aiding on the three ASW aircraft is thus at a low level and is largely uncoordinated. Each existing decision aid is designed to satisfy one function of the TACCO, and provide him with the single specific output which he must apply to a particular problem at hand. More complex aids, which assest the TACCO in solving more complex, cognitive problems are presently lacking an all three ASW platforms. In particular, there is a lack at the current time of decision aids which treat the interrelations between problems that confront the TACCO simultaneously. Such aids would integrate a variety of inputs, process them in a coordinated manner, and provide multiple and complex strategies/options for meeting the TACCO's callenge of optimally employing the aircraft's sensor system to detect, locate, and destroy hostile submarines. The general and numerous commonalities among the three principal ASW aircraft hold open the hopeful possibility that such high-level decision aids can be designed and developed in a unified manner for all Naval Air ASW platforms.

B. DECISION AIDING TECHNIQUES

This appendix contains brief descriptions of each of the decision aiding techniques included in the technique taxonomy developed in Sections 3.2 and 3.3 and shown in Table 3-3. The techniques are listed and described below according to the sequence used in the taxonomy. Thus, all outcome calculators are discussed first, all value models second, and so on.

B.1 OUTCOME CALCULATORS

B.1.1 Closed-Form Analytic Models

These models compute the specific outcomes of a process through the application of equations rather than through a discrete step-by-step simulation method. These analytic equations constitute transfer functions that compute process outputs from process inputs without modeling the intervening processes. An example is the well-known Lanchester combat equations which predict combat losses directly from the size of the engaging forces.

B.1.2 Probabilistic Models

These models compute the distribution of outcomes from a probability distribution of input conditions through analytic treatment of inputs and intervening processes. These models are stochastic analogs of the closed-form analytic models.

B.1.3 Deterministic Simulations

These models simulate the process mechanically (i.e., step-by-step through time) but do not treat the inputs or any part of the process as probabilistic or stochastic. They produce specific outcomes only. This kind of model includes the SOC campaign simulator and the simulataneous differential equation models handled by languages such as CSMP or DYNAMO.

B.1.4 Monte-Carlo Simulations

Monte-Carlo models simulate the process mechanically and use probability distributions of inputs and stochastic model components to predict distributions of outcomes of the process. These models are stochastic analogs of the deterministic simulations.

B.2 VALUE MODELS

B.2.1 Multi-Attribute Utility Models (MAUM)

MAUMs assume that all dimensions of the outcome description space are independent and that each dimension or attribute has a distinct weight or salience to the decision maker. The weight values are normally elicited directly from the decision maker. Both the salience weights of attributes and the attribute scales themselves are assumed to be real-valued so the utility (value) of an outcome, U(o), is given by:

$$U(o) = \sum_i a(i)\, w(i)$$

where a(i) is the outcome score on attribute i, and w(i) is the weight or importance of attribute i.

B.2.2 Adaptively Constructed MAUM

This technique is identical to the multi-attribute utility model except that the attribute weights are obtained by a mathematical inference algorithm from observations of actual decisions made by the decision maker.

B.2.3 Direct Assignment of Utilities to Outcomes

In this approach, no attempt is made to model the entire utility function of the decision maker. Instead, specific detailed outcomes are described and are assigned utility or value scores. No assumption is made about the utility of outcomes not directly evaluated by the decision maker.

B.2.4 Risk-Incorporating Utility Models

These models estimate the decision maker's full utility function and include a parameter indicating his attitude toward risk. Thus, risk in the situation is considered as well as the attractiveness of outcomes. Thus if outcome o has an overall value of x, the utility of o is given by:

$$U(o) = 1 - e^{-\lambda x}$$

where λ is a parameter indicting the degree of risk-aversion of the decision maker. λ must be empirically measured for each individual decision maker.

B.2.5 Nonlinear Utility Models

Nonlinear models combine one or more attributes of an outcome into a single assigned value but do not use the MAUM simple additive or risk-incorporating power function forms.

B.3 DATA CONTROL TECHNIQUES

B.3.1 Automatic Data Aggregation

Many outcome calculators and analytic algorithms use input data in a form more aggregated than that in which they are normally collected. Automatic data aggregation is particularly important in systems that use real-time data where time is not available for lengthy manual aggregation procedures. While data aggregation may be required for selected models and algorithms that use composite indices and averages, decision aids employing these devices must allocate a substantial amount of computer time to implicit data manipulation.

B.3.2 Data Management Techniques

Data management is not isomorphic to data aggregation. Data aggregation deals specifically with sampling and summing operations while management relates specifically to data output, whether for display purposes or for purposes of data base interrogation. Voluminous data may be collected, but unless they are retrievable on demand or upon some algorithmic basis, they provide no useful service. Data management is concerned with providing flexible, on-demand information filtering for utilization by and/or instantaneous display for the human decision maker and/or other decisions aid components.

B.4 ANALYSIS TECHNIQUES

B.4.1 Optimization Methods

These are techniques which maximize a dependent variable that is a function of several variables, where some or all of the independent variables have constraints on the values they may assume. Many different optimization techniques exist, including linear programming, nonlinear programming, dynamic programming, Fibbonaci search, and response surface methodology. Primary differences among these techniques lie in the forms of the constraints on the independent variables which they allow.

B.4.2 Artificial Intelligence Solution-Seeking Methods

These are techniques which use various approaches to "intelligently" seek the optimal solution to a problem, in contrast to strict optimization methods which use analytic properties of the problem and brute force computation to locate optima. Of particular importance are the techniques of heuristic search and Bayesian pattern recognition, because they previde solutions to problems commonly encountered in military applications.

B.4.3 Sensitivity Analytis

These are methods which allow the sensitivity of an outcome calculator's outputs to local variation in one or more of its more inputs to be examined. Typically, all but one input variable of an outcome calculator are held constant while the one remaining variable is systematically varied. This process is then repeated for all the other input variables, one at a time.

B.4.4 Intra-Process Analysis

These are methods in which the intermediate outcomes of mechanical outcome calculators (i.e., those which model processes as a series of time-sequential steps, and compute the outcome of each step in order and use the results as the input to the next step) are identified, along with their impact on the overall outcomes.

B.4.5 Algorithms for Information Processing

Techniques which calculate or approximate quantities that are totally determined by various input or independent values. This dependence may be the result of some intervening process as, for example, the location of an aircraft at some future time is totally dependent on its present and subsequent motion, its physical characteristics and the flying environment. Alternatively, the dependence may be just the result of many complex interrelationships among the independent variables. In either case, the dependent values can provide important information to the decision maker but the complexity of the process or mathematical interrelationships involved prevents the values being intuitively inferred or even manually computed from the input variables on which they depend.

B.4.6 Alerting

Algorithms can monitor a dynamic data base or data input streams, in a way invisible or 'transparent' to the decision maker, looking for anomolous information or certain "key" conditions which might require the decision maker's immediate attention. When such a condition is found, an "alert" or interrupt is created to notify the decision maker that some non-normal or threshold condition has been detected.

B.4.7 Statistical Analysis

Included here are standard descriptive and predictive techniques which may be used to obtain measures of central tendacy, variability, and correlation. Sampling procedures are also included, as are tests of significance such as F-tests, T-tests, Chi-square, and related methods which may be used to locate significant differences among sets of variables or to remove 'noise' from Monte-Carlo outcome calculator output. Also included are statistical analysis methods such as discriminant analysis or Bayesian updating, where the liklihood ratios are empircally determined.

B.5 DISPLAY/DATA ENTRY TECHNIQUES

B.5.1 Display Graphics

Use of color and/or black-and-white graphic devices to present information. The presentation can be either in a display format such as on a CRT unit, or in a printed format on paper.

B.5.2 Interactive Graphics

Entry of information, particularly two-dimensional (or three-dimensional) information through a graphic input device, such as a graphic tablet, joystick, trackball, light pen, or function board.

B.5.3 Windowing

Division of a CRT or graphic display into a series of "windows," each of which may display a separate piece of information or even be connected to a different aid. Each window can be separately and simultaneously controlled and/or communicated with by the operator.

B.5.4 Speech Synthesis/Recognition

Input/output of information through acoustical rather than visual means, via computer generated or understood speech.

B.5.5 Quickening

Displaying time-dependent relationships in a way that compensates for real-time delays between input, processing, and output.

B.6 HUMAN JUDGMENT REFINING/AMPLIFYING TECHNIQUES

B.6.1 Operator-Aided Optimization

In problems where the solution space is multidimensional and the solution surface is "hilly," normal optimization algorithms may converge to poor local optima or require numerous computations to find the true global optimum. By using the "intuition" of the decision maker to aid the optimization algorithm through suggesting subspaces to examine first or initial candidate solutions, the algorithms can locate all viable local optima quickly, and select the global optimum from among them.

B.6.2 Adaptive System Predictions

This method of incorporating human judgment couples an adaptively constructed MAUM (Section 4.5.2) with an algorithm that finds that alternative course of action which maximizes the utility function (i.e., the adapive MAUM) most in keeping with the decision maker's own implicit preference structure.

B.6.3 Bayesian Updating

This technique uses Bayes' theorem and human judgments on likelihood ratios to infer probable changes in the state of the world that are consistent with the implicit process models of the decision maker. Bayesian updating may also be used as a statistical inference technique where the likelihood ratios and indicator variables are empirically based, rather than intuitively based.

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