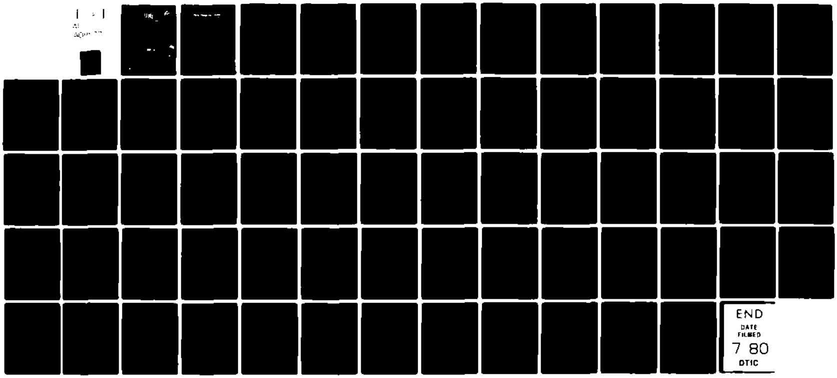
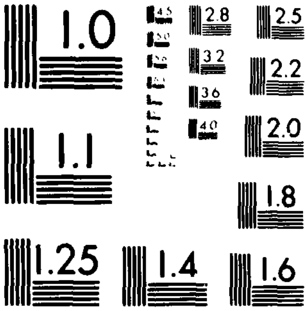
AD-A085 772 NAVAL WEAPONS CENTER CHINA LAKE CA F/6 5/8
REVIEW OF FIVE MILITARY DECISION AIDS.(U)
MAY 80 M J BARNES
UNCLASSIFIED NWC-TP-6171 NL



END
DATE
FILMED
7 80
DTIC


1.0
4.5
5.0
5.6
6.3
7.1
8.0
9.0
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

LEVEL II

Review of Five Military Decision Aids

by

Michael J. Barnes
Systems Development Department

MAY 1980

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

Approved for public release;
distribution unlimited.

Naval Weapons Center
AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

FOREWORD

This technical report documents a review conducted at the Naval Weapons Center between August 1979 and January 1980. This work was performed as part of the NAVAIR Human Factors exploratory development program and was supported by Airtask A03A-3400/001B/9F55-525-000 under the direction of CDR P. M. Curran and Dr. J. Hopson, Naval Air Development Center.

This report provides preliminary information for use in examining the feasibility of using computer-aided decision-making in Navy attack aircraft.

Approved by
M. M. ROGERS, *Head*
Systems Development Department
17 January 1980

Under authority of
W. B. HAFF
Capt., U.S. Navy
Commander

Released for publication by
R. M. HILLYER
Technical Director

NWC Technical Publication 6171

Published by .... Technical Information Department
Collation .... Cover, 32 leaves
First printing .... 190 unnumbered copies

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (14) NWC-TP-6171	2. GOVT ACCESSION NO. AD-A085 771	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) REVIEW OF FIVE MILITARY DECISION AIDS,		5. TYPE OF REPORT & PERIOD COVERED Aircrew workload study August 1979-January 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Michael J./Barnes / PE61153N		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Weapons Center China Lake, California 93555		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AirTask A03A-3400/001B/ 9F55-525-000
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Weapons Center China Lake, California 93555 (11)		12. ~~REPORT DATE~~ May 1980
		13. ~~NUMBER OF~~ PAGES 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 66		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(9) Technical publication. Aug 79-Jan 80,

18. SUPPLEMENTARY NOTES

(16) F55525 (17) ZF55525000

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Decision aids	Decision analysis
Human factors	Behavioral decision theory
Decision taxonomy	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See back of form.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED 403019

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(U) *Review of Five Military Decision Aids*, by Michael J. Barnes. China Lake, CA, Naval Weapons Center, May 1980. 62 pp. (NWC TP 6171, publication UNCLASSIFIED.)

(U) This report reviews decision-aiding approaches for military environments. Five aids were discussed: the DDI decision triangle, Perceptronic's ADDAM, Analytic's Nomograph displays, SKETCH models (ISC), and EWAR (Decision-Science Applications). A taxonomony was developed in order to compare the aids. Three characteristics of the aids were discussed in detail: type of decision tasks addressed, methods for incorporating conditioning elements, and the mathematical approaches used to develop the aids.

(U) The following trends emerged from the review. Determination of a single optimal action was not the primary purpose of most of the aids. Rather, the operator was given multiple decision criteria to help him structure the decision parameters in his own mind. Also, an attempt was made to reduce the amount of information displayed to the operator by integrating the information into concise formats. The mathematical approaches for generating the decision algorithms included: Bayesian statistics, pattern recognition models, dynamic and non-linear programming techniques and outcome calculators.

A

CONTENTS

ACKNOWLEDGMENT

A number of people reviewed portions of this report. The author wishes to thank Mel Moy and Richard Kelly from NPRDC, Julie Hopson from NADC, and Ron Erickson and Keith Gardner from NWC.

INTRODUCTION

Recent developments in aircraft technology have resulted in increased firepower and tactical flexibility during air-to-ground missions. However, these improvements have not been introduced without some cost to the aircrew by increasing their workload and decreasing the time in which they have to make decisions. This report is part of a Navy program whose goal is to look at the feasibility of alleviating aircrew overloading by using computerized decision aids. The purpose of these aids is not to automate decision-making, but rather to structure the decision task in such a way as to reduce the operator's processing load.

SCOPE

This report is a review of state-of-the-art decision aids being developed for various military applications. These aids address quite specific problems, some of which are unrelated to air-to-ground missions. However, the mathematical models and algorithms used to generate these aids are general in scope. Therefore, the general approaches used by the developers of these aids may prove profitable as aiding techniques in the fighter/attack aircraft environment.

Currently, a great number of decision aids are being developed for military use. Because of this, the review focuses on only five aids. This allows each aid to be described in detail while, at the same time, the diverse procedural approaches used by the various aids can be demonstrated. The first section of the report will describe general features of decision-aiding. This will form a basis for comparing the aids. As part of this effort, a taxonomy of decision-aiding will be developed. The purpose of the taxonomy will be to accent both differences and similarities among the aids. The latter sections of the report will be devoted to describing the individual aids.

This report will be combined with information from two other reports: (1) a report identifying aircrew decisions during attack missions,[1] and (2) a review of the operator's general decision-making characteristics.[2] This combination will lead to some specific recommendations for demonstrating the feasibility of using a computer-generated decision aid in attack aircraft.

---

[1] Naval Weapons Center. *Identification of Significant Aircrew Decisions in Navy Aircraft*, by J. Saleh et al. Perceptronics, Inc., China Lake, CA, NWC, June 1979. (NWC TP 6117, publication UNCLASSIFIED.)

[2] Naval Weapons Center. *Operator Decision-Making Characteristics*, by Michael J. Barnes. China Lake, CA, NWC, July 1979. (NWC TP 6124, publication UNCLASSIFIED.)

PRINCIPLES OF DECISION-AIDING: OVERVIEW

The aids which are discussed have been constructed using certain general design principles. This section is a review of the current principles which drive this design process. The research comes from two distinct disciplines: (1) psychology, whose domain concerns the problems associated with interfacing the aid and the operator; (2) decision analysis, which focuses on the mathematical rigor of the models on which the aids are based.

Research dealing with the interface problem has resulted in redefining the purpose of decision-aiding. It was found that aids which replaced the operator during important decisions resulted in system degradation.[3,4,5] This led to the current emphasis on constructing aids whose purpose was to aid rather than replace the operator. Kelly[6] perhaps best characterized the current thinking on the purpose of decision-aiding. It should be "a mechanism that extends the intellect of the decision maker and puts structure to what would otherwise be a confusing situation, rather than a device which makes decisions according to preset rules which are programmed without any form of intervention by the decision maker." This characterization implies three criteria for a good aid:

1. It brings structure to the decision situation.

2. It performs functions which would otherwise overload the operator's processing capacity.

3. It leaves the final decision to the operator.

---

[3] Halpin, S. M., E. M. Johnson, and J. A. Thornberry. "Cognitive Reliability in Manned Systems," *IEEE Trans. Reliability*, Vol. R-22, pp. 165-170 (1973).

[4] U. S. Army Research Institute for the Behavioral and Social Sciences. *Development and Application of a Decision Aid for Tactical Control of Battlefield Operations: A Conceptual Structure for Decision Support in Tactical Operational Systems*, by R. Levitt et al., Honeywell Inc. Arlington, VA, 1977. (Technical Report TR-77-A2, publication UNCLASSIFIED.)

[5] Smithsonian Institution. *Operational Decision Aids: A Program of Applied Research for Naval Command and Control Systems*, by H. Wallace Sinaiko. Washington, DC, 1977. (Technical Report No. 5, publication UNCLASSIFIED.)

[6] Decisions and Designs, Inc. *Decision Analysis and Decision Aids*, by C. W. Kelly. McLean, VA. (In-house paper, publication UNCLASSIFIED.)

In general, the reviewed aids meet these criteria. More detailed principles of aiding have been developed.[7]

1. Systems requirements for the system to be aided must be well-defined and explained in detail.

2. The output of the aid should address these requirements.

3. The displayed output should be human-factored in order to present information in an optimal manner.

4. The displayed information should be in sufficient detail to allow the operator to understand the state of the system being aided.

5. The aid should not display too much information (which could overload the operator).

6. The aid should be designed with user acceptance in mind.

This last principle is the crux of many problems that system designers have had with introducing new aids. No matter how sophisticated the aid, it is worthless if it is not accepted by the users. The best solution to this problem[3,7] seems to be to include potential users in the design process, during both development and testing of the aid. As a corollary to this principle, the training level necessary to use the aid should be commensurate with the skill level of the intended user population.

It would be an advantage if any of these criteria could be used to evaluate aids. Too often, however, there is not an objective measure of system performance for the complex systems the aids were designed for (e.g., command and control environment). Many of the reviewed aids are in the process of being tested, but the evaluation procedure remains somewhat controversial.[5,8,9] For this reason, the present report is a description of what the aids are designed to do and the mathematical models the aids are based on. Evaluation of the aids, except in the most general terms, is beyond the scope of this report.

---

[7] System Planning Corporation. *An Investigation of Operational Decision Aids*, by G. L. Lucas and J. A. Ruff. Arlington, VA, 1977. (Report 312, publication UNCLASSIFIED.)

[8] Analytics. *Measuring the Performance of Operational Decision Aids*. Willow Grove, PA, 1976. (Final Report 1161-B.)

[9] Naval Personnel Research and Development Center. *Significance of Risk in Navy Tactical Decision Making: An Empirical Investigation*, by C. Gettys et al. San Diego, CA. (NPRDC-TR-77-8, publication UNCLASSIFIED.)

DECISION TAXONOMY

A decision taxonomy was developed for this review to illustrate the general features of the various aids. Other taxonomic breakdowns for decisions were found to be either too specific or too detailed for the purposes of this report.[10,11,12] The scope of the present taxonomy is limited to tasks, approaches, and conditioning elements which would generalize to any decision category. The first part of the taxonomy is a breakdown of generic decision tasks. The aids themselves are defined in terms of the decision tasks they were designed to aid.

DEFINITION OF AN AID

Unless the definition of a decision aid is limited to specific tasks, the term itself becomes all-embracing. This is because all displays are designed to improve some aspect of the operator's decision-making performance. What separates decision aids from other displays is the specialized intent of the decision aid's output. Historically, aids designated as decision aids displayed information aiding the operator in such specialized decision tasks as probability estimation or utility assessment.[13,14] With this in mind, a decision aid is an algorithm or mathematical procedure whose output structures or generates information relating to some decision task. The particular tasks defined as decision tasks are discussed below.

DECISION TASK TAXONOMY

The taxonomic breakdown presented here is not particularly original. It is a synthesis of other taxonomic breakdowns that attempt to be complete without being overwhelming in detail. For more detail, the original papers contain in-depth discussions of the decision tasks reviewed.[2,12,15,16]

---

[10] Decision and Designs Inc. *Selecting Analytic Approaches for Decision Situations: A Matching of Taxonomics*, by R. Brown and J. Ulvila. McLean, VA, October 1976. (TR-76-10, publication UNCLASSIFIED.)

[11] Applied Decision Analysis, Inc. *An Analytic Characterization of Navy Command and Control Decisions*, by A. Miller et al. Menlo Park, CA, March 1979. (Final Report 3-31-79, publication UNCLASSIFIED.)

[12] Naval Training and Equipment Center. *Decision Making and Training*, by R. S. Nickerson and G. Feehrer. Orlando, FL, NTEC, 1975. (Technical Report 73-C-0128-1, publication UNCLASSIFIED.)

[13] Edwards, W., "Dynamic Decision Theory and Probabilistic Information Processing," *Human Factors*, Vol. 4, pp. 59-73, 1962.

[14] The Rand Corporation. *Judge: A Value-Judgment-Based Tactical Command System*, by L. Miller et al. Santa Monica, CA, March 1967. (RM-5147-PR, publication UNCLASSIFIED.)

Two distinct processes underlie most decision analysis: the decision situation is structured, and mathematical rules are computed to select among decision alternatives.[17] These two processes, structuring and selection, form the basis of at least one other decision taxonomy.[15,16] For the present taxonomy, this division into problem structuring and alternative selection dichotomizes decision-making into two classes of decision tasks. The taxonomy represents ideal decision-making, reflecting how the operator should make decisions, not necessarily how he does. These decision tasks are listed in Table 1.

Problem structuring is probably the most difficult part of decision making. It requires a detailed expertise in the parameters of the real world environment as well as expertise in decision structuring. The pitfalls in such an analysis are many, and the reader should not be mislead into thinking that the problem is trivial by the simplified example given below (for insight into the complexities involved see Fischhoff, 1980; Howard, Matheson, and North, 1977).[18,19] Figure 1 illustrates a decision tree approach to structuring a problem wherein two actions and three states-of-the-world are possible. The operator first decides what action options he has (A or B). Next, he must create an hypothesis set representing distinct states-of-the-world he feels are possible at the conclusion of each of the actions (H_1, H_2, or H_3). His last task, in our simplified example, is to generate a list of outcomes. Outcomes are the consequences of each action given a particular state-of-the-world (i.e., $A \cap H_1 = U, \cdots, B \cap H_3 = Z$).

Figure 2 depicts four steps in the alternative selection process. Basically, these tasks consist of computing certain values in order to generate a decision rule with which to choose an optimal course of action after the decision problem is structured.

---

[15] Keeney, R. L., and H. Raiffa. *Decision with Multiple Objectives: Preferences and Value Trade-offs*. New York, John Wiley & Sons, 1976. 549 pp.

[16] Naval Training Equipment Center. *Analysis of Requirements and Methodology for Decision Training in Operational Systems*, by J. Saleh, et al. Orlando, FL, NTEC, 1978. (TR-77-0055-1, publication UNCLASSIFIED.)

[17] Decision and Designs, Inc. *Handbook for Decision Analysis: Structure of a Decision Tree*, by C. R. Peterson, et al. McLean, VA, October 1973.

[18] Fischhoff, B. For Those Condemned to Study the Past: Reflections on Historial Judgment in *New Directions for Methodology of Behavioral Sciences Fallible Judgment in Behavioral Research*, eds. R. Shweder and D. Fiske. San Francisco, Jossey-Bass Co., 1980.

[19] Howard, R. A., J. Matheson, and J. E. North. "The Decision to Seed Hurricanes," *Science*, Vol. 176, 1972, pp. 1191-1202.

TABLE 1. Listing of Decision Tasks.

I. PROBLEM STRUCTURING

- a. List possible actions
- b. Generate hypothesis
- c. Determine outcomes

II. ALTERNATIVE SELECTION

- a. Information selection
    1. Information gathering
    2. Optional stopping of information gathering
- b. Probability estimation
    1. Event estimation (known distribution)
    2. Event estimation (unknown distribution)
    3. Update probability (conditional independence)
    4. Update probability (conditional dependence)
    5. Multistage inference
    6. Probabilistic model generation
- c. Worth assessment
    1. Outcome ranking
    2. Outcome interval scaling
    3. Multi-attribute interval scaling
- d. Action selection
    1. Worth selection
    2. Expected utility selection
    3. Other rules

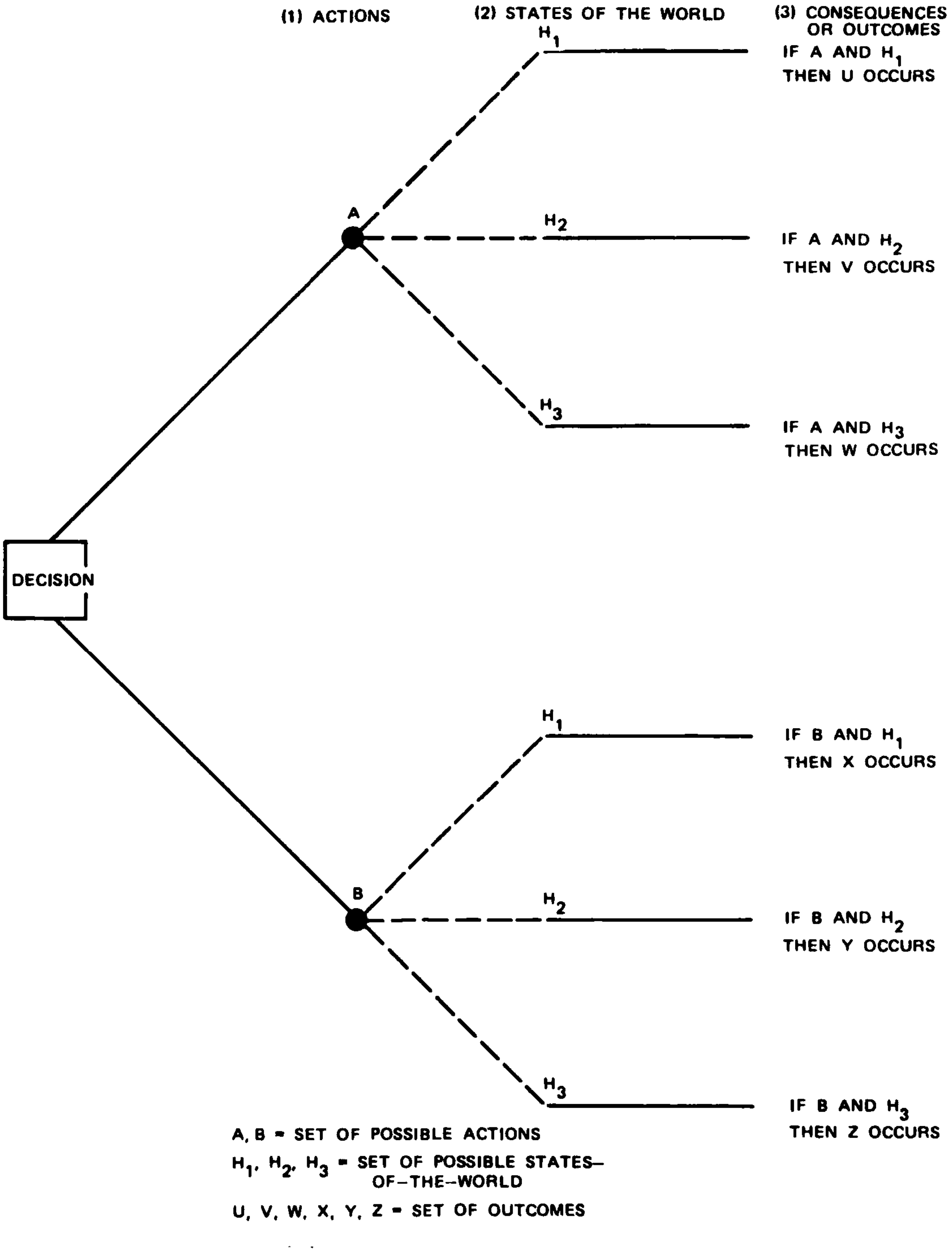


FIGURE 1. Problem Structuring Using a Decision Tree.

First, information must be sampled to compute probabilities for each of the hypotheses. The second step is the actual computation of probabilities based on sampled data and prior probability information. The third step is an evaluation of the outcome set. This consists of numerically assessing the worth of each outcome. The last step, action selection, involves generating the actual decision rule (usually an equation) used to choose the best action. The parameters of the rule are based on the computations from both probability estimation and worth assessment. However, as the feedback loop in Figure 2 indicates, this process is iterative in nature. Before a decision is made to choose an action, the decision-maker must decide whether it is more cost-effective to act or to sample additional information.[2]

The subtasks for each of these components of alternative selection are discussed next. These tasks have fairly technical definitions and as mentioned before, a complete discussion of these tasks is contained elsewhere.[2,12,15,16] Information selection tasks are either the first (subtask 1) or last task (subtask 2) done before selecting the final decision. The probability estimation tasks are listed in order of increasing complexity and the tasks themselves are not mutually exclusive. The worth assessment tasks are defined in terms of the scaling technique used to generate the worth functions. Here again the order is from least to most sophisticated technique. Action selection tasks are defined in terms of the types of decision rule used.

Information Selection

1. Information gathering consists of deciding which data sources to sample, depending on their information values and the cost of sampling.

2. Optional stopping is the decision as to whether to continue sampling or to stop sampling and choose a course of action.

Probability Estimation

1. Event estimation (known distribution) is an estimate of an event's probability given only current information. A frequency distribution concerning the event's occurrence is specified.

2. Event estimation (unknown distribution) is the same task except no objective frequency distribution concerning the event's occurrence is specified. A subjective probability distribution must be generated.

3. Probability updating (conditional independence) is an event estimation which is continually updated as more information is processed. The relationships among the processed data are mutually conditionally independent.

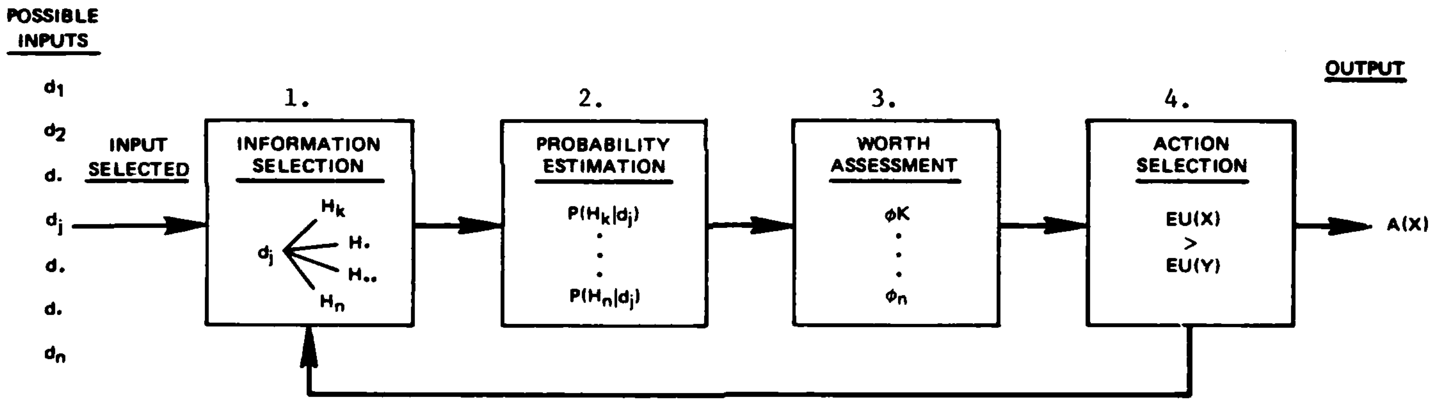


FIGURE 2. Stages of Probabilistic Decision-Making.

4. Probability updating (conditional dependence) is an updating task wherein statistical dependencies exist among the data sources used to update the probability estimate.

5. Multistage inference is a more complex event estimation task wherein the data are removed from the hypothesis set by two or more stages of intervening probability estimates (also known as hierarchical inferences).

6. Probabilistic model generation is an attempt to generate a model to predict the trend of the occurrence of future events (e.g., multiple regression model).

Worth Assessment

1. The outcomes are ranked in terms of their relative worth or value using an ordinal scale.

2. A worth scale with interval properties (usually a utility scale) is defined for the outcome set.

3. The outcomes are broken down into independent attributes (i.e., dimensions of worth) and modeled so that the resultant functions constitute an interval worth scale.

Action Selection

1. The decision rule consists of choosing the action associated with the highest worth (i.e., no probability estimate is used to generate the rule).

2. The decision rule is based on choosing the action with the highest expected utility.[20]

3. All other decision rules such as minimax, maximin, lexicographic ordering, or any rule not mentioned above.

---

[20] Utility is a measure of the worth of an outcome in an uncertain environment (see Coombs, Dawes, and Tversky,[21] 1970 for a precise mathematical definition). Expected utility is the expected utility value of an action with more than one possible outcome.

[21] Coombs, C. H., R. Dawes, and A. Tversky. *Mathematical Psychology*. Englewood Cliffs, NJ, Prentice Hall, Inc., 1970. 419 pp.

Other Characteristics

Two additional features of the aids pertinent to this classification are: the conditioning elements implicitly or explicitly assumed, and the mathematical models the aids are based on. Conditioning elements are features of the environment such as weather conditions and enemy strength which influence both probability and worth values. Conditioning elements are either implicitly assumed in computing these values or explicitly accounted for in the design of the aid. This report will focus on the various procedures used in order to incorporate conditioning elements into the aiding algorithms.

In comparing these aids, it will be evident that a wide variety of mathematical approaches have been used. Not only decision theoretic models such as Bayes theorem and utility theory, but other models based on dynamic and non-linear programming and discriminant analysis have been used to aid decision situations. Perhaps even more interesting from this project's point of view are some of the diverse uses made of the same general approach. The next section is a review of various aiding approaches. The last section summarizes these approaches and compares them.

REVIEW OF INDIVIDUAL AIDS

Most of the aids discussed were developed as part of an operational decision aid (ODA) project funded by the Office of Naval Research. These aids were designed mainly as research tools for studying decision-making. However, they were designed to be used in realistic command and control decision environments. A number of military scenarios developed by the Stanford Research Institute (SRI) were adapted by the developers of the aids to describe the parameters of their particular environments.

TACAID: DECISIONS AND DESIGNS, INC.

TACAID is a collection of aid modules. The aid is flexible and has been exercised using a variety of combat scenarios. The basic display is a triangle with its sides measuring three probability states and its interior divided into three or more action regions. The boundaries of the action regions are based on thresholds derived from multi-attribute utility models. Other factors which have been investigated using TACAID include multiple conditioning elements, risk aversion functions, prediction displays, and a four-state probability model.

Triangular Display

The triangular display's purpose is to show the relative uncertainty of three possible states of the world and at the same time to suggest a course of action to the commander. Figure 3A shows the skeleton of the triangle to illustrate how the probability information is displayed. Figure 3B shows a display as the operator would see it with the surface of the triangle divided into three regions representing the military actions the commander may wish to consider. The sides of the display indicate possible states of the world (S_1, S_2, or S_3) which influence the commander's choice of action.

Figure 3A shows three states of possible enemy intent: routine surveillance (S1), probing action (S2), or full scale attack (S3). The relative uncertainty concerning these three states is shown on the triangle's surface as a dot with a circle around it. This encircled dot, referred to as a probability bug, is placed at the intersection of the lines projecting from the sides representing each of the probability states (dark lines on Figure 3B). Thus the probability bug is situated on the triangle to give the operator a pictorial representation of the relative uncertainty for each of the three possible enemy intents [P(S1) = 0.2, P(S2) = 0.2, and P(S3) = 0.6, in our example].

The actual probability estimates are input parameters to the display. An intelligence analyst reports specific enemy movements which influence these estimates (e.g., enemy target platform deployed, missile signal report ...). Next, an algorithm combines the new reports with the present estimate of these events [($P(S_1)$, $P(S_2)$, or $P(S_3)$)] using Bayes theorem to update the three probabilities. Since these probabilities change as more information is received, the probability bug moves on the surface of the triangle whenever new data is received.

Figure 3B aids the commander by telling him what the suggested course of action is. Regions of the display are separated by boundaries which represent probability thresholds. The derivation of the equation representing the boundary is based on a multi-attribute utility model which will be discussed in the next section. Inituitively, the regions represent states of uncertainty wherein the best course of action is explicated. In our example, the probability bug indicates there is a moderately high probability that the enemy is engaging in a full-scale attack ($P(S_3) = 0.6$) and smaller probabilities that they are involved in either probing actions or routine surveillance ($P(S_1) = P(S_2) = 0.2$). For this situation, the TACAID display suggests that the commander commit a large force for counterattack. The boundaries are based on values elicited from the commander and his staff before the start of the current exercise. Such a display is not meant to automatically commit the commander to a course of action, but rather to suggest a normative

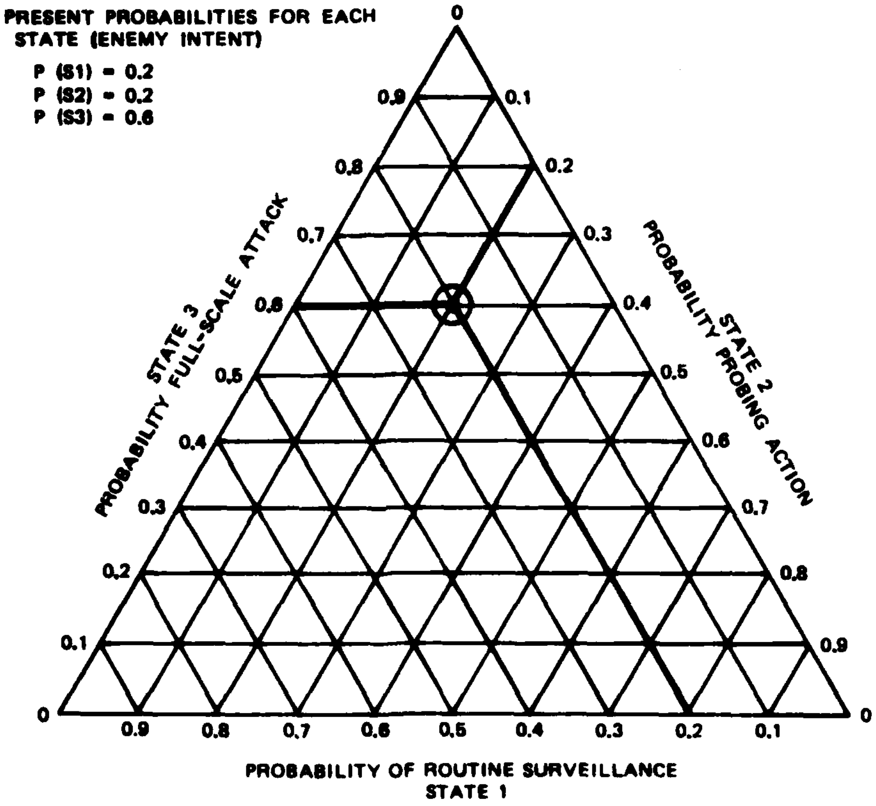


FIGURE 3A. Probability Plane for Three Enemy Intents.

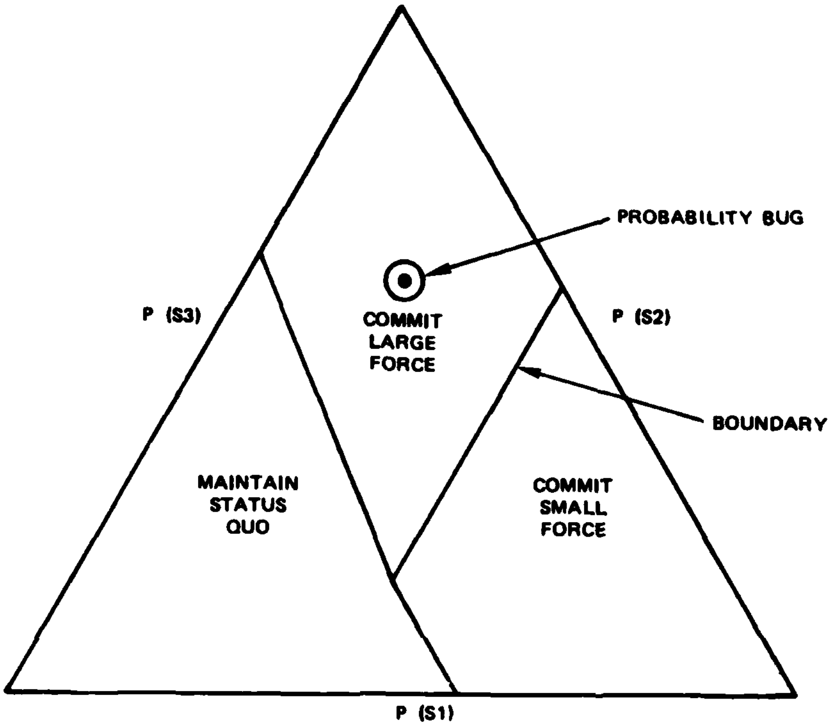


FIGURE 3B. Action Regions for the Three Action Case.

solution given a particular sequence of indicators from the intelligence analyst. Since the bug changes position as more data is received, the display also allows the commander to visually assess the changing military environment. Still, this general approach has been criticized, since the reasoning behind the suggested action is not necessarily transparant to the commander and might tend to be disregarded when the consequences of being wrong are serious. A more recent TACAID display configuration (Figure 4) has three triangles each suggesting actions depending on three separate conditioning elements: strength of own forces, enemy strength, and weather conditions. The rationale for the display is that the three triangles give the commander a better feel for the complexity that underlies a military environment. It also gives him more responsibility, since he must integrate this information before making a decision. As mentioned previously, the general trend in aiding is to inform the operator rather than select actions for him.

Mathematical Model

The models used for TACAID were developed using concepts from Bayesian decision theory and utility theory (see Savage (1954) for a discussion of their theoretical basis).[22] The TACAID is divided into action regions bounded by indifference planes called probability thresholds. Basically, these planes are equations which define a set of probability values for which the operator is theoretically indifferent between two actions. Table 2 illustrates how utility values are used to derive decision rules which define action regions. These tabulated values are examples of values elicited from the commander to represent the relative worth (e.g., utility) of each outcome. In our example the most desirable outcomes for each action are assigned a zero (on the top-bottom diagonal in Table 2), the values of the other cells are negative showing the commander's negative assessments using zero as an end point. Using these values, the expected utility value for each action is computed in Step 1 (i.e., $E(A_1)$, $E(A_2)$, $E(A_3)$). Step 2 is a setting of inequalities, based on the principle that Action 1 is preferred to Action 2 whenever $E(A_1) > E(A_2)$. The derivation of the decision rule involves the simplification of this inequality to a form which indicates that one of the probabilities is larger than the weighted combination of the other two probabilities. Since the surface of the TACAID display is defined in terms of the relative probabilities of three states, these inequalities are used to represent non-overlapping regions on the surface of the display. The boundaries of these regions are where these inequalities become equations or more formally they constitute the planes defined by those probability values resulting in equal expected value for at least two of the actions.

---

[22] Savage, L. J. *The Foundation of Statistics*. New York, John Wiley & Sons, Inc., 1954. 282 pp.

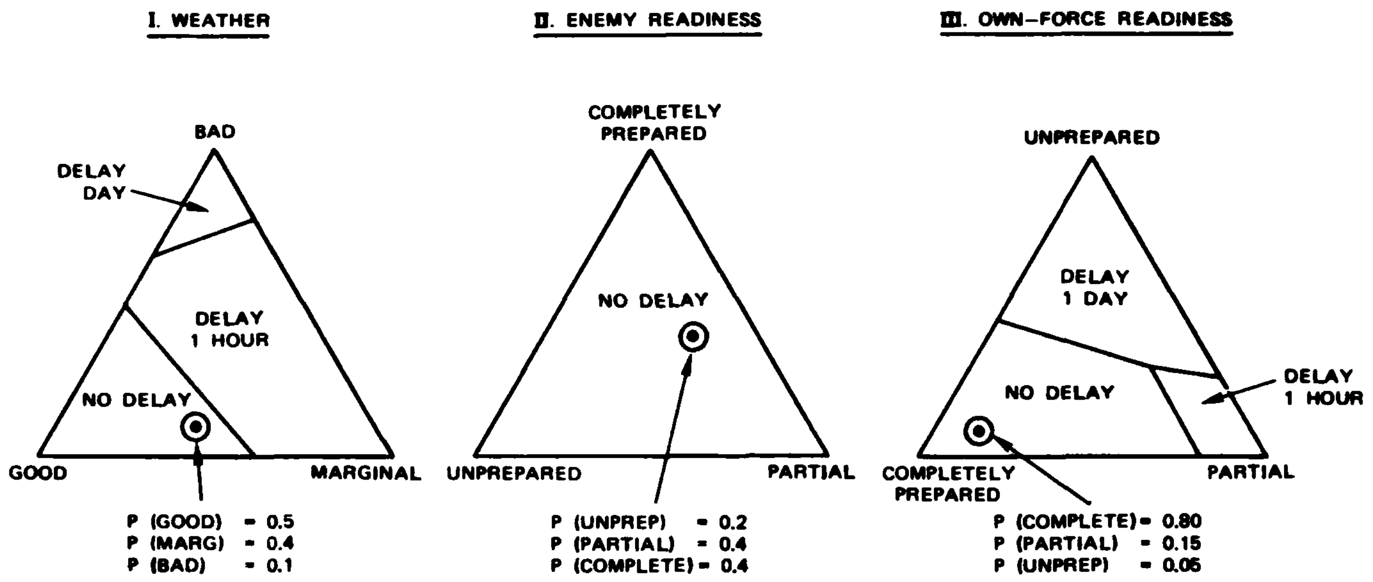


FIGURE 4. Separate Displays for Each of Three Conditioning Elements.

TABLE 2. Derivation of Decision Rules Using Utility Values.

STATES-OF-THE-WORLD

ACTIONS		S_1	S_2	S_3
	A1	0	A	B
	A2	C	0	D
	A3	E	F	0

UTILITY VALUES

where $A, B, C, D, E, F < 0$
and $B < D, A < F, C < E$

(1) Expected Utility

$$E(A1) = P(S2)A + P(S3)B$$
$$E(A2) = P(S1)C + P(S3)D$$
$$E(A3) = P(S1)E + P(S2)F$$

where P(S1), P(S2) and P(S3) are probabilities of states 1, 2, and 3 occurring.

(2) Decision Rules

$$A1 > A2 \text{ when } E(A1) > E(A2)$$
$$P(S2)A + P(S3)B > P(S1)C + P(S3)D$$
$$P(S1) > P(S2)\frac{A}{C} + P(S3)\frac{B-D}{C}$$

$$A_1 > A_3 \text{ when } P(S1) > P(S2)\frac{A-F}{E} + P(S3)\frac{B}{E}$$

$$A_2 > A_3 \text{ when } P(S2) > P(S1)\frac{C-E}{F} + P(S3)\frac{D}{F}$$

Decision Aid Modules

The triangular display is only part of the decision aiding research done for the TACAID project. However, it is the best defined aid developed for the project and many of the other aids listed in the decision module package (Table 3) are actually exploratory concepts rather then developed aids. The decision modules are independent aiding procedures designed to aid specific generic decision tasks. The scope of decision tasks addressed is wide and most of the tasks discussed as part of the taxonomy (Table 1) are addressed by specific modules. The rationale behind the modules is that any decision situation can be defined in terms of the specific decision subtasks which these modules are designed to aid. Thus, by combining various modules and redefining parameters, these aids theoretically can be redesigned to fit any number of decision environments. Of course, defining the system requirements for specific decision situations and developing an overall algorithm to coordinate the modules may prove to be more difficult for some decision environments than starting from scratch and developing new aiding approaches. However, approaches using algorithms similar to some of the modules have been used recently for aiding in a variety of decision situations by the TACAID developers (cf., Kelly, 1978; Amey, Feuerwerger, and Gulick, 1979). Table 3 lists the modules, decision task addressed, decision type (structuring or selection) and particular decision subtask where appropriate. The modules are described elsewhere (Peterson, Phillips, Randall, and Shaw Cross, 1977). The following descriptions are for modules whose functions are not obvious from Table 3 and may be important in this program.

Invent Course of Action. This module is an attempt to use a repertory grid technique to generate courses of action not considered by the operator. Apparently this approach was still in the early exploratory stages when the report was published.

Process Model. This module is an information display giving the operator information concerning basic processes relating to the system being aided (e.g., show fuel consumption as a function of flight time and airspeed).

Time-Discounting Module. This module shows the value of an outcome if it takes place at a future time as opposed to being done now.

Influence Model. A module where the operator estimates probability values for parameters which influence the variable of interest. An algorithm estimates the probabilities for the variables of interest based on these inputs.

TABLE 3. Decision Analytic Modules.

Type*	Decision Task	Subtask	Modular Aid
I	List action		A. Invent courses of action
I	Determine outcomes		B. Select level of decomposition and generate problem structure
II	Worth assessment	2	C. Assess values or utilities
II	Worth assessment	3	D. Assess multi-attribute values or utilities
-	-	-	E. Build and use process model
II	Worth assessment	2	F. Build and use time-discounting model
II	Probability estimation	2	G. Assess probabilities directly
II	Probability estimation	5	H. Build and use hierarchical inference model
II	Probability estimation	5	I. Build and use influence model
II	Probability estimation	3	J. Build and use Bayesian revision model
II	Information selection	1	K. Assess information content of information source
II	Information selection	2	L. Determine value of information
II	Action selection	2	M. Aggregate values with probabilities
II	Action selection	2	N. Perform sensitivity analyses
II	Worth assessment	3	O. Model bargaining/negotiation situation

*Task type and subtask are shown in Table 1.

Sensitivity Analysis. A range of values is given for either utilities or probabilities. This allows the operator to see how the suggested course of action changes as the values of important parameters change.

In summary, the modular approach is an attempt to describe decision environments as consisting of various molecular combinations of decision tasks. Modules are designed to be mapped to particular combinations. Such an approach is still in the developmental stage.

TACAID TAXONOMIC BREAKDOWN

Decision Tasks. The decision tasks addressed by the various aids are listed in Table 3. Perhaps the most impressive feature of the TACAID project is the wide variety of decision analytic techniques used. It remains to be seen whether operational aids based on these techniques prove useful in a realistic environment.

Conditioning Elements. TACAID considers approaches to using three conditioning elements to describe the state-of-the-world either as a composite probability or as separate sources of information (see Figure 3).

Mathematical Models. The aids are based on Bayes theorem and utility theory, as well as other standard statistical models used in decision analysis.

BIBLIOGRAPHY FOR TACAID

1. Decision and Designs, Inc. *Documentation of Decision-Aiding Software: OPINT Users Manual*, by D. M. Amey, P. H. Feuerwerger, and R. Gulick. McLean, VA, 1979.

2. Decision and Designs, Inc. *Satellite Surveillance Avoidance Optimization Aid*, by S. Barclay and L. S. Randall. McLean, VA, 1977. (Report PR-77-14-36.)

3. Decision and Designs, Inc. *Decision Analysis as an Element in an Operational Aiding System*, by R. V. Brown, C. M. Hobitzell, C. R. Peterson, and J. W. Ulvila. McLean, VA, 1974. (Technical Report 74-2.)

4. Decisions and Designs, Inc. *Decision Analysis as an Element in an Operational Aiding System: Phase II*, by R. V. Brown, C. R. Peterson, W. H. Shawcross, and J. W. Ulvila. McLean, VA, 1975. (Technical Report 75-13.)

5. Decisions and Designs, Inc. *Decision Analysis as an Element in an Operational Decision Aiding System: Phase IV*, by C. R. Peterson, L. D. Phillips, L. S. Randall, and W. H. Shawcross. McLean, VA, 1977. (Technical Report 4-6.)

6. Decisions and Designs, Inc. *Decision Analysis as an Element in an Operational Decision Aiding System: Phase III*, by C. R. Peterson, L. S. Randall, S. H. Shawcross, and J. W. Ulvila. McLean, VA, 1976. (Technical Report 76-11.)

7. Naval Postgraduate School. *Decision Aids: Engineering Science and Clinical Art*, presented at Command and Control Workshop by C. W. Kelly. Monterey, CA, 24-28 July 1978.

ADDAM: PERCEPTRONICS, INC.

The ADDAM algorithm is a versatile aid which combines a decision theoretic approach with techniques used in pattern-recognition research. The operator sees a list of suggested actions ranked according to a multi-attribute utility (MAUT) model. Furthermore, the utility values of the various attributes are updated as a function of the operator's responses. This is done using a pattern-recognition training algorithm which changes values of outcomes favored by the chosen response by raising their utility weights, and downgrades those with low levels. This adjustment of weights stabilizes after a relatively few trials if the decision environment remains stationary. The aid has been adapted for a number of different military environments including a command and control information system, remotely piloted vehicle (RPV) control and as an aid for the Tactical Coordination Officer (TACCO) during anti-submarine warfare (ASW) maneuvers.

The MAUT Model in ADDAM

For the MAUT model, consequences of an action are broken down into its constituent parts reflecting independent attributes or dimensions of the resulting outcome. The value of an outcome (referred to as its utility) is a linear function of these attributes.

$$V_J = \sum_{i=1}^{n} U_i \, a_{iJ} \qquad (1)$$

where

V_J = utility value of the Jth outcome

U_i = weighting constant for attribute i

a_{iJ} = value of attribute i for the Jth outcome

The value of a response is the expected value of the possible outcomes for that response.

$$R_K = \sum_{J=1}^{n} P_J \, V_J \qquad (2)$$

where

R_K = value of Kth response

P_J = probability associated with the Jth outcome

V_J = utility value of Jth outcome

The ADDAM aid displays the expected value of various responses ($R_1 \ldots R_K \ldots R_N$) to the operator. Also, probabilities associated with each outcome for these actions can be displayed to the operator. The ADDAM aid seems to be particularly effective for repetitive situations like the ASW environment. In such cases, since the operator must make the same type of decision a number of times, a model based on his past performance allows him to be consistent and reliable. For many such tasks, the operator's lack of consistency degrades performance. Linear models (such as Equations 1 and 2) have been shown to outperform the operator they model in a wide variety of decision environments.[23] The next section indicates how attribute weights are modified by the operator's previous responses.

Pattern Recognition Model in ADDAM

As mentioned before, ADDAM has been adapted to a number of different environments. The following discussion involves one of the simpler models used to update utility values ($V_1 \ldots V_J \ldots V_n$). However, the general principles applicable to other uses of the ADDAM model are illustrated by this example.

Figure 5 outlines the general pattern-recognition approach. Starting on the left-hand side of Figure 5, one can see that each possible response (i.e., choice) has a pattern of attributes associated with it. On the right-hand side of the figure, each response pattern is weighted and summed in order to derive a utility value according to Equation 1. The decision selection box on the far right represents the selection by the ADDAM algorithm of the response pattern with the highest utility value. The selected response is referred to as the predicted response. This predicted response is then compared to the operator's actual

---

[23] Dawes, R. M. and B. Corrigan. "Linear Models in Decision-Making," *Psychol. Bull.*, Vol. 81 (1974), pp. 95-106.

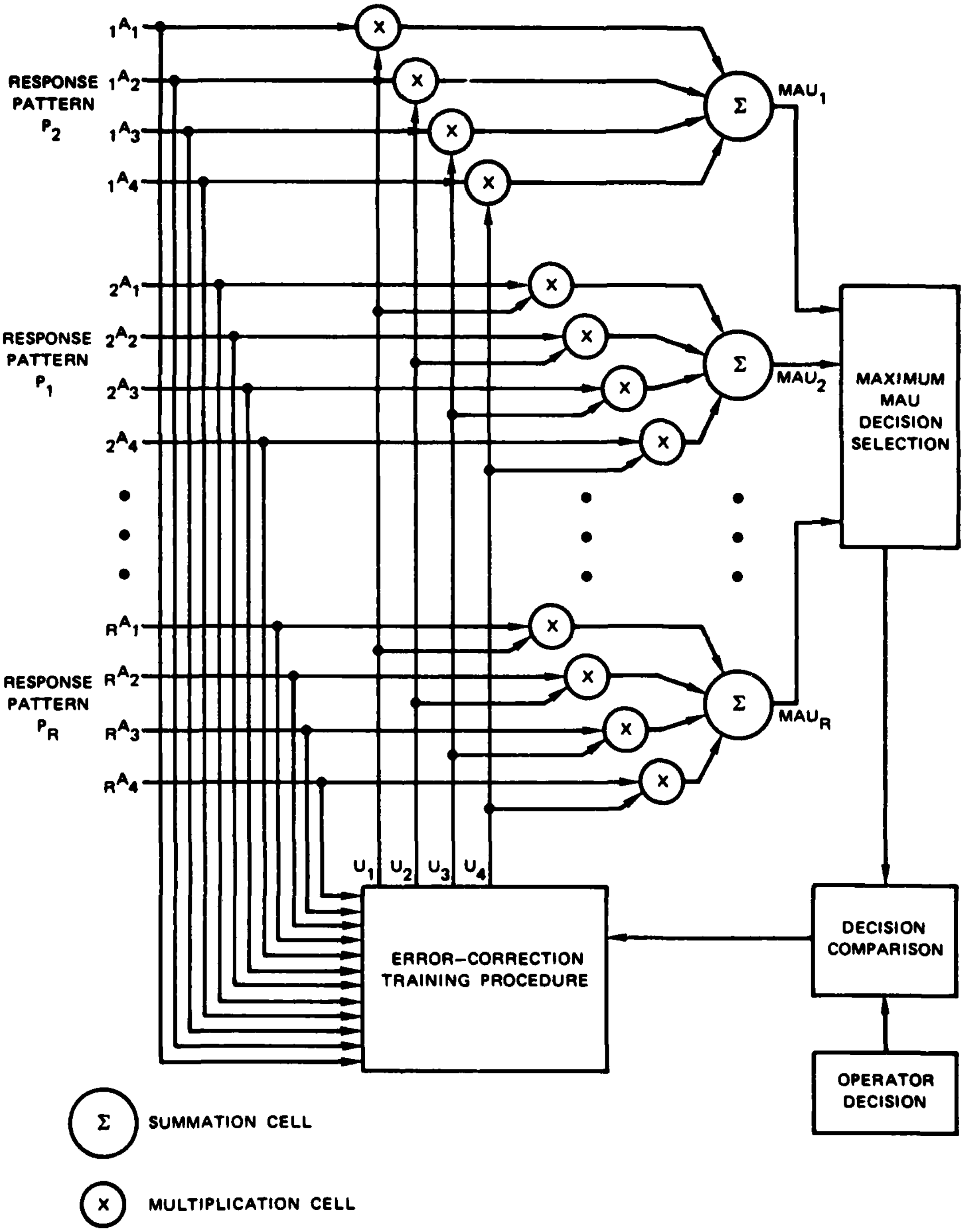


FIGURE 5. Outline of the ADDAM Algorithm Including Both Multiattribute Utility Selection and Pattern Recognition Error Correction Procedures.

decision (lower right hand corner). Next, based on this comparison, the error-correction training procedure readjusts the utility weights for Equation 1 (see Figures 6 and 7). The attribute levels are normalized and attributes with high levels on the chosen response compared to the predicted response result in increasing the weight for that attribute. Similarly, relatively low attribute levels for the chosen response result in lowering the weight for that attribute. Thus, the operator's actual response pattern determines the weighting for each attribute in Equation 1. These weighting values stabilize in a relatively short time if the decision environment remains constant. Another factor which determines the time it takes to stabilize is the value of λ shown in Figure 7 which is called the adjustment factor.

Stabilization is said to occur whenever the predicted response agreed with the chosen response for 7 of the last 10 responses. At this point, the operator can use the utility values generated by the model to choose the appropriate response. ADDAM also uses the concept of "environmental states" to correct for changes in the decision environment. Thus, as environmental states change, the parameters of the model change and different decisions are predicted. This requires a separate "training program" for each environmental state. The next section will demonstrate how this model works for the ASW environment.

ASW Environment

The ASW problem involves a TACCO who must choose the number and configuration of sonobouy patterns to drop at specific locations in order to track suspected enemy submarines. Four attributes of the possible configuration choices were considered important: detection index $[A_1]$ (i.e., probability of detecting submarine), area covered by the configuration $[A_2]$, uncertainity reduction $[A_3]$, and resource conservation $[A_4]$ (i.e., number of sonobouys that are available). Figure 6 shows that various levels of these attributes are associated with the possible configurations the TACCO can choose. Thus, each response (i.e., possible configuration) has a utility vector consisting of the levels of the attributes appropriate for that response [e.g., $P_1 = ({}_1A_1, {}_1A_2, {}_1A_3, {}_1A_4)$ where ${}_1A_1$ is the appropriate detection index level for P_1]. The relative weighting of each attribute is changed after each response which is different than the response predicted by ADDAM. A numerical example of the training algorithm and the utility model might help in understanding the procedures. Before any responses are made the utility weights for each attribute are 1 (U_1, U_2, U_3, U_4). The attribute levels for each response pattern are set and normalized. They are normalized so the range of values is the same for each attribute. For

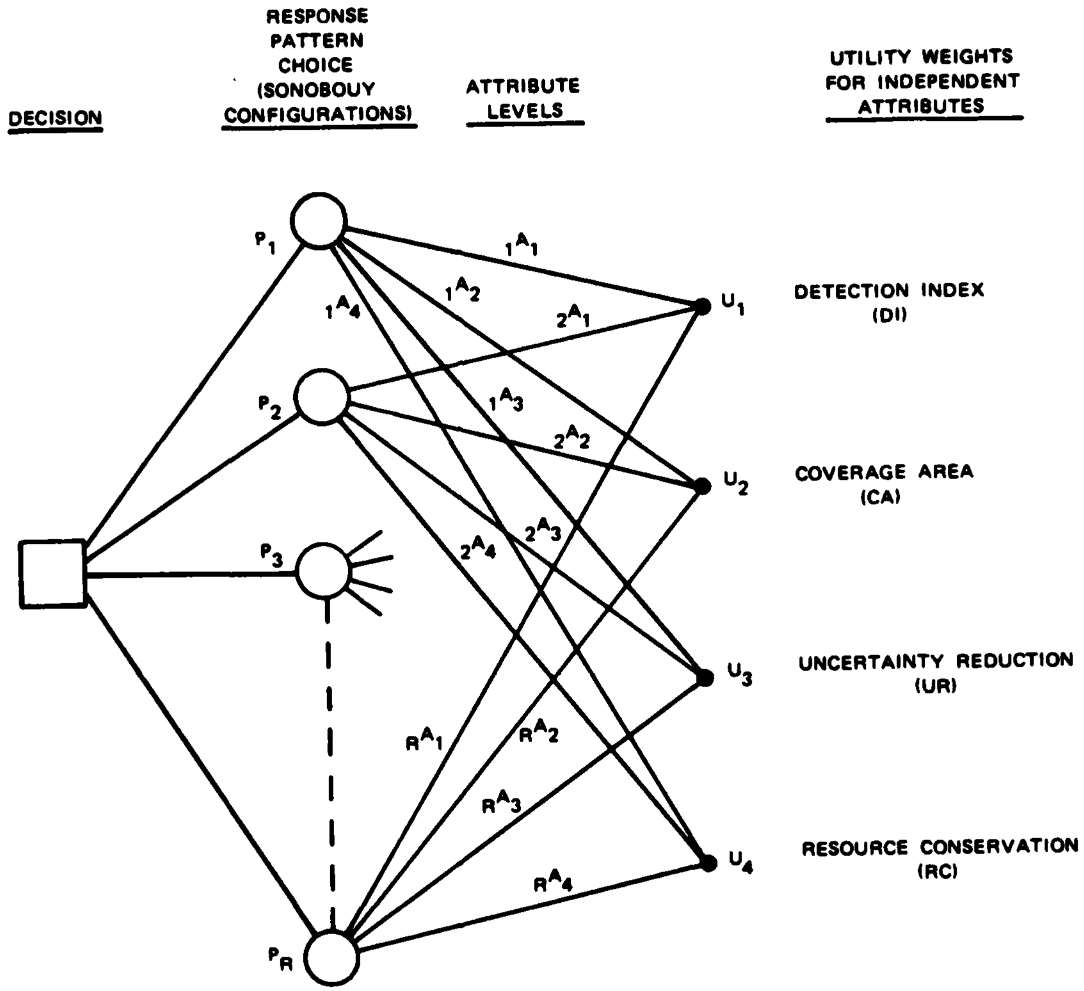


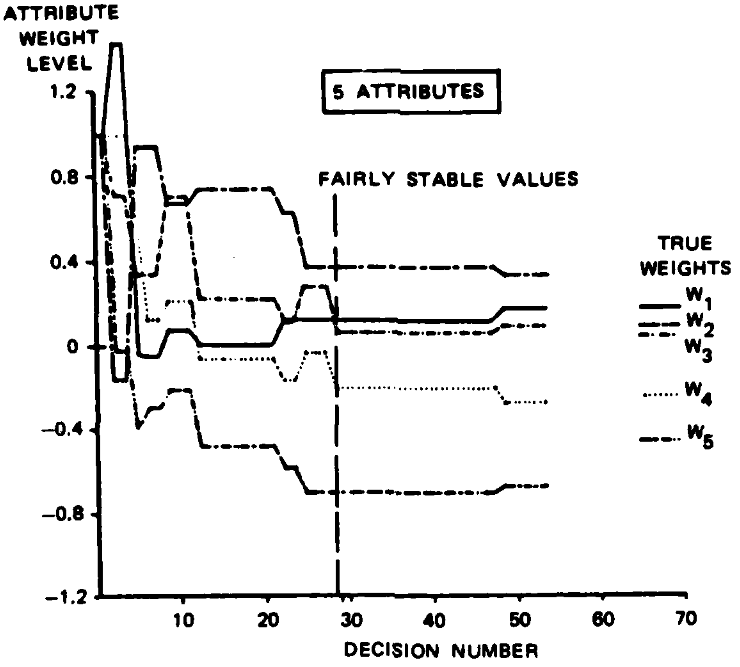
FIGURE 6. The Mapping of Attribute Levels to Particular Responses.

ADJUSTED WEIGHT $\hat{u}_i$		PREVIOUS WEIGHT u_i		ADJUSTED FACTOR λ		ATTRIBUTE VECTOR OF CHOSEN PATTERN ${}_cA_i$		ATTRIBUTE VECTOR OF PREDICTED PATTERN ${}_pA_i$
$\hat{u}_1$	$=$	u_1	$+$	λ	$\circ$	$({}_cA_1$	$-$	${}_pA_1)$
$\hat{u}_2$	$=$	u_2	$+$	λ	$\circ$	$({}_cA_2$	$-$	${}_pA_2)$
$\hat{u}_3$	$=$	u_3	$+$	λ	$\circ$	$({}_cA_3$	$-$	${}_pA_3)$
$\hat{u}_4$	$=$	u_4	$+$	λ	$\circ$	$({}_cA_4$	$-$	${}_pA_4)$

FIGURE 7. Error-Correction Training Procedure.

instance, in our example it will be assumed that the values for each attribute are transformed so that the levels range from 1 to 10 regardless of their underlying scale. To make our example simple, we will assume there are only two possible configurations, P_1 and P_2 with their levels set at (4, 3, 9, 3) for P_1 and P_2 = (6, 7, 1, 7). Using Equation 1, with equal unit weights for each attribute, the utility for $P_1 = 19$ and $P_2 = 21$. These values would be shown the operator and P_2 would be the predicted response. However, if the operator chose P_1 instead, then the utility weights would change, reflecting the fact that the operator apparently weighed attribute 3 more heavily than the other attributes in making his choice. Since the changes in the utility weights should be a gradual process reflecting a number of training reiterations, the training adjustment factor in Figure 7 (λ) is set at 0.04. Using this training algorithm, the weights for the four attributes would change to 0.92, 0.84, 1.32, and 0.84 which would cause the utility values for P_1 and P_2 to change to 20.60 and 18.60, respectively. It should be emphasized that attribute level values (${}_1A_1 \ldots {}_iA_j \ldots {}_mA_n$) do not change; rather, the weighting constants for the attributes in Equation 1 change ($U_1 \ldots U_j \ldots U_n$). Thus, the chosen response modified the utility values derived from Equation 1 through the use of the training algorithm. In particular, the modification changed the *predicted response* pattern from P_2 to P_1.

Figure 8 shows a computer simulation using the ADDAM model and the number of decisions made before the values stabilized for 3 and 5 attributes. These figures illustrate that stabilization depends on the complexity of the problem (i.e., number of attributes considered). However, these particular values stabilized pretty well at less than 30 decisions for complex situations and less than 20 for simpler ones. Thus, at least for these simple environments simulated in the laboratory, the model shows promise for applications where a great number of decisions must be made for relatively static environments. In the real world, the decision environment is apt to change rapidly under certain conditions. The ADDAM adapts to rapid changes by using a number of separate utility weight vectors depending on the conditioning elements. Thus, if the sea state changes from calm to rough, the ADDAM automatically uses a different training algorithm, resulting in different utility weights. In this way various environmental states are matched to various ADDAM models and adaption can be made rapidly to changes in the environment that are predictable. Also, if the operator realizes that none of the ADDAM models are appropriate he can be trained to rely on his own judgment until the training algorithm stabilizes to reflect the new situation. The crucial point is that the ADDAM system does not automatically make decisions but rather (after a sufficient training period) gives the operator a model of his past decisions. Thus, the



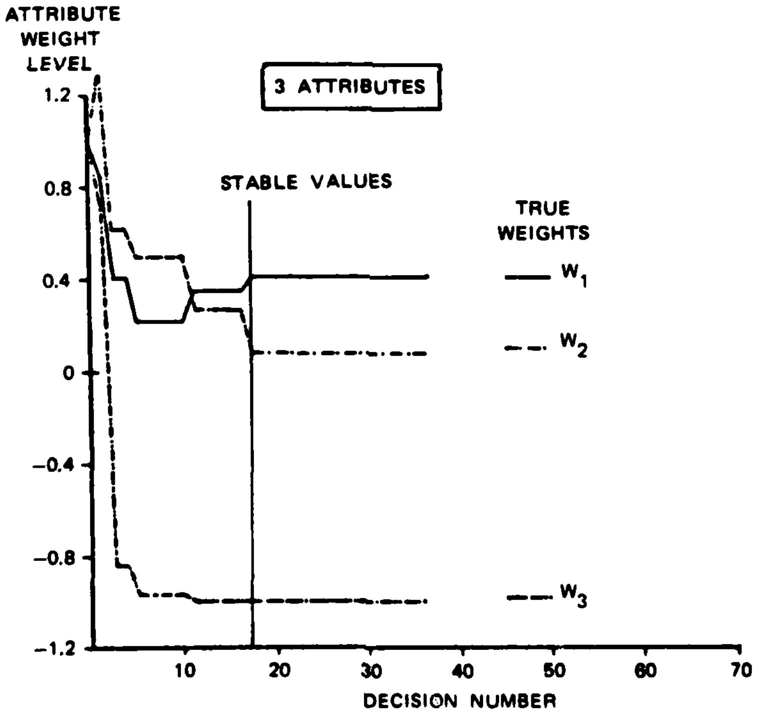


FIGURE 8. Number of Decisions for Stabilization for the 3 and 5 Attribute Cases.

operator is able to monitor and change the basic strategy as the situation dictates and to use the ADDAM aid for those situations when decision-making becomes a repetitive task.

Aid Characteristics

The aid described above is only one version of the ADDAM aiding approach. Other aiding approaches involved queries for an information system in a command and control environment, and optimal paths for an RPV. Also, some of the other versions were more complex. They used both Equations 1 and 2 for action selection criteria. The TACCO aid uses only Equation 1 and does not consider the implications of more than one outcome per response. However, the basic aiding approach and weaknesses were very similar for all versions of the aid. The main weakness is the lack of research done in an operational environment to test the aid. Laboratory simulations have shown the aids to be useful in a number of combat environments. However, these simulations, by their very nature, are not real tests of the system in their actual environment. The system must be tested in an operational environment before any meaningful evaluations can be made. This is particularly true because the system is unique and baseline data from similar operational systems cannot be used to predict performance.

Also, there are technical problems with the algorithm itself. The particular MAUT additive model discussed previously is not technically appropriate for the ASW environment. This is because the attributes used are highly correlated, a condition which violates the assumptions of MAUT models.[2,15] However, other research has found that the predictive power of such models is high even when some of their basic assumptions are violated.[24,25] The model used is simple and has face validity. The next step is to examine more complex models or even simpler models (perhaps by reducing the number of attributes). Then the competing models can be compared. It is even possible, that a preset weighting of various attributes based on an average of expert judgments might outperform any model generated with the training algorithm.

In summary, the ADDAM approach is promising for military environments in which a large number of repetitive decisions must be made. However, the actual usefulness of such an approach for operational situations has not been thoroughly evaluated; more tests, both in the field and the laboratory must be conducted.

---

[24] Edwards, W. *Computer-Aided Decision Making: A Short Course.* Class lecture, UCLA, Spring 1978.

[25] Gardiner, P. C. and W. Edwards. "Public Values: Multi-Attribute Utility Measurement for Social Decisions," *Proceedings of the 1975 International Conference on Cybernetics and Society*, San Francisco, CA.

ADDAM TAXONOMIC BREAKDOWN

Decision Tasks

The main tasks addressed were worth assessment and action selection. The worth assessment model resulted in a multi-attribute interval scale. The action selection suggestions which are displayed to the operator are based on both Equations 1 and 2 depending on the particular version of ADDAM used.

Conditioning Elements

The conditioning elements were handled in two ways. A "situation mask" approach consisted of introducing dummy variables into the linear models (Equations 1 and 2) which had a value of "one" if a particular environmental state existed and "zero" otherwise. On the other hand, the "environmental state" approach consisted of using a different linear model for each of the possible 16 "states-of-the-world". For this approach, the "conditioning elements" determined the linear model used for a particular exercise.

Mathematical Models

Two mathematical approaches were used: MAUT and pattern-recognition models. The first approach consisted of linear models (Equations 1 and 2) to rank order the various possible actions in terms of relative value. The second approach was used to update the utility weights in Equation 1 as a function of the operator's past response pattern. Attributes favored by the operator's pattern were given relatively heavy weights whereas non-favored attributes were given low weights. The actual weights were determined by a "training algorithm".

BIBLIOGRAPHY FOR ADDAM

1. Perceptronics, Inc. *Applications of Adaptive Decision Aiding Systems to Computer-Assisted Instruction: Adaptive Computerized Training System (ACTS)*, by W. H. Crooks, M. Kupin, and A. Freedy. Woodland Hills, CA, 1977. (Technical Report PATR-1028-77-1.)

2. Perceptronics, Inc. *Adaptive Computer Aiding in Dynamic Decision Processes: Methodology, Evaluations, and Applications*, by A. F. Freedy, K. P. Davis, R. Steep, M. G. Samet, and P. C. Gardiner. Woodland Hills, CA, 1976. (Technical Report PFTR-1016-76.)

3. Perceptronics, Inc. *Studies and Applications of Adaptive Decision Aiding in Anti-Submarine Warfare*, by A. Leal, K. Chen, P. C. Gardiner, and A. Freedy. Woodland Hills, CA, 1978. (PFTR-1034-78-4.)

4. Perceptronics, Inc. *An Interactive Computer-Aiding System for Group Decision-Making*, by A. Leal, S. Levin, S. Johnson, M. Agmon, and G. Weltman. Woodland Hills, CA, 1978. (Technical Report PQTR-1046-78-2.)

5. Perceptronics, Inc. *Studies and Applications of Adaptive Decision Aiding in Anti-Submarine Warfare*. Woodland Hills, CA, 1977. (Technical Report PTR-1035-77-2.)

6. Perceptronics, Inc. *Applications of Adaptive Models to Information Selection in C^3 Systems*, by M. Samet, G. Weltman, and K. Davis. Woodland Hills, CA, 1976. (Technical Report PTR-1033-76-12.)

7. Perceptronics, Inc. *Adaptive Estimation of Information Values in Continuous Decision-Making and Control of Remotely Piloted Vehicles*, by R. Steeb, K. Chen, and A. Freedy. Woodland Hills, CA, 1977. (Technical Report PATR-1037-77-8.)

ASTDA: ANALYTICS INC.

ASTDA uses a number of displays intended to improve shipboard planning of air strike timing for air-to-ground missions. The aid is part of a general framework of aiding procedures which gives the operator complex information in an understandable format using nomograpic display techniques. Since the mathematical model underlying ASTDA is particular to the air strike timing problem, this report will concentrate on the overall nomographic technology. One of the advantages to the ASTDA approach is that both "outcome calculator" models and "state" models can be addressed. The distinction between these two models will be discussed in a later section.

ASTDA Scenario

Figure 9 outlines the scenario ASTDA was designed to aid. The commander of an aircraft carrier must decide when to launch an attack against Onroda Island. Onroda Island has about 120 planes and 37 SAM and AA batteries for defense, whereas the attack force has 12 A-6, 24 A-7, and 18 F-14 available for the air strike. The following systems variables are considered important:

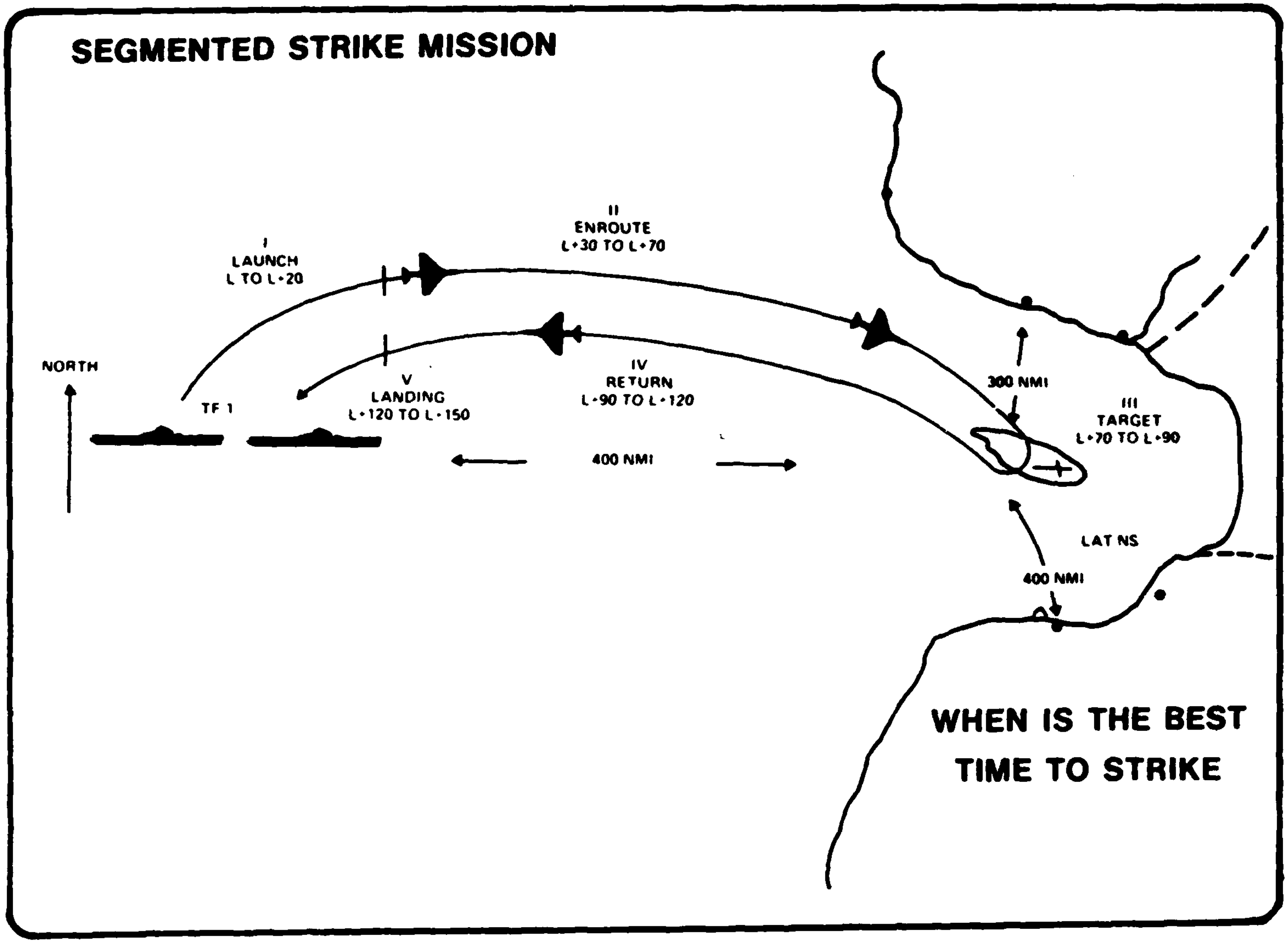


FIGURE 9. Air Strike Timing Scenario.

1. Mission segment
2. Fighters and attack force readiness (own)
3. Enemy force readiness at target
4. Enemy ground force
5. Weather at target
6. Weather at carrier

The purpose of the nomographs is to display as much pertinent information as possible to the decision-maker without overloading him.

Nomographic Displays

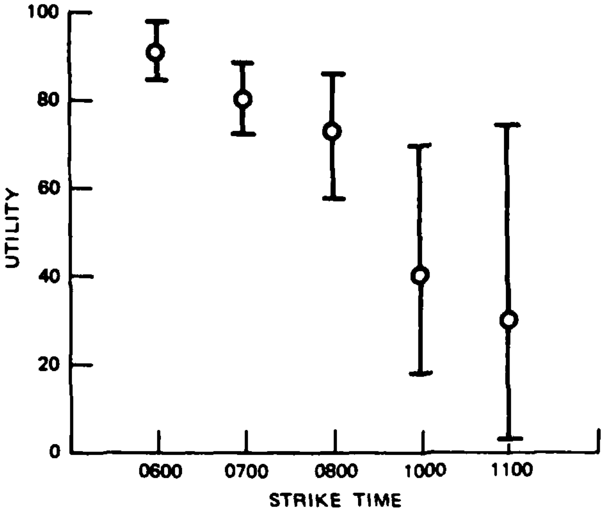
A nomographic display depicts the effects of two or more independent variables on the performance of some criterion variable. The display shows the decision-maker the relationships among a number of different variables which influence systems performance allowing him to both structure the decision situation and to choose among possible alternatives. Table 4 lists 10 displays for the air strike environment showing both independent systems variables and the criterion variable. The criterion variable is some measure of systems performance, whereas the independent variables are those likely to influence the air strike mission's success. Three points should be made concerning these displays: (1) utility is the most common criterion variable; (2) most of the criterion variables are a function of air strike launch time and some other variable; (3) some of the displays give range and variance estimates as well as showing the mean effect of the independent variables on the criterion.

Utility, although defined precisely in a mathematical sense, is often difficult to assess except in relative terms. This is because the scale does not represent a physical measurement but rather attempts to elicit worth values from the operator concerning particular outcomes.[22] The elicitation of these values is difficult[18] and often does not represent the true preference structure of the operator. The reports discussing ASTDA did not go into much detail on eliciting utility values and it must be assumed that such questions will be addressed in future developmental work.

As Table 4 indicates, the main purpose of the ASTDA displays is to depict the effects of various systems variables (i.e., weather, number of aircraft, etc.) as a parametric function of strike time. Figure 10 illustrates the type of formats used to display the nomographs. Figure 10A graphs the effects of number of A-7 aircraft on utility with strike time as a parameter (the ASTDA displays also uses color to code strike time differences). Figure 10B shows the average effect of strike time on utility, but also shows confidence limits bounding the mean effects.

TABLE 4. Nomographic Displays for Strike Time Problem.

Display Number	Criterion Variable	Independent Variable 1	Independent Variable 2	Range or Variance Given
1	Utility	Strike Launch Time	-----	Yes
2	Airplane Loss	Strike Launch Time	Mission Segment	-----
3	Utility	Strike Launch Time	Number of A-6, A-7, F-14	-----
4	Utility	Strike Launch Time	Number of enemy aircraft	-----
5	Utility	Strike Launch Time	Probability of good visibility at target	-----
6	Utility	Strike Launch Time	No. of A-6, A-7 and F-14 aircraft ready	Yes
7	Number of Enemy Aircraft	Strike Launch Time	-----	Yes
8	Probability of enemy being in particular readiness state	Strike Launch Time	Enemy ground readiness	-----
9	Target Visibility index	Strike Launch Time	-----	-----
10	Weather at Carrier index	Strike Launch Time	-----	Yes



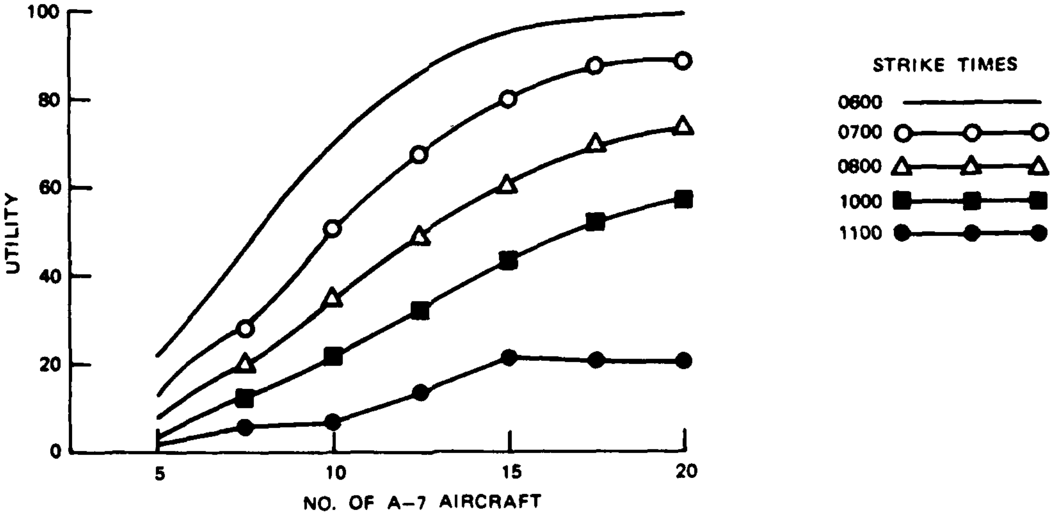


FIGURE 10. Examples of Possible ASTDA Display Configurations.

Although this information could be used to aid the operator in alternative selection, the main advantage in giving the decision-maker such detailed information is to simplify problem structuring (e.g., Table 4). These displays are an attempt to reduce the mass of information inherent in a combat situation to manageable levels so that the decision-maker can structure the scope of the decision problem in his own mind before choosing among alternative strike times.

One of the features of ASTDA approach is the "outcome calculator". This is an attempt to circumvent the problems associated with utility measures by modeling the combat environment so that the criterion value is some physical measure of systems performance. The relationship of the outcome calculator to decision theory is discussed next.

"State" versus "Outcome Calculator" Models

Figure 1 shows the usual "state" model approach to structuring the decision problem. First, the decision-maker lists distinct actions and states-of-the-world. Next, he generates a utility value for each outcome evaluating directly the effects of the occurrence of non-overlapping states-of-the-world given a particular action. A "state" model is inconvenient for two reasons: (1) states-of-the-world must take on discrete values; (2) outcomes may be uninterpretable in some cases. For example, it may be very difficult to measure the utility of attacking at 9:00 am when the weather is poor and the enemy is prepared, because "poor weather" and "enemy preparation" are not quantitatively defined.

An "outcome calculator" is a mathematical model which uses operational research techniques to compute the consequences of an outcome in terms of physical criteria. In the above example, an outcome calculator would use values for visibility, probability of precipitation, number of enemy planes and ground defense installations as input variables. The model's equations would then predict the extent of damage to both the attack and enemy forces. Using an outcome calculator, the commander could make decisions in terms of physically meaningful criteria and not have to generate utility values. Also, an outcome calculator could be used to generate utilities. In this case, the utility values would be generated from the "outcome calculation" values using MAUT models discussed previously (e.g., 12 friendly aircraft destroyed, 6 enemy targets destroyed = 11 utility units). There are a number of disadvantages to an "outcome calculator": (1) the model is usually mathematically sophisticated, incorporating assumptions which are valid only if the relationship among the model's parameters are well understood; (2) the model is situation specific -- if parameters not included in the model are important (i.e., enemy morale, new weapons...), then the model is likely to make inaccurate predictions. Thus, an outcome calculator is only practical for situations that are readily modeled and are important enough to warrant the effort.

ASTDA TAXONOMIC BREAKDOWN

Decision Tasks. The main decision tasks addressed are problem structuring and information selection. In a combat environment, the number of variables and inherent uncertainty makes the structure of the decision situation extremely complex. The nomographs reduce the complexity and allow the decision-maker the opportunity to limit the scope of the decision problem to manageable levels. In particular, the "outcome calculator" allows the decision-maker to quantify outcomes in order to evaluate them. This reduces the number of possible actions, since some possibilities can be screened out without resorting to more formal decision analysis. Also, the displays are designed to depict concisely the most valuable information in the decision environment. Thus the information selection task is simplified by using optimal information displays.

However, the "outcome calculator" and displays developed by Analytics, and the models on which they are based are still evolving. They have not yet been evaluated thoroughly in a laboratory situation or, even more importantly, used in an actual operational environment. Thus all that can be said is that they are interesting concepts, which, when developed, may prove to be useful tools.

Conditioning Elements. Conditioning elements are handled two ways by the ASTDA aid. For state models, values of conditioning elements define particular states-of-the-world. For example, temperature 91°, visibility 13 miles, enemy forces 50% prepared would define one state; qualitatively it would be S_i = hot, fair visibility and enemy preparation moderate. For the "outcome calculator" these variables would be used as inputs to the "outcome calculator" model. These inputs would be used to solve equations to predict the outcome of an air strike in terms of own and enemy forces destroyed.

Mathematical Models. The ASTDA approach uses decision analytic and traditional operational research modeling techniques. The general evolution of the ASTDA approach is away from "state" models and towards "outcome calculators". The mathematical model for the calculator is complex, using a number of parameters built into the algorithm as well as a number of input variables. The distributional aspects of the model's parameters are considered (mean, standard deviation, skewness, and type of distribution). Monte Carlo methods can be used to predict output distributions in terms of own and enemy losses.

Decision theoretic modeling is used in the ASTDA approach, especially in Bayesian updating models and expected utility calculations. However, the trend seems to be moving toward giving the decision-maker outcome data in terms of physically meaningful units (weather, number of aircraft loss etc.) rather than in utility units.

BIBLIOGRAPHY FOR ASTDA

1. Analytics, Inc. *Measuring the Performance of Operational Decision Aids*, by Staff of Analytics. Willow Grove, PA, 1976. (Final Report 1161-B.)

2. Analytics, Inc. *Decision Aids in Naval Tactical Warfare*, by S. D. Epstein. Willow Grove, PA, 1978.

3. Analytics, Inc. *Operational Decision Aids: The Application of Nomography and Uncertainty Analysis to Decision-Aiding Systems*, by S. Epstein, M. Strieb, F. Gleen, R. Wherry, and R. Goldman. Willow Grove, PA, 1977. (Technical Report TR-1218A.)

4. Analytics, Inc. *Integration of Decision Aids for Strike Campaign Planning*, by F. Glenn and W. Zachery. Willow Grove, PA, 1979. (Technical Report 1344-C.)

SKETCH MODEL: INTEGRATED SCIENCES CORPORATION

The SKETCH model is an attempt to use aiding systems in which "the man helps the machine help the man" (Figure 11). The operator performs tasks which aid the machine by limiting the decision problem and the machine, in turn, computes optimal solutions which feed back to the operator and cause him to further structure the task. The most important feature of the aid is the interactive nature of the tasks that are assigned to man and machine. The purpose of the aid is to help an aircraft commander plan his flight path for an air strike mission. Two mathematical approaches for implementing the aid have been investigated: non-linear programming and dynamic programming.

Scenario

The aid helps the commander find optimal paths for air strikes against the airport on Onroda Island. Figure 12 shows an example of a SKETCH display. The crosses are radar installations, whereas the concentric circles around the island represent isocontours indicating locations with equal probability of detection by the radar. The commander's task is to choose a flight path which minimizes both probability of detection and fuel consumption.

Interactive Aiding

The operator visually examines the display to choose likely avenues of approach. He then marks the candidate flight paths on the SKETCH display in the following manner (Figure 12). He generates six points

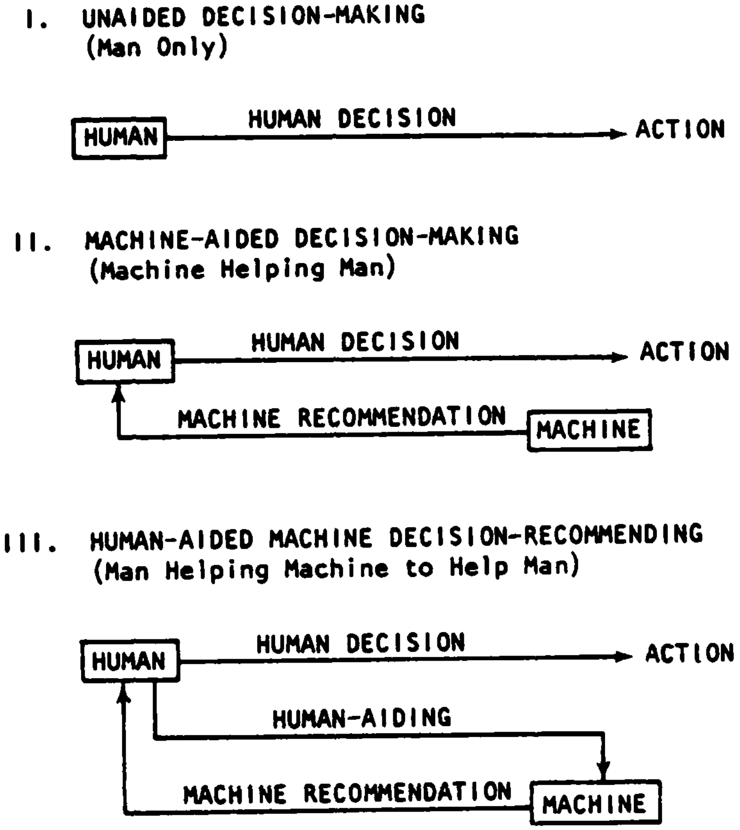
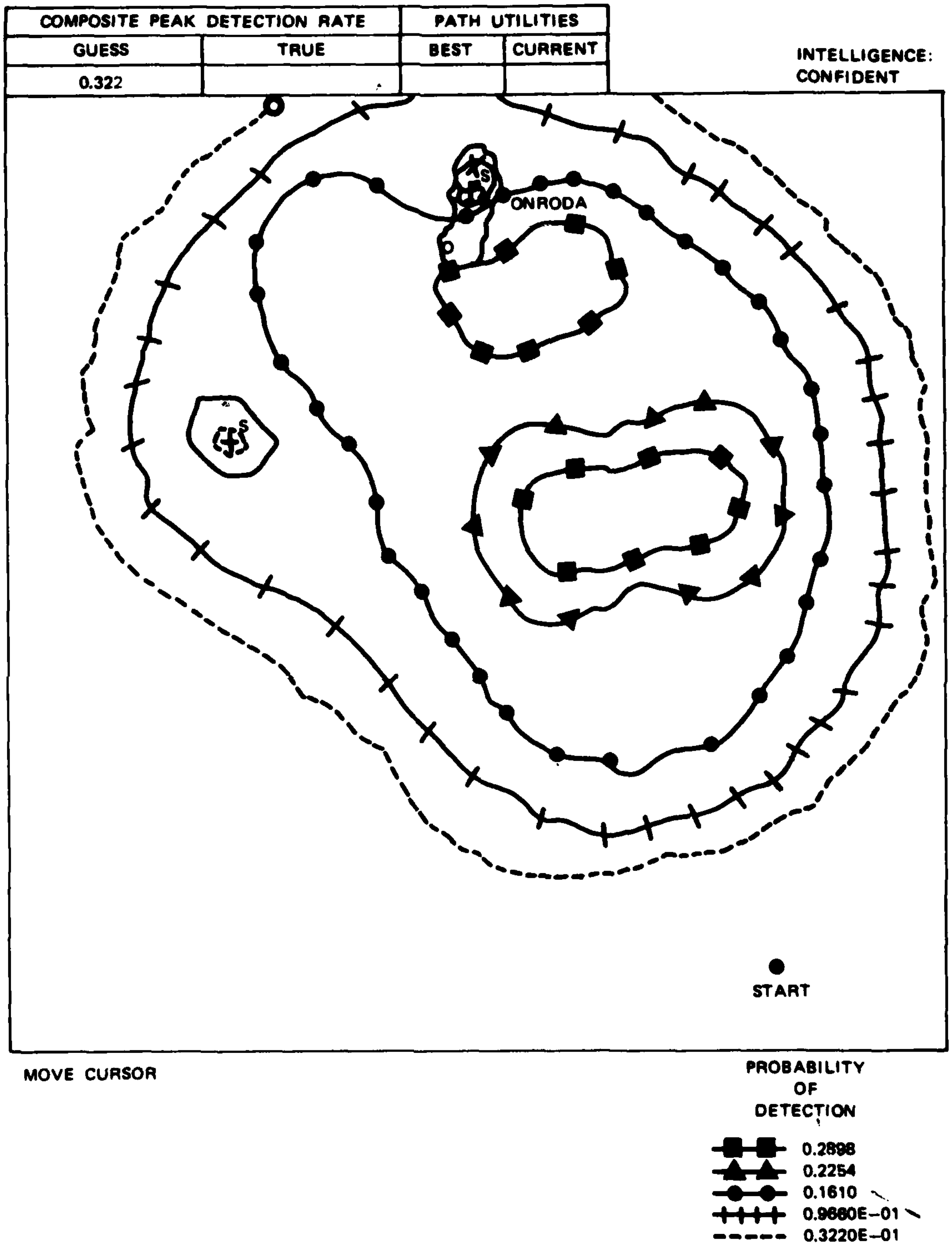


FIGURE 11. Three Strategies for Decision-Aiding.



COMPOSITE PEAK DETECTION RATE		PATH UTILITIES	
GUESS	TRUE	BEST	CURRENT
0.322			

INTELLIGENCE: CONFIDENT

MOVE CURSOR

FIGURE 12. Example of a Possible SKETCH Aid Display.

spaced at equal distances to determine the flight path. Actually, two of these points are predetermined, since the first and last points are the starting point and Onroda Island, respectively. The other four are referred to as part "way" points for the proposed flight path (i.e., connecting all six points defines the flight path). The computer examines these points using non-linear programming optimization techniques. The program attempts to minimize a trade-off function between fuel consummed and probability of detection. Thus either flying directly toward the airport (marked with an X) or flying around all high probability contours does not necessarily represent an optimal flight path in terms of the trade-off. The non-linear programming algorithm (cf., Walsh and Schecterman, 1979, Appendix B) examines points near the chosen "way" points in order to find a more optimal path. The process is reiterative in nature with different points being chosen until either the improvement fails to surpass some minimal criterion or a pre-set time has elapsed. The result is that an optimal path, in the general vicinity of the path chosen by the operator, is displayed on the SKETCH model display. The trade-off function also is used to display a utility value for that particular path.

The operator then chooses a path in a different region and the computer finds the optimal path in that general neighborhood and displays the results to the operator. The final result is that the operator can view optimal paths for a number of different regions of the SKETCH display with a measure of merit given for each path. The aiding system attempts to allocate to both man and machine tasks they are best suited for. The operator is responsible for global strategy, choosing a number of likely flight paths based on his own experience and the displayed contours. The computer, in effect, does the fine tuning by choosing the best paths in the general area picked by the operator. The aid also computes a measure of merit based on the trade-off function. This is what is meant by the "man helping the machine help the man." The operator's ability to see a number of plausible strategies aids the machine by restricting the amount of computation necessary. The computer, in turn, does fine tuning and computations which are beyond the scope of the operator's capabilities. Besides the non-linear algorithm discussed, the aid can also use dynamic programming algorithms. A brief description and comparison of the two methods follow.

Non-Linear and Dynamic Programming Techniques

The following descriptions are simplified versions of the algorithms and are intended only as an overview of the process involved.

The form of the equation driving the non-linear programming algorithm is given below.

$$U = f\ (X_1 \ldots X_j \ldots X_n)$$

where

X_j is an independent variable.

$f(X_1 \ldots X_j \ldots X_n)$ is a function defined on these variables.

U is a utility value which is maximized when the trade-off between fuel and probability of detection is minimized.

The 13 variables of interest include both the longitudinal and latitudinal locations of the four "way" points and the airspeeds for each of five legs of the flight path. A trial is the changing of the value of one of the variables. The effect of each trial on U determines the next step in the algorithm. For the first trial, the value of the variable changes an arbitrary amount E. If U increases or stays the same, E itself increases on the next trial. Thus, every time a value change either does not affect or increase U, its value in the next trial increases at a greater rate. However, whenever a trial results in decreasing U, the value of the variable is set and the next variable of interest enters into the algorithm. After all 13 variables are examined, the algorithm repeats the process until the value of U increases by less than 1% or a time limit criterion expires.

The dynamic programming algorithm uses similar logic. However, the size and direction of value changes are determined by predefined rules. The SKETCH display is overlaid by a grid system (for example, a 16 x 16 grid would entail 256 points on the display and every possible flight path would have to go through these points). Figure 13 shows an allowable point change in the flight path that passes through point A. Thus, the flight path can change point by point in order to maximize U. Also, for each change in flight path, the maximization function considers the effects of three airspeeds (high, medium, and low). The process of constructing a flight path entails the algorithm considering every legal transition from point to point, combined with each of the three airspeeds. Thus, if the grid system is large, the number of reiterations necessary to find an optimal path would be large and time-consuming, especially for the computers available for the SKETCH aid. The operator can aid the computer by limiting the dynamic programming to regions in the display that would contain likely flight paths and by using a coarse (i.e., one having few points) grid system for initial determination of optimal flight paths. For subsequent reiterations, the algorithm could be refined by limiting the regions further and increasing the density of the grid system (it should be obvious that the more points in the grid system, the more accurate the algorithm). Thus, again, the operator is helping the machine to help the man. In this case, he would aid the machine by limiting the scope of the dynamic programming to areas that are likely to contain the optimal paths. The next section is a review of experimental work done using variations of the SKETCH model.

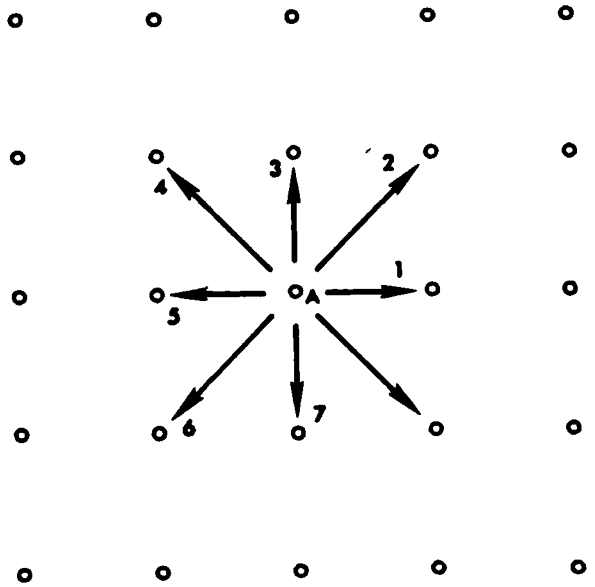


FIGURE 13. Allowable Transitions From Point A on a 5 by 5 Grid Using the Dynamic Programming Algorithm.

Experimental Comparisons

The SKETCH model was evaluated in two experiments using three main experimental conditions: man alone, man-machine combinations, and machine alone. Also, the two types of programming were considered in separate experiments. For both experiments, the initial path chosen by the operator was the estimate of man alone. The man-machine combination consisted of the type of interactive aiding described in the previous two sections. A number of different runs using the computer to solve the problem automatically were done to measure the performance of machine alone. The results for the non-linear programming are shown in Figure 14. The figure suggests that the man-machine system out-performs either the man-alone or the machine-alone system. The man-alone results are somewhat confounded, because they are estimates of performance at the beginning of the session, and it might be argued that, if the operator took longer, his results would be the same as the man-machine system. However, Figure 14 shows that the man-machine system found a nearly optimal path at approximately 3 minutes into the problem, strongly suggesting the advantages of using the man-machine system. By comparison, both machine-only systems were inferior to the man-machine system.

The dynamic programming data came from a different experiment and could not be directly compared to the non-linear results. However, the experimenters concluded for a number of reasons that the non-linear programming algorithm was superior. Thus, it appears that future work using the SKETCH model will concentrate on the non-linear programming algorithm using the man-machine mode.

SKETCH TAXONOMIC BREAKDOWN

Decision Tasks. The non-linear programming algorithm computes the utility weights for various flight paths. However, the uncertainties (isocontours in Figure 12) involved in choosing the paths are considered in the utility function. Thus, the utility values are both worth assessments and action selection criteria. Furthermore, the algorithm actually generates possible actions (i.e., possible paths). Thus, the aid does some of the listing of actions subsumed in the problem structuring task. However, most of the problem structuring is done by the operator, since the aid only looks for better paths in the general vicinity of those chosen by the operator. The display depicts probability estimations using isocontours. However, the actual values are supplied as a result of operational and intelligence inputs.

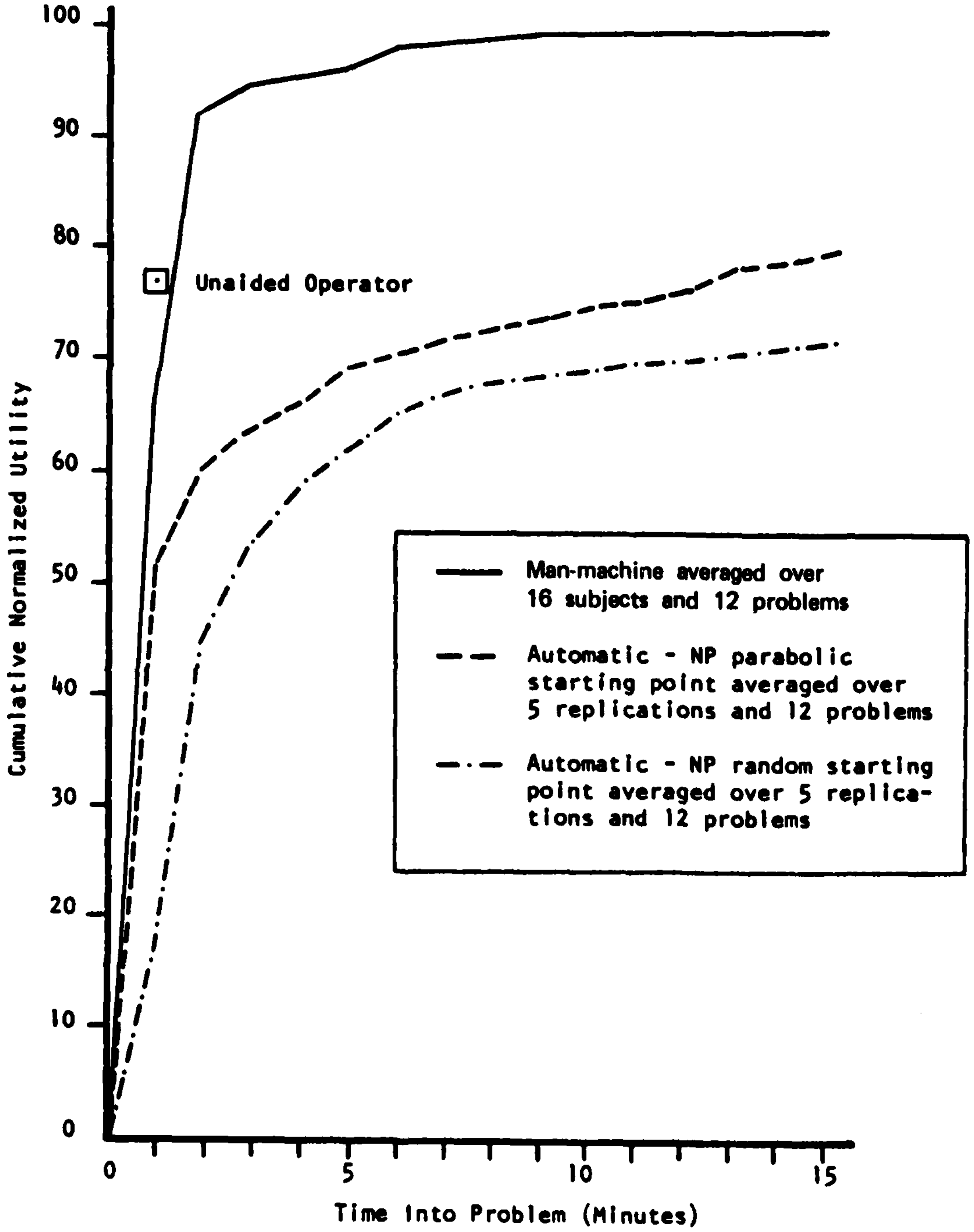


FIGURE 14. Results From the Man-Alone, Man-Machine and the Two Automatic (Machine-Alone) Conditions in the Non-Linear Programming Experiment.

Conditioning Elements

One of the weaknesses of the aid is the use of fuel consumption and probability of detection as the only conditioning elements. The utility function incorporating these two elements is explicitly outlined in Walsh and Schecterman (1978). Basically, it is a non-linear, fairly complex trade-off function which is not obvious to the operator and thus the computation done by the aid would overload the operator in a normal planning environment. However, conditioning elements such as weather, number of aircraft, force at Onroda Island, etc., would have to be considered before any realistic assessment of flight paths could be made. This only points out that the SKETCH model is still basically an experimental concept. Its use in an operational environment would entail major revisions to insure that the aid is useful in a realistic environment.

Mathematical Models

Non-linear programming and dynamic programming algorithms, popular as economic and operational research tools, are the basis of the models used by the SKETCH aid. The non-linear techniques seem to be emerging as the approach the developers of the aid will use in future research efforts.

BIBLIOGRAPHY FOR SKETCH

1. Integrated Sciences Corporation. *Experimental Investigation of Sketch Model Accuracy and Usefulness in a Simulated Decision Aiding Task*, by G. Irving, J. Hornick, P. Chan, and D. Walsh. Santa Monica, CA, 1977. (Report No. 215-3.)

2. Integrated Sciences Corporation. *ODA Pilot Study II: Selection of Interactive Graphics Control Device for Continuous Subjective Functions Applications*, by G. Irving, J. Hornick, D. Walsh, and P. Chan. Santa Monica, CA, 1976. (Report No. 215-2.)

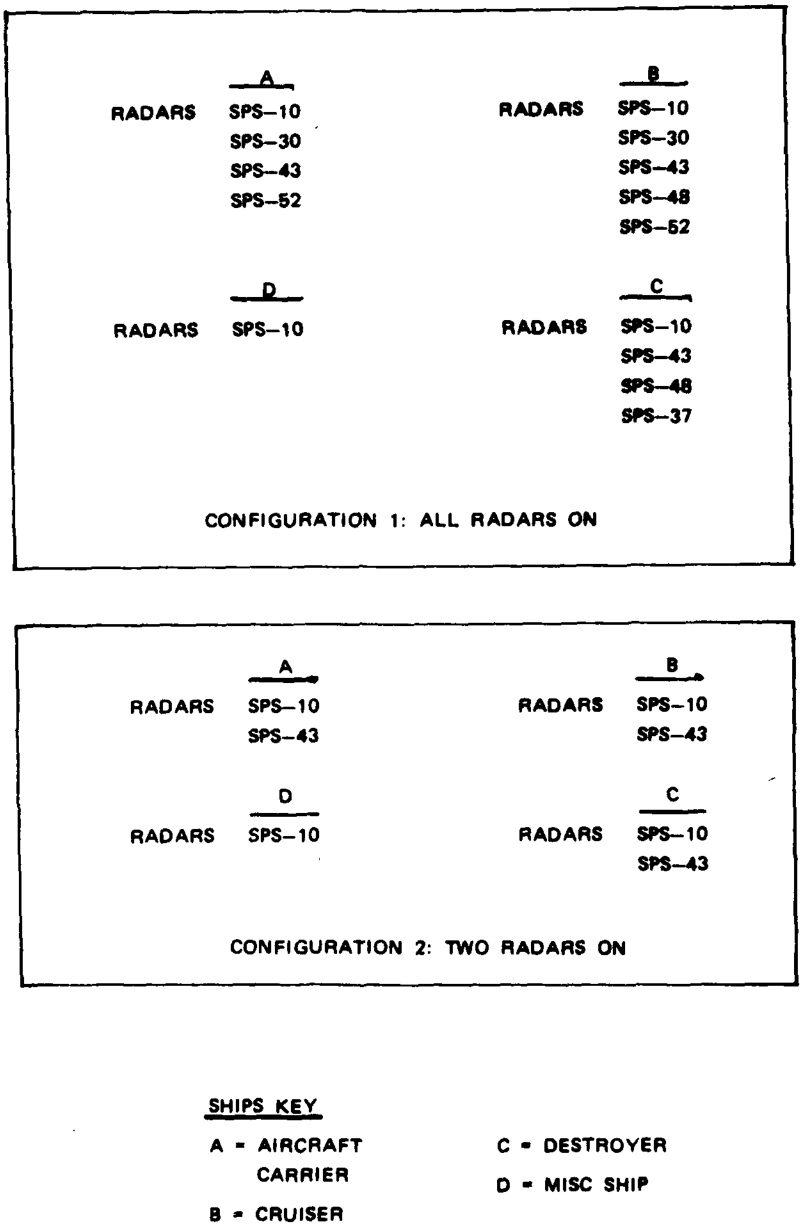
3. Integrated Sciences Corporation. *Experimental Investigation of the Usefulness of Operator Aided Optimization in a Simulated Tactical Decisions Aiding Task*, by D. Walsh and M. Schecterman. Santa Monica, CA, 1978. (Report No. 215-4.)

EWAR: DECISION-SCIENCE APPLICATIONS, INC.

The EWAR devices are a collection of displays intended to aid the operator in choosing optimal radar configurations which maximizes surveillance capabilities while minimizing identification from enemy aircraft because of radar emissions. The displays range from simple displays giving information concerning a single system parameter to complex displays depicting trade-off functions between surveillance and security. Most of the displays are not designed to show the operator one optimal course of action. Instead, the aids allow the operator to explore the advantages and disadvantages of using various radar configurations. The individual aids are sequenced in a manner designed to increase the operator's insight into various aspects of the combat situation. They suggest alternatives he might not have considered without the aids.

Scenario

The general combat scenario involves a task force consisting of an aircraft carrier (CV), a cruiser (CA), and two smaller ships. The electronic-warfare (EW) officer must develop a plan for radar surveillance. The EW officer knows that there is a high probability of an enemy missile attack. His problem is that he must be able to track as many of the missiles as possible on the radar. However, the emissions from the radar give distinct signatures that inform the enemy of the type of radar coming from each ship. It is assumed that the enemy knows the location of the task force, but cannot identify each ship. Thus, if eight missiles were available, the enemy commander would be forced to target two missiles at each ship in the task force. This would mean that the carrier would have a good probability of surviving an attack especially if the carrier had adequate radar surveillance. Unfortunately, the more radar coverage the CV elects to use, the more precisely the enemy can determine its locations. If the enemy knew exactly where the CV is located, then he would target all eight missiles at the carrier, making it very vulnerable. Figure 15 illustrates two possible radar configurations the EW officer might consider. The first configuration uses all radar equipment on all ships. The radars are listed under the letter designations (e.g., under A are SPS-10 ... SPS-52) and each ship has a unique pattern of signatures. Thus, the enemy commander, based on intelligence information, could pinpoint the type of ship at each location and make targeting decisions accordingly. On the other hand, the enemy commander would be able to determine the exact location of only the least valuable ship for the second proposed radar configuration. The EW officer must determine the cost of reducing radar surveillance for the second plan and weigh this against the benefit of denying the enemy commander information about particular ship locations.



A

RADARS SPS–10
SPS–30
SPS–43
SPS–52

B

RADARS SPS–10
SPS–30
SPS–43
SPS–48
SPS–52

D

RADARS SPS–10

C

RADARS SPS–10
SPS–43
SPS–48
SPS–37

CONFIGURATION 1: ALL RADARS ON

A

RADARS SPS–10
SPS–43

B

RADARS SPS–10
SPS–43

D

RADARS SPS–10

C

RADARS SPS–10
SPS–43

CONFIGURATION 2: TWO RADARS ON

SHIPS KEY

A = AIRCRAFT CARRIER
B = CRUISER
C = DESTROYER
D = MISC SHIP

FIGURE 15. Display Showing Two Possible Radar Configurations.

EWAR Displays

There are three objectives for EWAR aids:

1. Compute quantitative information
2. Display the effects of EW plans on both surveillance and security
3. Show trade-off functions

The first group of displays are the "order of battle" displays. These displays give the EW officer information concerning:

1. The type of radars possible for each ship in the task force
2. The relative value of each ship
3. Characteristics of the threatening missiles (velocity, altitude, etc.)

The next group of displays give information concerning surveillance. Isocontours, depicting probability of detecting enemy threats, are shown encircling the task force (Figure 16) with both maximum range and cumulative probability information. An "outcome calculator" also figures probable damage to the task force from an attack. This aid needs inputs regarding the type of surveillance configuration and size and type of the enemy threat. The calculation assumes the enemy has perfect information concerning the locations of the ships in the task force.

The next series of displays is intended to show the effects of turning off radars in order to deny the enemy information. For example, the "all on" configuration in Figure 15 gives the enemy perfect information whereas an "all off" configuration would entail maximum uncertainty. The information denial displays show confusion matrixes based on possible changes in radar configurations. For example, the CV *Kitty Hawk* would have a 67% probability of being confused with a cruiser or destroyer for the second configuration in Figure 15. Also, the probabilities associated with identifying the ships for a particular radar configuration plan are used to compute the perceived value of the ship.

$$V_k = \sum_{i=1}^{n} P(S_i/S_k) \quad A_i$$

where

V_k = perceived value of ship k under the proposed plan

$P(S_i/S_k)$ = the probability of enemy identifying ship as being i, given that it is k

A_i = actual numerical value assigned to ship i by the task force commander

n = number of ships in task force

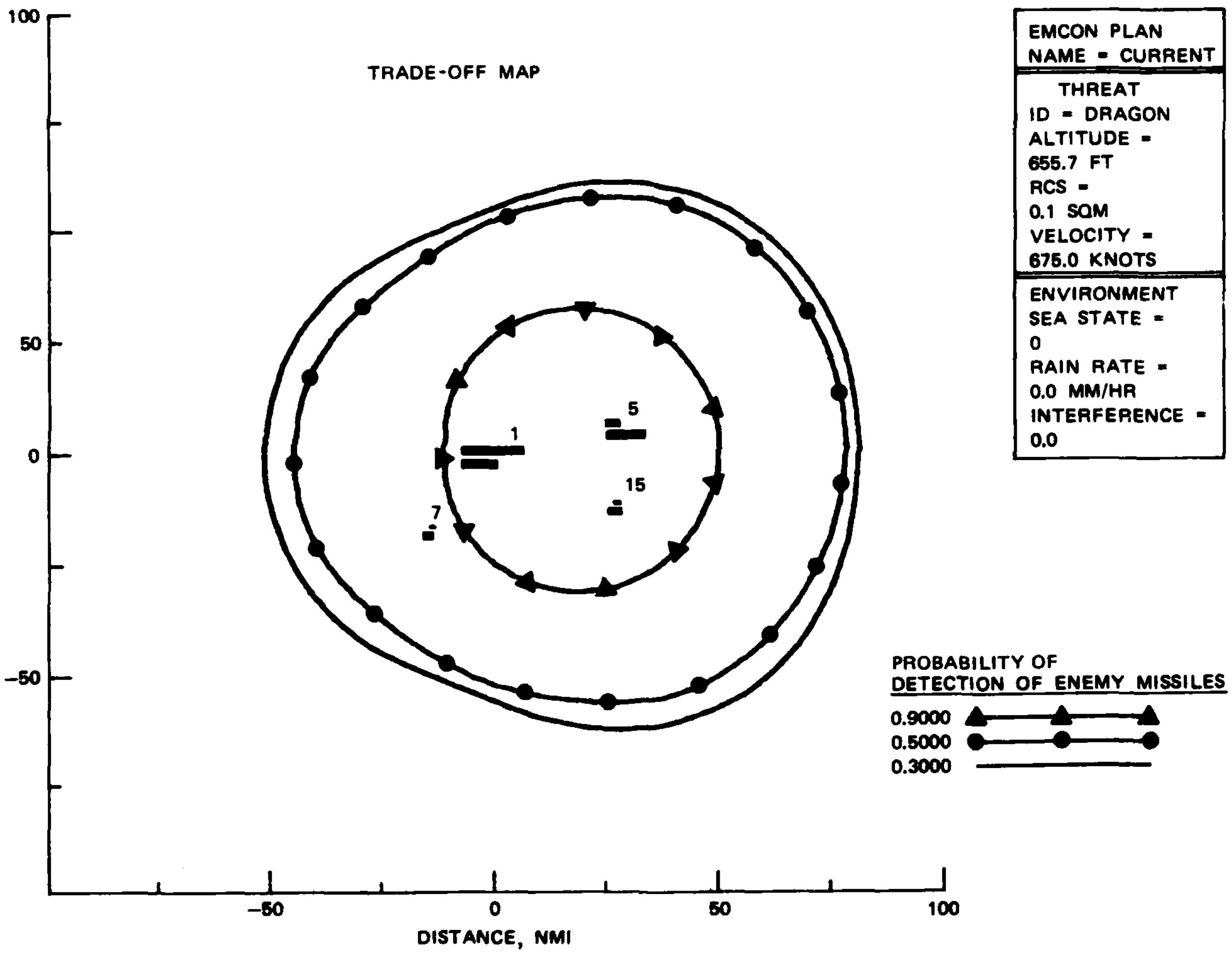
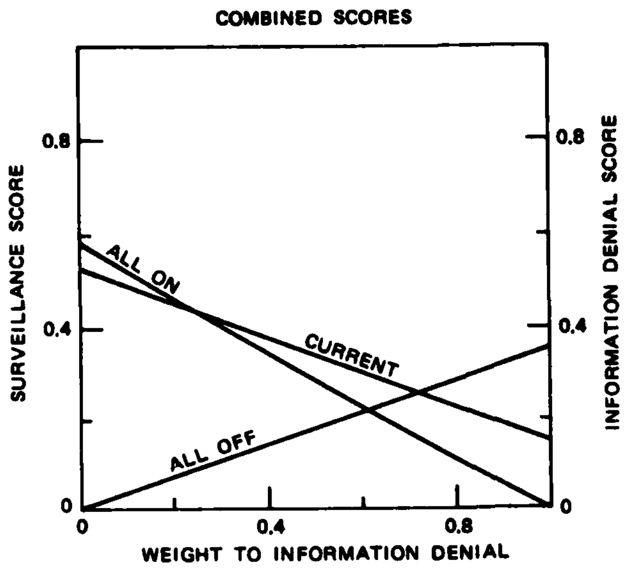


FIGURE 16. Example of a Possible Trade-Off Map for the EWAR Displays.

The purpose of informational denial is to lessen the perceived value of high value ships, while increasing the perceived value of low value ships. Thus, the operator receives independent displayed information concerning both the surveillance and information denial aspects of the radar configuration plans he is considering. The last set of displays is an attempt to combine this information and give the operator enough information to make a trade-off between surveillance and information denial in order to evaluate possible configurations.

Figure 16 shows a trade-off map. The surveillance capabilities are shown as isocontours. The information denial component is displayed by the size of the bars associated with the number representing each ship. The top bar under each number is the actual value of the ship and the bottom bar is the perceived value. The ratio between the two gives the operator a visual cue as to the impact of a particular configuration on information denial. Figure 17 shows the possible trade-off functions between surveillance and information denial. Both components are scaled by a "measure of merit" between 0 and 1.0. Zero represents both no surveillance and complete information to the enemy and 1.0 was the opposite for both cases. The graphs show how the combined (i.e., additive) value of these two components changes as the operator's weightings for information denial varies (the weights for surveillance are 1 - Information denial weights). The cross-over points are the place where one configuration plan becomes preferred over another. Thus, the all-radar-on is preferred to the all-radar-off plan until information denial has a 0.6 weighting, after which the all-radar-off plan is preferred. However, for the middle range of weights (~0.20-0.70), the plan designated current is preferred to either of the other two plans. The graph does not show the optimal solution to the operator. Rather, it allows the operator to choose his own weightings for the two components (surveillance and security) and see how it affects the proposed configuration alternatives. The final aid in the EWAR inventory is another "outcome calculator". The previous "outcome calculator" mentioned as a surveillance aid computed the amount of damage done to the Fleet, if the enemy had perfect knowledge. This final "outcome calculator" recomputes this estimate given the actual information value and surveillance values for each of the candidate configuration plans. It should be noted that both "outcome calculators" are based on extremely simple assumptions, especially compared to complex models such as the ASTDA calculator (e.g., given a .80 probability of detection, 5 of 7 dragon missiles directed towards the *Kitty Hawk* would impact, causing 60% damage). Simplicity seems to be the hallmark of the EWAR aids. This has a great advantage because the models underlying the display can be explained to the EW officer without too much difficulty. This allows the operator to build up an accurate picture of what is taking place and why. Contrasted with some of the earlier aids such as the "triangle" aid, this group of aids is designed more to develop insight than to suggest optimal courses of action. The sequence of looking at the aids structures the operator's ability to understand the EW problem. First,



EMCON ALTERNATIVES	PURE SCORES SV.	I.D.
CURRENT	0.53	0.16
ALL ON	0.59	0.00
ALL OFF	0.0	0.36

I.D. = INFORMATIONAL DENIAL
SV. = SURVEILLANCE SCORES

FIGURE 17. Example of a Possible Trade-Off Function Display.

he is given general knowledge about the combat environment. Next, he looks at both the surveillance and information denial problem in isolation. Only when he understands the important parameters of each of these problems considered separately does he combine this information in order to figure a trade-off that will lead to an optimal configuration. However, the simplicity of the aid may be a drawback as well. It remains to be seen if the simple algorithms the aids are based on accurately reflect an operational environment. Only testing in this environment could determine the ultimate usefulness of the EWAR system.

EWAR TAXONOMIC BREAKDOWN

Decision Tasks. The aids help the operator mostly in worth evaluation and information selection. The tasks are well structured because the operator follows steps outlined by military doctrine. The aids help the operator understand the consequences of different configurations for both surveillance and security. This information helps the operator evaluate the worth of the various possible plans. In a manner similar to the ASTDA displays, the EWAR displays condense a great deal of information into a few fairly easily understood information displays. Furthermore, the "outcome calculators" lead to action selection criteria. However, the operator should be so familar with the military situation because of the other displays that this advisory would be only part of the data upon which he bases his decision.

Conditioning Elements. A few conditioning elements, such as a type of threat, are used as input values when computing display values. However, a number of important conditioning elements for the EW situation are not considered by the aids at this time (e.g., weather, enemy intelligence resources, enemy tactics). It is assumed that, when the aids are introduced into an operational environment, the number of conditioning elements considered will increase considerably.

Mathematical Models

Rather than following any particular type of mathematical procedures (e.g., decision theoretic techniques, pattern recognition modeling), EWAR aids seem to be developed using pragmatic approaches to modeling.

BIBLIOGRAPHY FOR EWAR

1. Decision-Science Applications. *An Emissions Control Aid*, by D. Noble, G. Pugh, R. Kerchner, P. Tomlinson, and J. Densmore. Arlington, VA, 1978. (Technical Report DSA-66.)

2. Decision-Science Applications. *Manual for Test Subjects Using the Electronic Warfare (EWAR) Decision Aid*, by D. F. Noble and M. T. Nunenkamp. Arlington, VA, 1979. (Technical Report DSA 126/I.)

COMPARISONS

Tables 5, 6, and 7 serve to compare the aids on the three components of the taxonomic breakdown. Only the most important decisions addressed are shown in the fifth table. The modules from Decision and Designs are not shown since they are a collection of aids, some of which were still in the conceptual stage when this review report was written. Instead, the best developed of these aids (the triangle displays) is shown. The number of checkmarks for each aid should not be confused with a measure of merit, since the aids were developed for quite different reasons.

SUMMARY AND CONCLUSIONS

Five aiding systems developed for naval combat environments were reviewed. Particular emphasis was placed on decision tasks addressed, how conditioning elements were accounted for, and the basic modeling approach on which the aids were based. A number of general trends seem to emerge from the review.

Determination of a single optimal action was not considered the primary purpose of most aids. Rather, the aids tended to generate multiple criteria which the operator could use to structure the problem in his own mind before making a decision.

There is no one general methodological approach to decision aiding. Models based on a wide variety of procedures were used to help evaluate decisions. Besides the more traditional decision analytic techniques such as Bayes Thereom and utility theory, procedures based on dynamic and non-linear programming, pattern recognition models and "outcome calculations" were employed. If anything, decision-aiding is best characterized in terms of the diversity of approaches used.

TABLE 5. Most Important Decision Tasks Addressed by the Aids.

Decision aid	Problem structuring			Alternative selection														Type
	List actions	Generate hypotheses	Determine outcomes	Information selection		Probability estimation						Worth assessment			Action selection			Tasks
				1	2	1	2	3	4	5	6	1	2	3	1	2	3	Subtasks
Triangle Display								X					X			X		
ADDAM														X	X	X		
ASTDA			X	X				X						X				
SKETCH	X			X										X		X		
EWAR		X	X	X		X								X		X		

TABLE 6. Methods for Incorporating Conditioning Elements Into Aids.

Decision aid	Composite probability for state model	Individual display for each element	Input variable for "outcome calculator"	Situation mask using dummy variables	Separate model for each value change in conditioning element
TRIANGLE	X	X			
ADDAM				X	X
ASTDA	X	X	X		
SKETCH		X			
EWAR		X	X		

TABLE 7. Mathematical Approaches Used by the Various Aids.

Decision aid	Bayesian and Utility models	Pattern recognition models	"Outcome calculator" models	Non-linear programming	Dynamic programming
TRIANGLE	X				
ADDAM	X	X			
ASTDA	X		X		
SKETCH				X	X
EWAR			X		

Most of the aids helped the operator in such tasks as probability updating and worth evaluation, particularly where there were complex computations or memory storage problems. For the most part, generation of a global strategy and the final structuring of the problem were left to the operator or commander. However, some of the aids enhanced information-gathering by using optimal formating techniques. These aids displayed the most important systems information to the operator in a concise form. This helped the operator in problem structuring, since the displays encourage the operator to eliminate obviously poor choices. Also, the variety of information sources displayed by these aids could suggest to the operator actions or hypotheses he might not have considered otherwise.

On a more negative note, there is little evidence that these aids would be useful in an actual operational environment. This is not a criticism, since most of these aids were originally conceived as a research tool. However, the ultimate test of any decision aid is whether it can help the operator in the real-world. Further development, laboratory experimentation, and field tests will be necessary before these aids can meet this requirement. Preliminary testing at the University of Pennsylvania and proposed further development of these aids suggest that decision-aiding may prove to be a useful tool in the near future.

INITIAL DISTRIBUTION

- 12 Naval Air Systems Command
  - AIR-04 (1)
  - AIR-104 (1)
  - AIR-30212 (2)
  - AIR-340D (1)
  - AIR-340F (1)
  - AIR-4131 (1)
  - AIR-510 (1)
  - AIR-5313 (2)
  - AIR-950D (2)
- 6 Chief of Naval Operations
  - OP-098 (1)
  - OP-102X (1)
  - OP-102XB (1)
  - OP-55 (1)
  - OP-982 (1)
  - OP-987 (1)
- 2 Chief of Naval Material (MAT-0344)
- 4 Naval Sea Systems Command
  - SEA-03 (1)
  - SEA-03416 (1)
  - SEA-99612 (2)
- 3 Chief of Naval Research, Arlington
  - ONR-211 (1)
  - ONR-455 (1)
  - ONR-461 (1)
- 1 Bureau of Medicine & Surgery (Code 513)
- 1 Commandant of the Marine Corps
- 1 Air Test and Evaluation Squadron 4
- 1 Air Test and Evaluation Squadron 5
- 1 Naval Aerospace Medical Research Laboratory, Pensacola (Code L5)
- 6 Naval Air Development Center, Warminster
  - Code 6003 (1)
  - Code 602 Dr. Julie Hopson (1)
  - Code 6021 (1)
  - Code 6022 (1)
  - Code 603 (1)
  - Technical Library (1)
- 1 Naval Air Force, Atlantic Fleet
- 1 Naval Air Force, Pacific Fleet
- 1 Naval Air Test Center (CT-176), Patuxent River (SY-72)
- 1 Naval Avionics Center, Indianapolis
- 1 Naval Ocean Systems Center, San Diego

4 Naval Postgraduate School, Monterey
  Dr. James Arima (1)
  CDR William Moroney (1)
  Dr. Gary Poock (1)
  Technical Library (1)
2 Naval Research Laboratory
1 Naval Submarine Medical Center, Naval Submarine Base, New London
1 Naval Surface Weapons Center, Dahlgren Lab., Dahlgren (Technical Library)
1 Naval Surface Weapons Center, White Oak (Technical Library)
2 Naval Training Equipment Center, Orlando
  Code 215 (1)
  Technical Library (1)
6 Naval Personnel Research and Development Center, San Diego
  Code 02 (1)
  Code 03 (1)
  Code 311 (2)
  Code 312 (2)
1 Office of Naval Research Branch Office, Pasadena
1 Operational Test and Evaluation Force
3 Pacific Missile Test Center, Point Mugu
  Code 1226 (2)
  Technical Library (1)
1 Office Chief of Research and Development
1 Army Armament Materiel Readiness Command, Rock Island (AMSAR-SAA)
2 Army Armament Research and Development Command, Dover
  DRDAR-SCF-DA (1)
  DRDAR-TSS (1)
1 Army Combat Developments Command, Armor Agency, Fort Knox
1 Army Combat Developments Command, Aviation Agency, Fort Rucker
1 Army Combat Developments Command, Experimentation Command, Fort Ord (Technical Library)
1 Army Combat Developments Command, Field Artillery Agency, Fort Sill
1 Army Missile Research and Development Command, Redstone Arsenal
1 Army Training & Doctrine Command, Fort Monroe
1 Aeromedical Research Laboratory, Fort Rucker
1 Army Ballistic Research Laboratories, Aberdeen Proving Ground
  (DRDAR-RSB-S (STINO))
2 Army Human Engineering Laboratory, Aberdeen Proving Ground
2 Army Materiel Systems Analysis Agency, Aberdeen Proving Ground
3 Army Mobility Equipment Research & Development Center, Fort Belvoir
  Camouflage Laboratory (DRDME-RT) (2)
  Library (1)
1 Fort Huachuca Headquarters, Fort Huachuca
1 Night Vision Laboratory, Fort Belvoir (Technical Library)
1 Redstone Arsenal (DRXHE-MI)
1 White Sands Missile Range
1 Air Force Logistics Command, Wright-Patterson Air Force Base
1 Air Force Systems Command, Andrews Air Force Base (SDW)

1	Tactical Air Command, Langley Air Force Base
1	Aeronautical Systems Division, Wright-Patterson AFB (ASD/AERS)
1	Aerospace Medical Research Laboratory, Wright-Patterson AFB (Code HEA)
1	Air Force Armament Laboratory, Eglin Air Force Base (Technical Library)
2	Pacific Air Forces
	Operations Analysis (Headquarters PACAF/OA) (1)
	Technical Library (1)
12	Defense Technical Information Center
2	Director of Defense Research & Engineering
	TST&E (1)
	DAD/E&LS (1)
1	Defense Intelligence Agency
1	Ames Research Center (NASA) (Aviation Safety Research Office, Technical Library)
1	Applied Physics Laboratory, JHU, Laurel, MD
2	Autonetics/Rockwell International Corporation, Anaheim, CA (Human Factors Group)
2	Calspan Corporation, Buffalo, NY (Life Sciences Avionics Department)
1	Decision Research, Eugene, OR (Dr. Paul Slovic)
2	General Research Corporation, Santa Barbara, CA
3	Hughes Aircraft Company, Los Angeles, CA (Display Systems Department)
1	Human Factors Research, Incorporated, Goleta, CA (C-320)
1	IBM, Owego, NY (Human Factors Group, 304A535)
1	Institute for Defense Analyses, Arlington, VA (Technical Library)
2	McDonnell Douglas Corporation, Long Beach, CA (Director, Scientific Research, R&D Aircraft Division)
2	McDonnell Douglas Corporation, St. Louis, MO (Engineering Psychology)
2	Martin-Marietta Corporation, Orlando, FL
	Image Processing Laboratory - (MS 362) (1)
	Technical Library (1)
1	National Academy of Sciences, Vision Committee, Washington, DC
1	Perceptronics, Woodland Hills, CA
1	Rockwell International Corporation, Columbus, OH (Technical Library)
2	Systems & Research Center, Minneapolis, MN (Vision & Training Technology)
5	The Boeing Company, Seattle, WA (Crew Systems MS-41-44)
1	The Rand Corporation, Santa Monica, CA (Natalie E. Crawford)
1	University of California, Scripps Visibility Laboratory, San Diego, CA
2	Virginia Polytechnic Institute, Blacksburg, VA (Industrial Engineering Department)
2	Vought, Corporation, Systems Division, Dallas, TX (Human Factors Group)

DATE

ILME

– 8