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

The problems addressed in this study stem from the increasing supervisory loads imposed on the operator in airborne system operations. Future aircraft will be characterized by high information loads, several time constraints, and complex decisions regarding allocation of operator's attention, as well as display resources. The information costs and the limited processing capabilities of the human operator make it necessary to optimize the information selected, processed, and displayed.

20. ABSTRACT (CONT'd)

Techniques for information selection were developed based on multi-attribute utility models and queueing formulations. These techniques take into account both subjective, individual preference factors and needs of the operator. An experiment was conducted based on a computer-aided, multi-task airborne information-handling situation with different aiding and demand levels. Model-based recommendations led toward superior performance, both in low and high stress situations. The techniques provided an analytic framework that was helpful in identifying the individual operator's information handling strategies. These techniques are expected to be useful in specifying needs and for training operators or systems to efficiently perform information handling tasks.

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1. INTRODUCTION

1.1 Summary

This report summarizes a three-year program of research and development directed toward analysis of information needs and real-time handling of information selection and display in supervisory control of advanced aircraft. Its purpose is to establish new techniques for the selection of the immediate, essential information in airborne tactical operations. The techniques center on the use of multi-attribute utility models, adaptive estimation methods, and queueing theory formulations to model an individual's multi-task supervisory control behavior.

Specific objectives of the three-year program included the following:

(1) Formulate a working taxonomy of supervisory control functions in advanced aircraft operations. Relate types of computer-based aiding to classes of supervisory control functions.

(2) Develop aiding programs for continuous information monitoring and control in advanced aircraft operations. The programs take into account the immediate needs of the operator and the impact on other unattended processes.

(3) Investigate experimentally the performance and domain application of the continuous information monitoring and control programs.

(4) Investigate the behavioral issues of operator acceptance and confidence with the varied forms of model-based aiding.

(5) Develop explicit rules, in the form of a knowledge-based system, for controlling transitions between aiding forms.

(6) Produce guidelines for field application of the information evaluation and management programs in operational airborne systems.

The initial year's work established techniques for real-time information evaluation and selection based on an application of an adaptive multi-attribute utility (MAU) model and queueing theory formulation. The combined MAU/queueing model was tested in a Monte-Carlo simulation, and the information management concept based on the proposed model was superior to those based on traditional priority assignment. The study also suggested the usefulness of the model in guiding information selection in other continuous decision and control situations. The work reported here builds on these findings by experimentally investigating the effectiveness of the model for real-time information selection and presentation and for evaluating information display configurations.

1.2 The Problem

Future aircraft will be charcterized by high information loads, severe time contraints, and complex decisions regarding allocation of the operator's attention as well as display resources. The problems addressed by this research stem from these increasing supervisory loads imposed on the pilot in advanced aircraft operations. This is a prime example of the larger problem facing virtually all modern military command and control system--processing and selection among the ever increasing amounts of information. Local and remote computerized systems make available copious amounts of information concerning remaining resources, environmental state, potential computer aiding, and predicted circumstances and actions. In such cases, the costs of communications and the limited processing capabilities of the human operator make it necessary to optimize the information selected, processed and displayed.

The central problem in performing an analysis of information needs is the structuring of the decision process. On the one hand, choices need to be modeled regarding continuous variables such as the flow of information: sensing, processing, encoding, transmitting and display at any point in time. On the other hand, event-driven parallel activities from situation assessment to execution strategies must be described, along with such situational criteria as system confidence, operator load and capability, and task characteristics. This R&D program represents an effort to develop, integrate and implement models and techniques that represent and enhance the airborne information handling tasks.

1.3 Technical Approach

In brief, the information handling tasks in command and control situations can be represented as a multi-level, multi-stage decision task of information acquisition and action selection (Chu, Steeb and Freedy, 1980). At each stage of each level, the decision of what information to display reflect the task circumstances, the operator's and automatic system's capabilities, and the communication channel characteristics. These decisions can be expressed analytically using three different methodologies: (1) production rules guided by pattern-directed process control, (2) multi-dimensional sets of utilities tied to the potential action consequences, and (3) sets of weighted criterion functions represented in terms of state-space variables.

The previous MAU-based information model (Steeb, Chu, Clark, Alperovitch and Freedy, 1979) handled the single-stage decisions present in airborne operations, but did not deal with the many continuous behaviors present in monitoring and sampling. Many of these continuous, stochastic processes can be modeled by embedding the MAU decision model in a queueing model. Here the time distributions of event arrival and the demanded attention for information handling can be postulated and measured and queues of potential messages or sampling options are presented. The multi-attribute decision model is then incorporated as a criterion function in the queueing model.

The model evaluation was accomplished by determining the effectiveness and capabilities provided in an advanced aircraft task situation. This experimental situation included both multiple threat intercept and multiple subsystem monitoring tasks in a continuous-time, multiple-display simulation. Also provided in the experimental situation were extensive data collection and performance analysis capabilities. An experiment was conducted based on this multi-task, airborne information-handling situation with different aiding and demand levels. Model-based data aggregation and option recommendations led toward superior performance, as well as favorable subjective ratings. The model also provided an analytical framework that was helpful in identifying the individual operator's information strategies.

1.4 Current Objectives

The focus of the work reported here is the demonstration and study of the MAU/queueing model as an expanded version of an adaptive decision model in a real-time monitoring and control environment. The specific objectives that were addressed include:

(1) Develop a real-time, multi-task experimental situation representative of an information handling environment in advanced aircraft.

(2) Implement the MAU/queueing model in an experimental situation. Perform full scale experimental study of model effectiveness.

(3) Determine experimentally the effect of model confidence, aiding form, and task demands on operator acceptance of aiding.

(4) Identify forms of model-based aiding obtainable using the MAU/queueing formulation. Develop a set of transition rules for controlling the form and level of aiding in response to operator needs, tasks demands, and model confidence.

1.5 Applications

The combined approach of adaptive information value estimation and real-time estimation of information traffic appears to be most applicable to decision tasks featuring some or all of the following operational characteristics:

(1) High Information Load. The operator is in a time-stressed decision task. For each decision, he can process only a portion of the available data set and must choose an action within a short time.

(2) Costly Information Transmission. The transmission of data to the operator is subject to cost, risk of detection, or limited transmission capabilities. Immediately valuable information must be selected.

(3) Significant Judgmental Factors. The decision maker must consider the credibility and content of the evidence along with the probabilities and utilities of the consequences associated with each ensuing action.

(4) Multiple Competing Information Sources. A variety of diferent systems or sensors must be monitored, and each unattended system increases in uncertainty over time.

Among the examples of actual military decision making situations that require such tasks are:

(1) Supervisory control and decision making in advanced aircraft.

(2) Air traffic control.

(3) Remotely piloted fleet guidance and control.

(4) Supervision of distributed subsystems and platforms.

(5) Satellite intelligence coordination.

(6) Supervision of air, ground, or sea support operations.

2. MODELING AND SIMULATION OF INFORMATION HANDLING TASKS

2.1 Overview

The activities surrounding the selection and processing (acquisition and dispatching) of sensed information often constitute a majority of the operator's supervisory functions in advanced aircraft. The operator must maintain an awareness of the sensed environment, the machine states, the capacity and quality of the communication, and the progress toward the overall objectives. This chapter will explore the techniques for the modeling and simulation of these information related activities, which is subsumed under the term "information handling" in this study.

In particular, the selection and presentation of information in tactical airborne systems provides a prime example of a new information management demand. The analysis of information handling in supervisory airborne systems will be discussed in Section 2.2. Further, activities in information handling, selection, acquiring and processing, can be described only as multiple concurrent proceses, resulting from interaction with multiple targets, multiple sensor sources, multiple subsystems and multiple stages. Models of the operator's information handling task performance would be of use both in describing the interaction between operator and system and in predicting the performance gains to be expected from the introduction of varying levels of computer aiding. Further, in situations in which the responsibilities for some tasks are shared by other crew members or by an automated decision maker, these models might also be used within the system to coordinate the actions among the decision makers. The modeling approach of information handling tasks will be described in Section 2.3.

The simulation approach presented in this chapter expands the previous time-variant, event-paced information value model into the operational domains of time-varing information characteristics and sporadic event occurrence. Here the time distributions of physical events, such as system faults, course errors, and threat arrival, can be estimated. The process model embedded in the queueing framework provides all the necessary updates of subjective and objective information value estimates. The combined MAU/queueing model simulation is used in depicting the operator's continuous monitoring and control functions as standard information handling tasks ranging from situation assessment to intermittent control. The simulation of an information handling task will be outlined in this chapter and further described in Chapter 3.

2.2 Supervisory Information Handling

The initial idea of supervisory control narrowly referred to the task of monitoring automatically controlled processes and, when necessary, intervening and adjusting reference points. As an example, piloting an aircraft requires monitoring the aerodynamic configuration to ensure that the autopilot is working, trimming the set points to compensate for disturbance, and intervening in the case of autopilot failures and emergencies. When a process is automated or semi-automated, the control actions need not be continuously produced, and the opertor need not devote full attention to that process. This makes it possible for the operator to be responsible for multiple proceses. As a result, the narrow sense of supervisory control can be expanded to include a broad spectrum of concurrent activities from control to supervision and planning. This broad sense of supervisory control can be defined as "Managing and controlling a semi-autonomous system through the intermediary of a computer. The human supervisor performs upper-level goal-oriented functions such as planning system activities, programming the computer, monitoring the system behavior when computer-controlled, adjusting parameters on-line when appropriate, and intervening to take over control in an emergency or for normal reprogramming or repair." (Seifert, 1979).

2.2.1 Supervisory Handling Paradigm. In the context of supervisory control functions in advanced aircraft, the pilot or the operator as the *airborne system manager* faces a variety of information sources and displays--such as a master monitor display, and an integrated multifunction display. These displays may be event driven or functional or procedural. The pilot has the responsibility to (1) monitor the aircraft subsystems, detect possible hardware failures and potential hazards; (2) respond to events such as communication of tactical information, change of aircraft configuration, and reduction of 4-D guidance errors; and (3) react to unexpected events such as identification of threat, change of flight plan, establishment of the backup mode, and declaration of emergencies, etc.

If the task is viewed as the totality of the situational information and required actions imposed on the pilot, it appears that complete supervisory handling task descriptions should include interactive activities of the operator in defining, initiating and monitoring subtasks. While the pilots usually accept the overall goal and plan as instructed, the process of organizing the activities of situation assessment and dynamic *replanning* at the top level, status monitoring and action execution at the intermediate level, and observation and control at the bottom level, is a continued and recurrent one. The three-level hierarchy of supervisory information handling is described in Figure 2-1.

The major subprocesses involved in situation assessment in the context of supervisory control of advanced aircraft include the following:

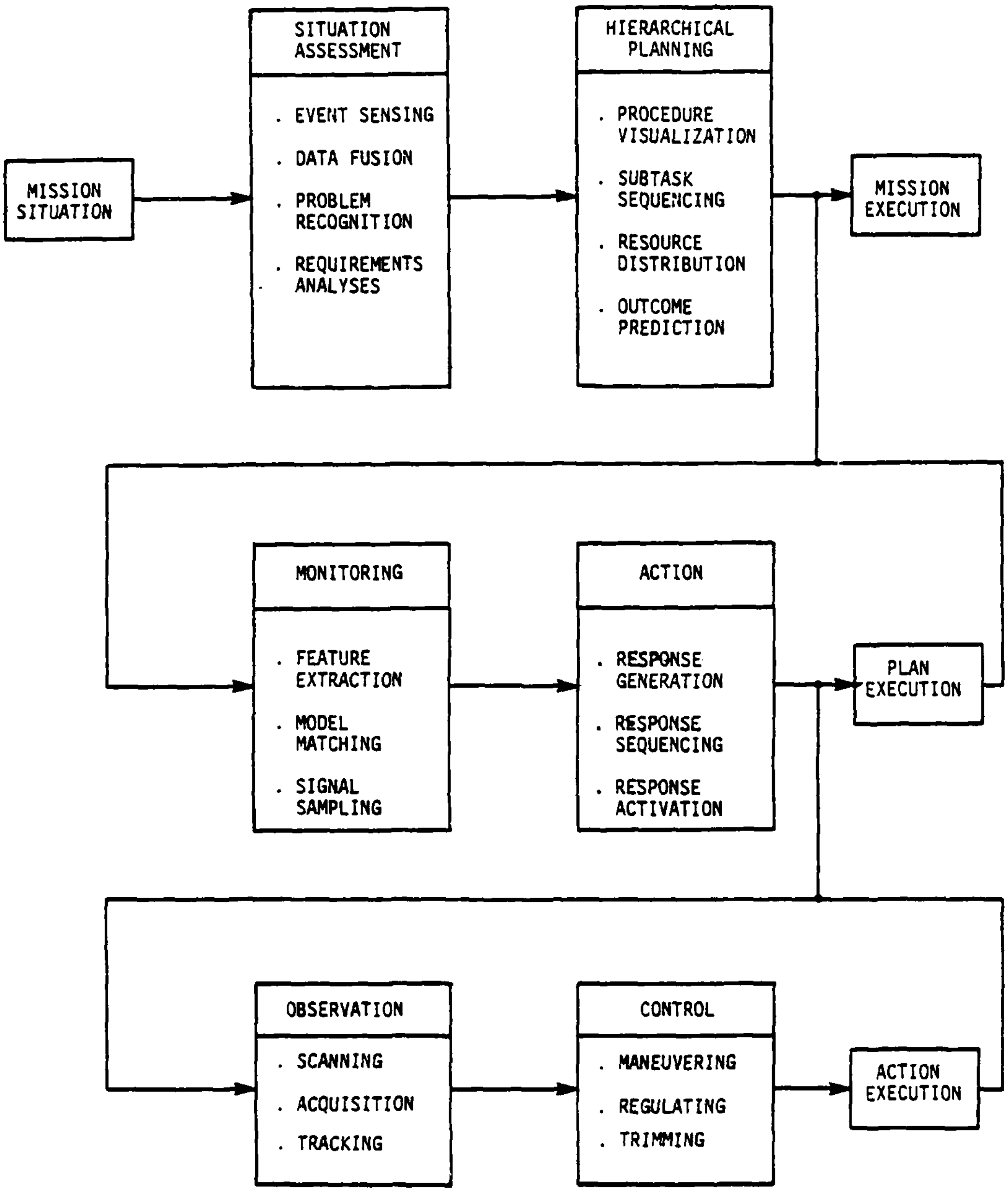


FIGURE 2-1.
SPECTRUM OF OPERATOR ACTIVITIES IN
SUPERVISORY CONTROL OF ADVANCED AIRCRAFT

(1) Event sensing: directing sensors. establishing communication and managing data flows.

(2) Data fusion: generating hypotheses and updating situations estimates.

(3) Problem recognition: identifying conflicts or problems requiring resolution.

(4) Requirement analyses: defining actual activities required and possible intervening functions.

The situation assessment activities are tightly coupled with the dynamic planning activities. These planning activities include procedure visualization, subtask sequencing, resource distribution, and outcome prediction. Most of these high-level activities are realized, as shown in Figure 2-1, at a group of a lower level of activities (the monitoring action pair). The major monitoring processes include:

(1) Feature extraction: partitioning information into subsets, assessing the relevance of a particular information set.

(2) Model matching: refining the hypothesis at the appropriate level of detail. Weighting the importance of situation states.

(3) Signal sampling: updating probability estimates. Reassessing the values and utility of potential outcome.

The action process, on the other hand, deals with response generation and execution issues. This monitoring-action loop represents the major portion of in-task *information handling*, since many assessment-planning activities are performed in a pre-task fashion, and the trend toward future aircraft suggests that pilots will be less and less concerned with manual observation and control.

At the lowest level of the task hierarchy is the observation and control pair, which require continuous scanning, acquiring, and tracking of a specific target or event of importance. Usually this lowest level involves the highest-frequency functions, such as target track and vehicle stabilization. These functions are typically automated, but unexpected events and system malfunctions may arise, making the operator back-up activities crucial. In the following discussion, we shall concentrate the intermediate level of the supervisory control paradigm.

2.2.2 Supervisory Information Characteristics. In general, the interactive supervisory information handling involves one or many of the following activities:

(1) Continually sense and symbolically characterize all information with respect to the operation ranges and their relative importance.

(2) Continually update situational hypotheses, by hypothesis formation, model parameter selection and experimentation (accessing information).

(3) Systematically relate maneuvers and action sequences to verifiable consequences.

(4) Provide consistent interpretation, by keeping track of focus-of-attention (e.g., target) and resolving ambiguities or contradictions.

In our previous study (Chu et al., 1980), the handling features were analyzed along decision dimensions, characterizing the situation by, for example, the danger or frequency of threats, the time available for decision making, and the options and characteristics of information concerning the aircraft and the environment.

<u>Timelines</u>. The information available at a given time is dependent on the environmental situation, the sensor characteristics, the data base content, and the display capabilities. The information itself may consist of data regarding weather conditions, aerodynamic status, target track, ECM, and mission status.

<u>Handling Cost</u>. The costs of acquiring information result from the sensor characteristics, the direct and indirect costs of sensor deployment, information processing and display, and the amount of attention the operator can contribute. The direct costs of information acquisition include such factors as energy expenditures and equipment expenses. Indirect costs include increased possibilities of detection and countermeasures. The available operator attention, finally, is defined by the task demands and the individual capabilities of the operators.

<u>Expected Payoffs</u>. The costs and payoffs associated with the myriad possible outcomes vary with mission phase. The consequences are defined not only in terms of equipment and attainment of objectives, but also as a function of organizatiuonal policy and procedures. The relative importance of fuel expenditures, vehicle survival countermeasures, etc., change as the mission objective is approached, attained, or past. The relative importance of these factors must be assigned by the human operator or by the command group.

Time Stress. Available time for decision making varies throughout the mission as a direct function of the varying vehicle speed, altitude, and surrounding weather conditions. Altitude, cloud cover and ECM determine the distance from which obstacles, navigation points, or targets can be observed. The speed then determines the available time. Decision time can be expected to influence the amount of information that can be processed and the probability distribution of the possible consequences.

The above analysis is based on a multiple-threat intercept scenario developed in a previous study. A separate analysis was performed based on a flight management scenario by Rouse and Neubauer (1978) and resulted in a similar set of information requirements: (1) type of information (reports vs. forecasts), (2) time period, (3) uncertainty, (4) cost (fixed vs. recurring), and (5) format. As the purpose of their study was to define the attributes of an information system from the design point-of-view, the following interpretation of the above information characteristics were given. Type of information includes reports of what has happened or is happening, and forecasts of what might happen. Time period refers to the time interval that the report or forecast covers. Uncertainty reflects the finite sample sizes upon which reports are based or the likelihood that forecasts are based on imperfect models. Cost can vary in type and magnitude. Fixed costs apply to information sources that incur no additional cost after they have been initially acquired. Recurring costs are those that are incurred every time an information source is used. Some information sources may involve both fixed and recurring costs. Reduction in uncertainty may incur extra costs. Thus information cost and uncertainty involve a tradeoff for a manager. The format of an information system involves the way in which the manager queries the system and the way in which the system responds. Examples cited include menu keyboard, voice, or free format such as graphics and other physiological links.

2.2.3 Categories of Aiding in Information Handling. The various handling subprocesses described in the previous sections indicate the possibility of aiding the operator at a number of levels. The levels range from simple aggregation to complete information system management, and different ones may be invoked according to the situational demands and operator needs. The levels correspond roughly to the five levels of automation recommended for future airborne information management systems (Mertes and Jenney, 1974). The various levels are described below in order of increasing complexity.

Aggregation. The decision aiding system has access to event likelihoods, situational data, and preference data. Aggregated information may be abstracted and presented to the operator for use in decision making. For example, the system may ascertain the immediate likelihood of enemy threats, the expected effectiveness of an avoidance maneuver, or the fuel consumption anticipated for a climbing attack. A number of probability aggregation displays have been demonstrated in making diagnostic decisions about reconnaissance data (Howell, 1967). Howell states that improvements in diagnostic decisions of about 10-15% can be expected with automated aggregation. Improvements become particularly noticeable under conditions of time or load stress or low input fidelity (Kelly and Peterson, 1971).

Alerting. The aiding system may sense an out of threshold condition requiring operator intervention. An alerting display can be shown to the operator along with a description of the problem. This is especially important for monitoring of infrequent or long duration events (Mertes and Jenney, 1974). Again, no action recommendation is made, although explanations may be provided.

Option Recommendation. The aiding system may recommend information to acquire or actions to execute. The multi-attribute model represents the policy of the specific user. It has access to the factors characterizing each information choice, and it has inputs from the queueing model. The model can thus be configured to scan the available information sources and action options, and recommend the immediately most effective choice.

Because of the "look-ahead" approach implicit in the aiding system's decision tree, the reasons for alternative selection can be automatically generated and presented to the operator. For example, in a multiple intercept situation, the pilot may want to know why the computer recommended a change to low azimuth track-while-scan radar mode. Rather than simply giving numerical comparisons, which are hard to decipher, the decision tree may be analyzed and translated into meaningful information about likelihoods of target acquisitions and the effects of associated engagement maneuvers.

Information Management. The functions of recommendation may be extended to automation by linking the aiding system to the onboard information control system. The model may be used to direct the sensing systems, to select information, and format the data display to the opertor. This process may be accomplished through use of weighting matrices specifying the effects of the various information sensing and formatting choices on the following:

(1) Event Sensing. This aspect of the information handing process involves the sensing and communication of environmental conditions, threat type and location, own force status and other relevant information. The sensors may include video, infra-red, radar and on board detection systems.

The information may need to be routed adaptively from the point of acquisition to the appropriate processing and display unit.

(2) Data Fusion. Data fusion is the aggregation of the information obtained from the various sensors and the generation and testing of situational hypotheses. In this way, the local or global situation estimate is updated using production rules or Bayesian methods.

(3) Problem Recognition. Problem recognition involves the monitoring of tolerance ranges around critical variables (fuel limitation, flight surface constraints, launch acquisition region, etc.) to determine if correct actions need to be initiated. Problem recognition in aircraft supervision involves tolerance checks either on the current state or on the predicted future state. The aiding system might, for example, use models of the operator to detect and warn of inconsistencies in the operator's performance.

(4) Source Selection. Simultaneous consideration of multiple alternatives portrayed against multiple criteria quickly becomes too complex for the opertor to resolve. Computer based aggregation of the various factors is typically faster and more consistent than is possible by the operator. The multi-attribute utility model represents the policy of the specific user; it has access to the factors characterizing each information choice, and it can be linked to the on-board information control system. The model can be configured to automatically scan the available information source, select the immediately most useful source, and and display it to the operator.

(5) Event Sequencing. Once data has been collected from the sensors, situation estimates updated, and potential problems recognized, then procedures associated with the event must be sequenced that will resolve conflicts and achieve goals. The sequenced actions may be synthesized using one or more of the following approaches: (a) means-ends analysis, (b) backtracking, (c) hierarchical planning, and (d) production system; or using simply the priority rules or queing disciplines.

(6) Consequence Evaluation. Implicit in the value-based event sequencing is the concept of an evaluation function--maximization of operation time, optimization of jammimg/communication, etc. Each candidate course of action should be scaled along the common set of criterion dimensions. Weighting of the choices in importance then allows systematic comparison of the possible action choice. If the criterion dimensions are probabilistic in nature, e.g., detection of communications, tactical gains, or losses sustained, then the expectation of the outcome is used in the evaluation. Additional risk factors can be added if the selection policy is not risk neutral.

(7) Event Selection. Event (procedure) selection involves the comparison by the affected subprocesses of all candidate events, since the affected subprocesses may have different goal sets, and may compete for resources under different criterion functions. In this case, it is necessary to bargain or to select according to aggregated value judgment.

2.3 Information Handling Task Model for Supervisory Control

2.3.1 General. Analysis of the supervisory information handling tasks and the aiding categories described in the previous section has supported the needs for modeling the recurrent decisions of selecting information sources. A particularly attractive approach is one that incorporates the key factors--aircraft state, environmental conditions, operator capabilities, acquisition costs, etc.--into a multi-attribute decision model. This individualized model of information seeking policy has been found to be useful for evaluating alternative information system configurations and for automating the information handling task. The models have, for simplicity, been time-invariant and driven by paced events. The decisions have been indiscriminantly triggered by sensing an environmental obstacle or threat. The model then selects the most effective information source for dealing with the unequivocal event.

Information handling in advanced aircraft also concerns process aspects such as the sequencing of information handling, especially when there are a number of continuous processes--supervision of subsystems, communications, aerodynamic surfaces and multiple threats, etc. Many of these time continuous processes can be considered as separate classes of event queues for pilot decisions. Even the most complicated procedures in information handling can then be modeled as a network of sequences that as a whole guides the information flow from system to operator. The approach adopted in this study expands the previous time invariant, event-paced information model into the operational domains of time varying information characteristics and sporadic event occurrence. The time distributions of aircraft environment and physical events, such as system faults, course errors, and threat assessment are estimated, and updates of subjective information values and objective information attributes are evaluated. Central to this evaluation study is the marriage of the evaluation model and the process model and a method based on the use of multi-attribute utility theory and queueing theory to organize the various objective and subjective factors that enter into the information handling decision. The concept for the modeling of supervisory information handling is summarized in Figure 2-2. The multi-attribute utility model and the continuous information process model each will be discussed in the following sections.

2.3.2 Multi-Attribute Utility Model. Use of the multi-attribute utility (MAU) models, pioneered by Raiffa and his colleagues (Raiffa, 1969; Keeney and Raiffa, 1975) and by V. Winterfeldt (1975) makes the information handling process more goal directed, normative and axiomatic. Instead of simply attempting to pre^ict behavior on the basis of a set of independent features, the utility models tie the information decisions directly to the ensuing action decisions. The value of obtaining information is determined by calculating its impact on the expected utility of the subsequent action decision. The information is assumed to change the probability distributions of the consequence set and, in turn, to revise the expected values of the alternative actions. Nevertheless, the form of the model is simply a linear additive rule. The utility of an action is considered to be an aggregate of many possible outcomes, each expressed along a set of attributes:

$$EU\,(a_k) = \sum_{\substack{\text{states}\\ \ell}} P(z_\ell) \sum_{\substack{\text{attributes}\\ i}} U_i(a_k,\, z_\ell)$$

Where $EU(a_k)$ is the expected utility of action k, $P(z_\ell)$ is the probability of state z_ℓ occurring, and $U_i(a_k, z_\ell)$ is the utility function over the i^{th} attribute associated with state ℓ and action k. The formulation is the result of several key simplifying assumptions. The decision maker is assumed to be risk neutral, so that he is indifferent between the

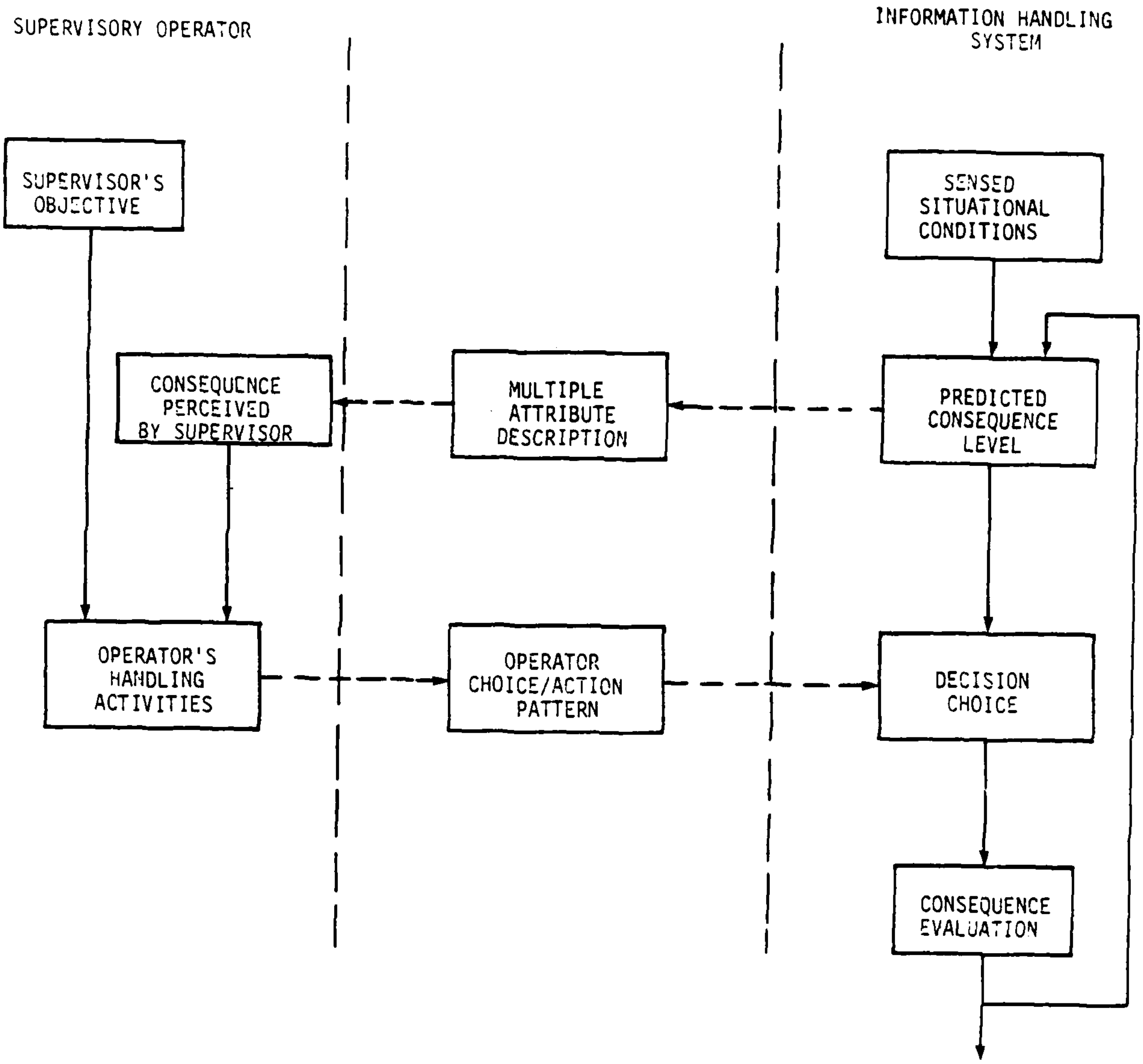


FIGURE 2-2.
MODELING CONCEPT OF SUPERVISORY INFORMATION HANDLING

expectation across a set of uncertain outcomes and the uncertain outcomes themselves. This allows the probabilities to be entered as simple coefficients. Also, the attributes are assumed to satisfy additive independence, allowing the linear additive form of aggregation. Tests for compliance with these assumptions can be found in V. Winterfeldt (1975) or Keeney and Raiffa (1976).

The impact of a message or item of data is to change the probability distribution of the states z_ℓ. Once the message is received, a maximum utility action $a*(y)$ can be identified. The expected utility of selecting an information source S then becomes (Emery, 1969):

$$EU\ (S) = \sum_{\substack{\text{messages} \\ y}} \sum_{\substack{\text{states} \\ z}} P(z_\ell)\ P(y|z_\ell)\ u(a*(y),z_\ell)$$

Here, $u(a^*(y),z_\ell)$ is the utility of taking action $a^*(y)$ given that state z_ℓ occurs. The utility function is again multi-attributed, but for simplicity, $u(a^*(y),z_\ell)$ is portrayed as having already been aggregated across the various dimensions.

This type of analysis is suited for highly structured tasks. Not only must the possible states, messages, actions, and outcomes be specifiable, but the prior state probabilities and the conditional probabilities characterizing the information system must be derivable. The sequence of decision stages can be depicted using a decision tree, as shown in Figure 2-3. The tree is folded back by associating with each possible message the maximum expected utility of the subsequent actions. This folding back represents graphically the process of EU maximization. The favored information source S is then identified by comparing the expectations taken over all possible messages.

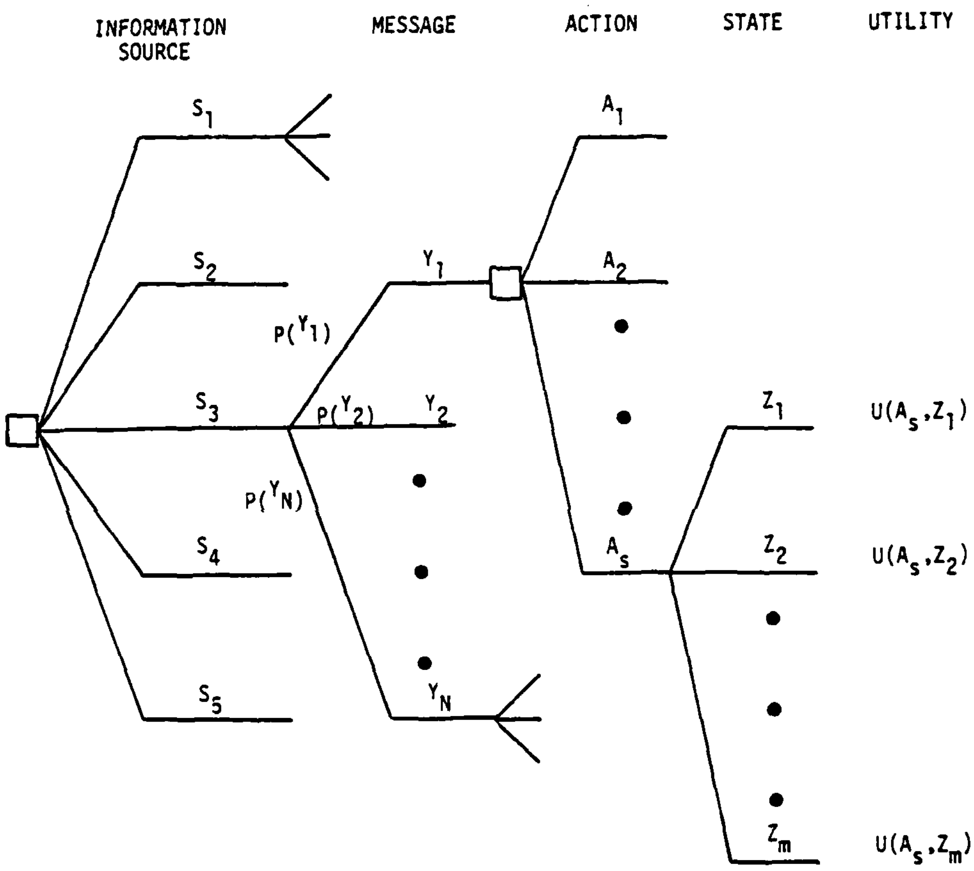


FIGURE 2-3.
DECISION TREE FOR INFORMATION SEEKING

Factor Choice. As described above, the multi-attribute decision model of information seeking behavior is based on a weighted aggregation of the factors which enter into a decision. In its simplest form the aggregation is a linear additive model:

$$MAU\ (a_k) = \sum_{\substack{\text{attributes} \\ i}} W_i\, U_i\, (X_{ik})$$

where $$X_{ik} = \sum_{\substack{\text{states} \\ \ell}} P(z_\ell) X_{ij\ell}$$

where $MAU\ (a_k)$ is the aggregate utility of action k

W_i is the importance weight of attribute i

X_{ik} is the level of attribute i associated with action k

$P(z_\ell)$ is the probability of occurrence of state z_ℓ

The choice of factors or attributes in this model is extremely important. It was noted in our earlier study (Steeb, Chen and Freedy, 1977) that the attribute set should be accessible, monotonic, independent, complete and meaningful. Also, a single set must account for both information acquisition and action selection behavior. Finally, the attribute set must be manageably small in dimension. With these considerations in mind, an initial taxonomy of consequences can be organized around the following five areas:

(1) Communication costs--such as energy, equipment, and attention.

(2) Equipment attrition--fuel expenditures, probability of vehicle damage, etc.

(3) Objectives attainment--area reconnoitered, payload delivered.

(4) Dynamic effects--effects on time delay, availability of future information and system capabilities.

(5) Subjective factors--preferences regarding control continuity, operator load.

Attribute Level Determination. The level or quantity of each attribute for a given outcome can be determined in several ways. For example, mappings between predictive features and the attributes can be established by observation and adjustment. Here, data available to the decision program concerning the environmental state, vehicle state, channel characteristics, sensor capabilities, and operator load can be used to predict the attribute levels. Alternatively, the attribute levels may be estimated subjectively or established from performance histories. Use of mappings from predictive features is more attractive than subjective estimates as no load is imposed on the operator, and situation-specific factors may be taken into account. For example, the communication delay may be directly predicted from sensor queue length, sensor response characteristics, and transmission distance. Subjective estimates or pre-established values for the attribute levels would tend to be much less reliable than such in-task calculations.

Attribute Weight Estimation. The operator's goal structure and policy for information handling, expressed as importance weights, could be elicited or inferred and then incorporated in the model. There are a number of advantages to such subjective estimation, particularly with respect to allocation of function. By incorporating individualized operator weights in the model, the complex evaluation and goal direction functions remain the responsibility of the operator, while the normative aggregation functions are assumed by the computer. Also, operator acceptance of aiding by the model may be increased since individual preferences are incorporated in the machine decisions.

The operator's subjective weights may be defined off-line by elicitation or on-line through inference. The off-line methods include direct elicitation of preference, decomposition of complex gambles into hypothetical lotteries, and use of multi-variate methods to analyze binary preference expressions. These techniques are accurate and reliable in many circumstances, but they have a number of disadvantages when applied to operational systems (Chu et al, 1980).

Estimation techniques relying on inference from in-task behavior may be more useful. The inference techniques can be based on non-parametric forms of pattern recognition. Here a model of decision behavior is assumed and the parameters of the model are then fitted by observation and adjustment. Briefly, the technique developed considers the decision maker to respond to the characteristics of the various alternatives as patterns, classifying them according to preference. A linear discriminant function is used to predict the decision maker's choices, and when amiss, is adjusted using error correcting procedures.

The adaptive nature of the estimation program is shown in Figure 2-4. Expected consequence vectors associated with each information source are input to the model. These consequence vectors are multiplied with the weight vector, resulting in evaluations along a single utility scale. The maximum utility choice is determined and compared with the

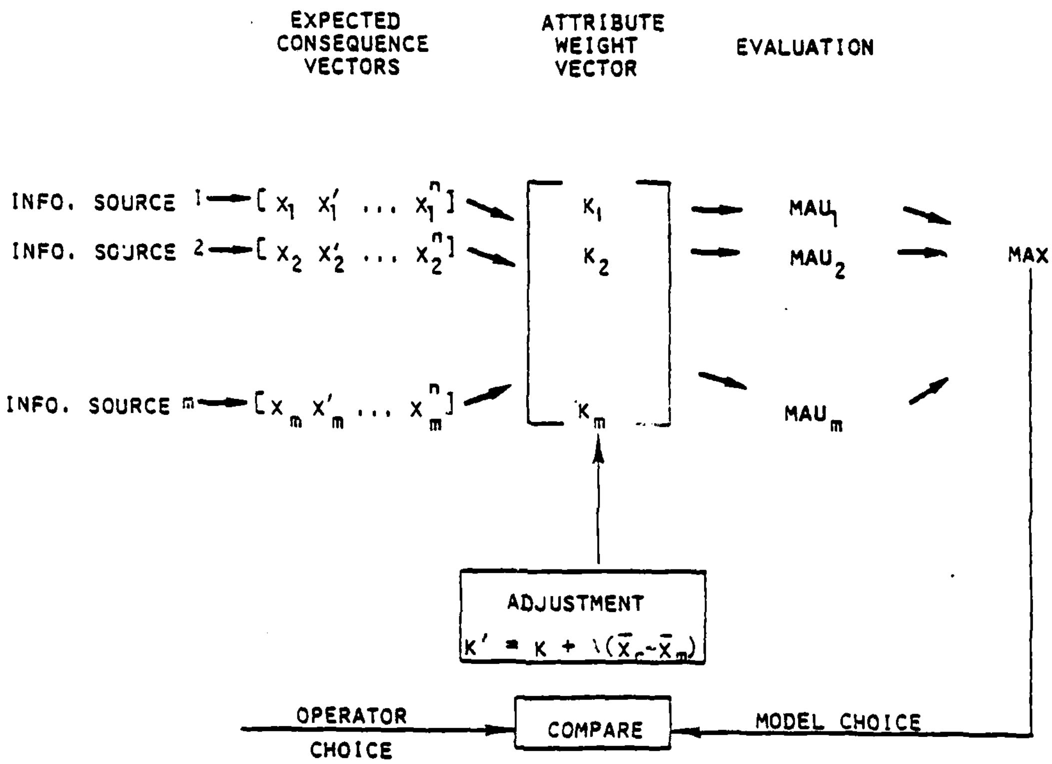


FIGURE 2-4.
ADAPTIVE ESTIMATION PROCESS

operator's actual choice. If a discrepancy occurs, the weight vector is adjusted according to the following rule:

$$\underline{w}' = \underline{w} + \lambda (\underline{x}_c - \underline{x}_m)$$

where $\underline{w}'$ is the updated weight vector

$\underline{w}$ is the previous weight vector

λ is an adjustment constant

$\underline{x}_c$ is the attribute vector of the chosen alternative

$\underline{x}_m$ is the mean attribute vector of all alternatives ranked by the model above the chosen alternative

Ideally, the error correction moves the weight vector in a direction minimizing subsequent errors. The amount of movement depends on λ, the adjustment increment.

The utility model could be trained subjectively by observation of the operator's choices. If the sequence of choices led to an objectively favorable outcome, the trained parameter set would be retained. If the outcome was unfavorable, the parameter set would be returned to the levels present prior to the sequence of decisions. In this way, objective criteria would guide overall training, but the explicit decision-by-decision policy for information management would be subjectively derived.

Experimental Validation. Evidence for the usefulness of the multiattribute utility formulation and adaptive estimation programs was initially obtained in an earlier program (Steeb, Chen and Freedy, 1977). A simulation resembling control of a remotely piloted vehicle (RPV) was used in this study. The adaptive model was found to be significantly more predictive of the subject's behavior than either a constant, unity weight model or an off-line method of weight estimation. Also, the model was found to be useful in identifying different decision policies or styles.

The following efforts (Steeb, Davis, Alperovitch and Freedy, 1978; Steeb, Chu, Clark, Alperovitch and Freedy, 1979) re-directed the application area from one of remotely piloted vehicle supervision to one of information selection in advanced aircraft. A simulation based on multiple threat intercept operations in advanced aircraft was developed. Comparisons were made between (1) automated information selection based on the adaptive model described earlier, (2) automated information selection based on information seeking strategies elicited directly from the operator, and (3) manual information selection. The adaptive technique was found to be superior to direct policy elicitation, both for automated information selection and as a basis for information system evaluation.

2.3.3 Approaches to Model the Continuous Information Handling Process. There are two general approaches to model continuous information handling behavior. Descriptive modeling is designed to describe actual or observed behavior, whereas prescriptive modeling prescribes optimal or goal/criterion-directed behavior. As rational, effective behavior of the operator is the main concern, the use of prescriptive models is emphasized in this study.

Prescriptive models are often based on optimization of underlying descriptive models. These models include control and estimation approaches (Govindaraj, 1979; Rouse, 1980), process interaction approaches (Seifert and Chubb, 1978; Tulga and Sheridan, 1980), and heuristic-based approaches (Wesson, 1977; Goldstein and Grimson, 1977; Engleman, Berg, and Bischoff, 1979). Based on the context of task, the detail level in supervisory control and the characteristics of the task demand, it appears that optimal controller and observer models are suitable for the modeling of lowest-level, supervisory control task and the knowledge and heuristic-based techniques can be successfully applied to the high-level, situation assessment plan generation task. At the intermediate level, various approaches have been used to model the monitoring and execution activities of information handling. These approaches will be discussed in the following paragraphs.

A considerable amount of research effort has been directed at understanding the human operator in multi-task, supervisory control situations. One general approach is to start with control theory from a general perspective that includes control with respect to continuous events as well as discrete events. This approach is represented by Muralidharan and Baron (1979), Govindaraj and Rouse (1979), Krishna-Rao and Ephrath and Kleinman (1979).

Muralidharan and Baron (1979) have studied supervisory control of multiple, remotely piloted vehicles (RPVs), The operator has to choose which RPV to monitor and whether or not to intervene with discrete corrective control actions based on the venicle's lateral deviations. Muralidharan and Baron's model is an extension of the optimal control model of the operator derived by infusion decision theoretic notions into control criteria. The model has been employed to study the effects of error tolerance and the number of RPVs per operator on overall system performance in terms of timing errors and deviations from the desired trajectory.

Govindaraj and Rouse (1979) have studied intermittent control with a preview of map displays for flight management. In such a case, the operator must divide his attention between control and discrete tasks. An analytical model is developed based on optimal control theory with differential weight structure embedded in the cost function. The model performs the discrete control task whenever the perceived error exceeds certain bounds, as it matches to the operator's behavior.

Krishna-Rao, Ephrath and Kleinman (1979) have sought to "transform" the optimal control model into an optimal decision model that is suitable for the multi-task situation where tasks of different value, time requirements, and deadlines compete for the operator's attention. The model, bearing conceptual similarity to the optimal control model, consists of two separate blocks: information-processor and decision processor. The information-processor block provides the estimates of the "decision-state," i.e., the amount of time required and the amount of time allowed to complete each task. These estimates, along with task values under the subjective expected utility framework provide the selection of a task in the *decision-processor* block. The approach is quite general and suitable for discrete task dynamics.

Another approach, apart from general state-space control theory points-of-view, is to start with task analysis or task-paradigm development, and then to identify the subprocesses and the interactions among them. Abstraction of the process dynamics and interaction then leads the way toward simulation techniques and models. This approach is represented by Seifert (1979), Baron et al. (1980), Tulga and Sheridan (1980), Greenstein (1979), and Chu and Rouse (1979).

Seifert (1979) has proposed a combined SAINT discrete network model with an optimal control model formulation. The objective is to realistically examine and model an advanced man-machine system in which both discrete tasks and continuous tracking behaviors are exhibited. The mutual interaction between discrete tasks and continuous state variables is achieved through "mix-initiation," i.e., either by tasks being completed or by state variables crossing specific threshold values. The feasibility of employing this modeling approach has been demonstrated in a combined flight control with multifunction keyboard tasks in the Digital Avionic Information System.

Baron, Zacharias, Muralidharan and Lancraft (1980) have studied flight crew procedures in approach to landing. A simulation model based on time-line analysis of nominal procedures was developed. Their approach draws heavily on the concepts and submodels of the optimal control model for the human operator. The overall model structure, however, is one of subprocess interaction.

Tulga and Sheridan (1980) developed a multi-task, supervisory control paradigm and a dynamic programming model of monitoring and control behavior. The paradigm addressed is one of allocating in time a limited attention resource to multiple simultaneous demands of varying duration, production rate, and rewards. The model, embedding several criterion functions and including response time and future discount constraints, allows one to explore the interacting factors of task demands, operator's "plan-ahead" behavior, and task parameter estimation on the performance of multiple-process supervision.

Greenstein and Rouse (1982) have considered the operator's monitoring of multiple displays of stochastic processes. A two-stage model that represents the operator's event detection task and attention allocation task is developed. In the first stage, a discriminant analysis technique is used to model the operator's generation of probability estimates that events have occurred after the observation of display. In the second stage, action times and delay costs, along with event probabilities, are used in the queueing framework to determine the order of tasks to be attended.

Rouse (1977) and Walden and Rouse (1978) have modeled the pilot in a multi-task flight management situation as a "server" in a queue where events are the control and check-list procedure tasks. The events are assumed to arrive with exponentially distributed inter-arrival time, and to be serviced according to their priority. The "arrival rate" for control tasks was measured from experimental results for control activities, and the service rate was determined as a free parameter of the model. The model performance (mainly waiting time statistics) matches well with the experimental data.

Chu and Rouse (1979) considered human-operator interaction in the multi-task, flight management situation. Allocation of responsibility between operator and computer is modeled as a control process of the queueing system. It was proposed and demonstrated in the study that the operator's workload can be maintained within an acceptable level, if routing of information handling responsibility (such as check-list procedure) between operator and computer can be achieved and adapted to task demand.

All the above models address the process aspect of the information handling only. The important issues of information value and the associated decision strategy in information selection, in weighing probable payoffs against costs of acquiring the information, have not been taken into account in all of the previous work reviewed. To compensate for this deficiency, a continuous information handling model based on combined multi-attribute utility and queueing model will be described in the next section.

2.4 A Time-Continuous Information Handling Model

Among the operator task models of information handling reviewed in Section 2.3.3, the most relevnt modeling concepts include that of Sander's (1964) visual sampling model, Smallwood's (1967) instrument monitoring model, Carbonell's (1968) queueing model of visual sampling, Doetsch's (1975) supervisory flight control concept, DAIS system concept (Aviation Week and Space Technology, 1979), SAINT network model (Kuperman, et al., 1977), Greening's (1978) crew/cockpit modeling survey, Rouse's (1978) airborne information management and Cavalli's (1978) discrete-time pilot model. These studies point out the emerging need for a general model for operator information handling tasks, that is capable of representing (1) stochastic aspects of information processing, (2) general top-down system organization and bottom-up system synthesis process using integrated display control, (3) discrete events of underlying continuous processes, (4) parallel and serial operations, and (5) interactive control and display systems.

To fulfill these modeling requirements, the information flow concept derived in this study is based on pragmatic information value and multiprocessing organization. The former notion refers to the assumptions of the close interrelationship between information and decision and the abilities of the operator to quantify and compare information (Whittemore and Yovits, 1973). The later notion refers to the use of analogy of a time-shared computer in viewing operator's attention allocation among a variety of tasks (Johannson and Rouse, 1979). If one is concerned with time performance and productivity (i.e., throughput), the queueing theory may be an appropriate formulation.

The queueing theory framework assumes that the operator has sequentially or randomly monitored the process and has updated the estimates of event probabilities. Upon detecting or judging an event's arrival, the operator then places the event in memory or in a physical queue for attention. The atomic decisions actually involved in this information handling task are (1) monitoring or attending to a specific event, (2) selecting an event for attention, (3) selecting an information source, (4) continued information sampling/processing, (5) selecting an alternative event for action (if preemption is allowed), and (6) action selection. In this study, decision (1), (4), (5), and (6) will be prespecified and decisions (2) and (3) will be the main focus of the modeling effort. The usual practices related to decisions (1) and (4) are to attend a specific event if there is one and to continue information processing only when there is an incorrect response in information handling. Therefore, except for decision (5) which is determined by rules or strategies (e.g., preemptive, nonpreemptive) all the prespecified decisions can be incorporated in a set of stochastic functions, such as probabilities of false alarm, incorrect response and missed event; and a set of probabilities for possible actions taken.

2.4.1 <u>Mathematical Formulation</u>. In the context of the mathematic formulation (Rouse, 1977), the assumption and approach to characterize the information flow of handling tasks are as follows:

(1) The information system possesses N independent state (or feature) vectors.

X_i, i = 1, 2, ..., N (System States)

Y_i, i = 1, 2, ..., N (Observer States)

(1) The <u>events</u> e_i (the state or feature variations observed which call for information handling and response activities, such as check-list procedures, fault procedures, en-

vironment clearance, tactical maneuver, and threat estimates) arrive as independent stochastic processes with a priori probability density function (pdf) of:

$$f_i(\cdot) = f_i(\lambda_i), \; i = 1, 2, \ldots, N$$

where λ_i is the arrival rate of event i

(1) The events e_i are perceived to have occurred after a monitoring epoch with the status display, with probability $P_i(\cdot|Y_i)$, the conditional probability of the event given the observed state.

(2) The prior statistics of information handling (service) time for event i using information j with state observation Y is given as:

$$g_{ij}(\cdot|Y) = g_{ij}(\mu_{ij}), \; i = 1, 2, \ldots, N$$
$$j = 1, 2, \ldots, N; \; J = \sum^{N} I_j,$$

where $g_{ij}(\cdot|Y)$ is the pdf of service times t_s for observation Y, μ_{ij} is the mean service rate for given event i using information j.

2.4.2 Combined MAU/Queueing Model Functions. Illustrating the combined modeling approach of information evaluation and processing, Figure 2-5 shows the functional block diagram of the MAU and queueing model for the shared man-computer information handling task. The information arrivals are generated from external information sources and transformed into a visual format (graphic, schematic, alphanumeric, symbol, or tones, etc.). Each new information arrival causes a reevaluation and then a reformatting and a reordering of the event queue. The computa-

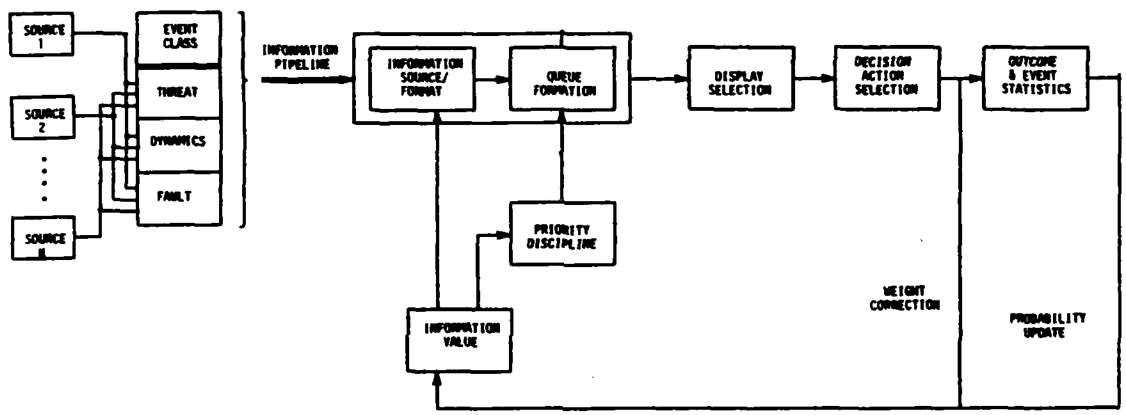


FIGURE 2-5.
FUNCTIONAL BLOCK DIAGRAM OF MAU/QUEUEING MODEL

tion of information value if carried out by the MAU model according to the set of criteria established in the pervious section -- cost, detection and expected payoffs/loss, etc. The attribute levels and weights may be pre-assigned or estimated adpatively from the previous decision outcomes. Present development assumes a nonpreemptive priority discipline.

2.4.3 Incorporation of Multi-Attribute Criterion Function. The development to this point has not considered the criteria for the selection from multiple information choices. In the context of supervisory control of advanced aircraft, multiple-objective criterion function needs to be considered. The complete "state of nature" is assumed to be characterized by the states related to threat, navigation, and subsystem situations:

$$N = \{z_\ell (z_t, z_n, z_s)\}$$

where z_t, z_n, z_s are time-varying random state vectors.

The selection of process or source s and message type j at a particular time is assumed to be based on maximizing expected utility

$$\max_s \max_j [EU(e_{sj})] \quad s = 1, 2, 3, \ldots, S; \quad j = 1, 2, \ldots, m_s$$

where $EU(e_{sj})$ is the utility of selecting message type j with source s,

and $EU(e_{sj}) = \sum_k \sum_h P(O_h|s, j, k)\ U(O_h|s, j, k)$

where $P(O_h|s, j, k)$ and $U(O_h|s, j, k)$ are the probability and utility of outcome O_h given information source s, message j, and state k; $h = 1, 2, \ldots, H_s$; $k = 1, 2, \ldots, K_s$.

If we let $MAU(e_{sj}) = \sum_{i=1}^{5} W_i X_{ijs}$, as suggested in Section 2.3.2, then the attribute X_{ijs} is given by:

$$X_{ijs} = \sum_{h} \sum_{k} P_s (O_h|j, k) \cdot \bar{X}_{si}(O_h|j, k)$$

where $\bar{X}_{si}$ is the scaled expected utility of outcome payoffs on given information I_j and state z_k.

A man-machine simulation based on the combined MAU information model and queueing framework was developed for the continuous monitoring and control situation. Central to this simulation is the implementation of the derived situation formulation and information selection criteria described above. Figure 2-6 provides a schematic diagram of the implementation of model-based evaluation procedure. As the diagram shows, the evaluation process can be used in a time-continuous manner, move from one event to the next, one decision epoch to another, generate the probability and utility updates using the MAU model, select the information sources, and record actual system changes. Details of the task simulation will be described in the next chapter.

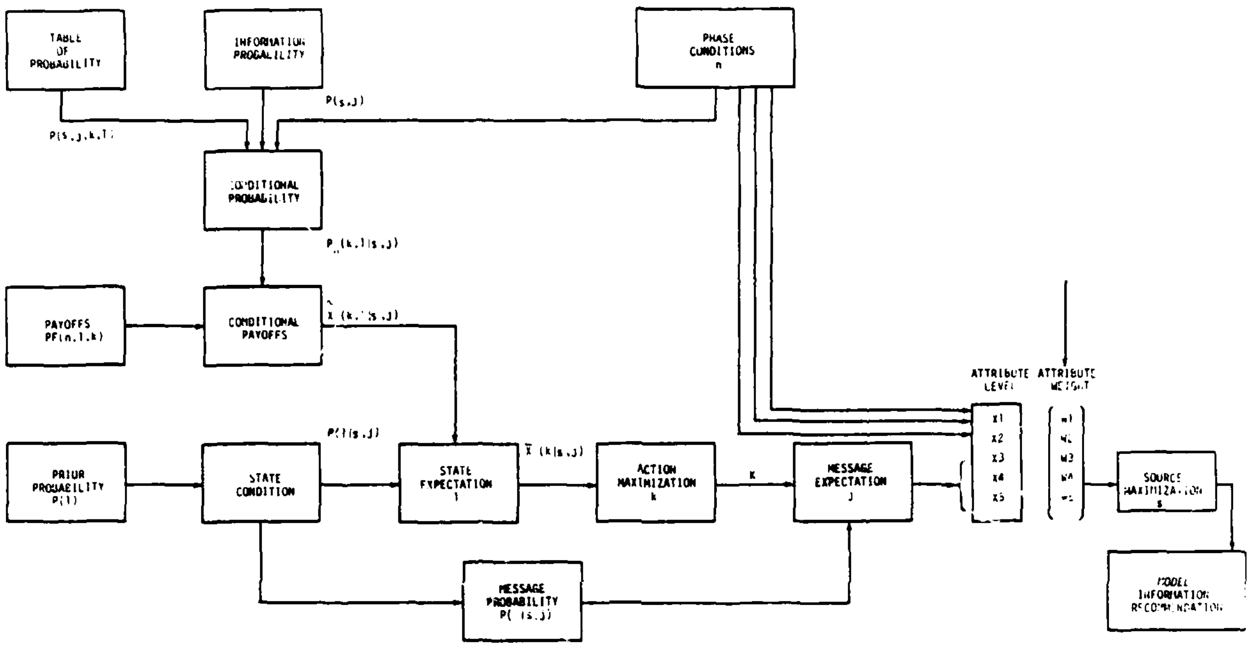


FIGURE 2-6.
IMPLEMENTATION OF MODEL BASED EVALUATION PROCEDURE

3. EXPERIMENTAL STUDY

3.1 Overview

The present experiment was designed to assess the effectiveness of value-based information management schemes and the validity of the MAU/Queueing model in describing an operator's information handling task. An advanced aircraft simulation of a multi-task situation was developed. Individual subjects were required to pilot a simulated aircraft in a changing, hostile environment. In doing so, they were provided with various forms of information concerning the multiple threats encountered and subsequent evasive or aggressive actions. In addition, the subjects were required to monitor subsystem functions and to perform checklist procedures. Performance comparisons were made in the study levels of computer aiding and between levels of task demands.

3.2 Hypotheses

The following experimental hypotheses were tested:

(1) A combined queueing/multi-attribute utility model is suitable for representing various information handling operations in advanced aircraft. The multi-attribute model is useful for evaluating the effectiveness of different information system configurations under a variety of task conditions. The queueing model is useful for describing information handling characteristics (such as demand, procedure, and performance) for multiple information situations and for a variety of task conditions and computer aiding. The combined model is capable of depicting the operator's preference in information selection.

(2) The improvement of aided performance under option recommendation and automatic selection will be enhanced in conditions of high information load.

3.3 Task Simulation

Information requirements and operator tasks in advanced aircraft operations were presented in last year's report (Chu, Steeb, Freedy, 1980). The operator's functions include navigation, communication, and monitoring enemy activity; searching, acquiring and tracking; delivering weapon; and evading enemy action. The operator's tasks include: selection of equipment/mode, monitoring and observing; visual search, acquisition and tracking; monitoring and following command, etc. Both sequential and parallel information handling are required. In the task simulation developed, the parallel and independent handling requirements were represented by a multiple-process check-list monitoring and executional procedure. The sequential information handling requirements were represented by a three-stage (search-selection-action) threat-intercept operation. In addition, under the categories of computer aiding (aggregation, alerting, and option recommendation), the operation procedures presented the possibility of various levels of interaction requirements. Overall, the task situation was a multi-task one, with mixed levels of computer aiding.

The task environment chosen was an adaptation and extension of the multiple threat intercept simulation employed in the previous program (Steeb, Chu, Clark, Alperovitch, Freedy, 1979). The symbols and types of threat information were similar to that used previously, but the display format and threat occurrence were varied, encompassing time-varying multiple-task situation. Consequently, a wider variety of tasks and information handling options were available to the operator. Multiple task demands, including (a) threats of uncertain capability and location, and (b) subsystem events of sporadic occurrence but with a structured procedure arose continuously. The operator had the option of selecting a particular event to attend to and the option of accessing a particular source of information. The characteristics of the event differed in payoff, urgency, and delay. The forms of information differed in threat discrimination capabilities, transmission costs, processing delays, and potential of detection. The simulated task environment is shown in Figure 3-1 and will be discussed in the following subsections.

3.3.1 Category of Task Demands. As described above, there are two categories of task demands: high priority and low-priority. The high-priority task was the threat intercept task of navigating a simulated aircraft through a changing, hazardous environment. The environment contained threats of uncertain form and location, and the identity and location of the threat could be determined by requesting different types of information. The different types of information varied in cost and content, so that, at each threat, the subject either took an avoidance action or an aggressive action. The low priority task monitored the subsystem displays that simulated status indicators of aircraft functions, and processed interactive check-list procedures for the correction of malfunctions. The two categories of tasks are discussed in the following paragraphs.

Threat Intercept Task. The threat environment and the vehicle were shown in a moving-map display, where incoming threats appeared at random, presented with symbol the "D" at the upper edge of the screen, and moved downward at a constant velocity. The operator could move the vehicle symbol horizontally to avoid the obstacles, or to fire at the nearest threat.

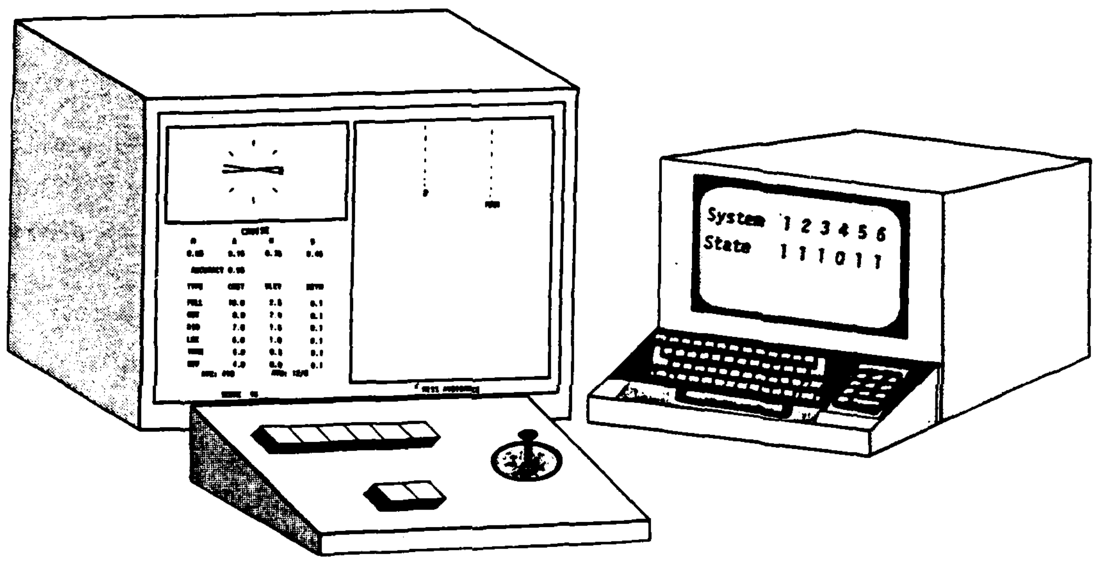


FIGURE 3-1.
SIMULATED INFORMATION HANDLING TASK SITUATION

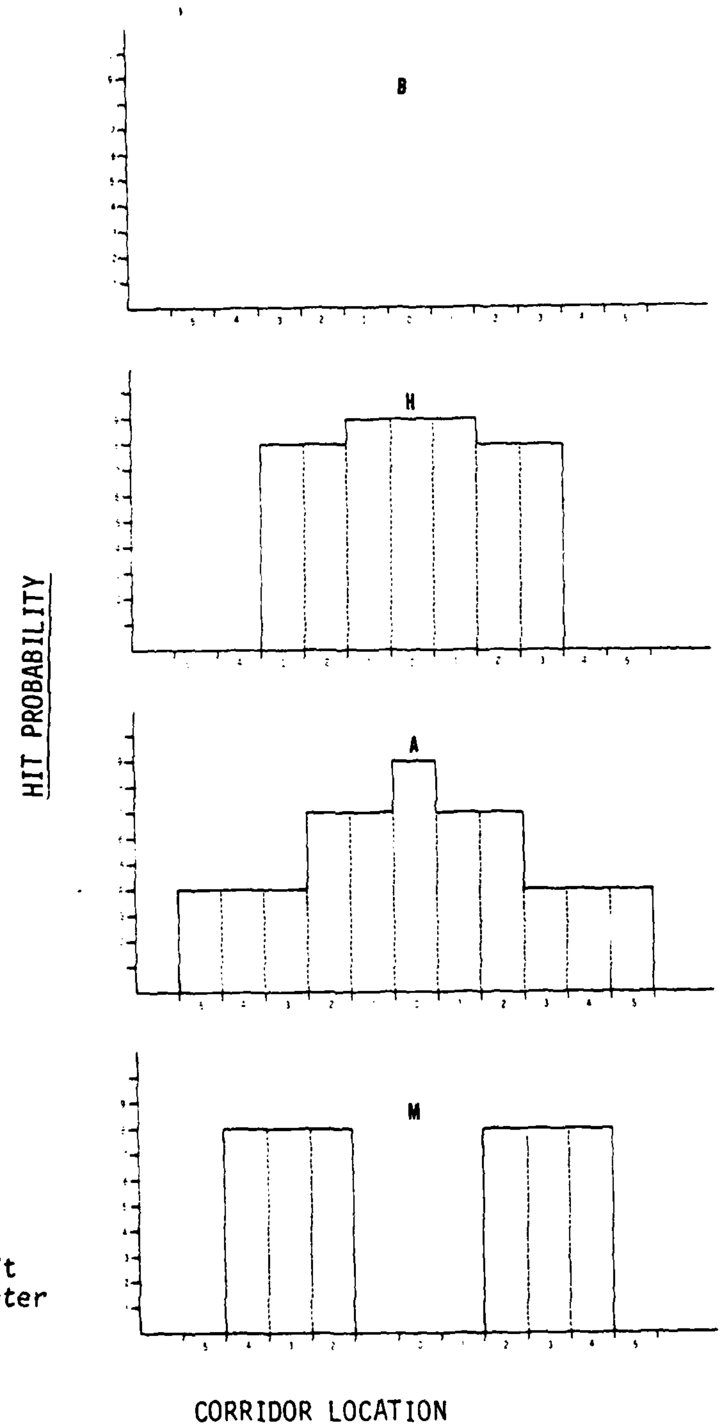
The threats introduce both uncertainty and danger to the task simulation, and each type of threat has a region of possible damage to the aircraft as shown in Figure 3-2. The probability of damage is a function of the horizontal distance between the threat and the piloted aircraft. For ease of learning, the four obstacle types are designed to be evocative of the types of contact expected to occur in actual flight missions -- missile, fixed-wing aircraft, helicopters, and false alarms (birds).

Threat information was categorized into six types: Full, Outline, Biological, Location, Left/Right, and Default. The corresponding type and location discriminability and symbols used are given in Table 3-1. In such an environment, a typical sequence of operations in threat information handling is as follows:

(1) Event detection -- when a "D" symbol appears and moves down the screen.

(2) Event selection -- when both threat and subsystem events are present.

(3) Information seeking -- where various types of information are evaluated and the selection of detailed information is performed.



M-Missile
A-Aircraft
H-Helicopter
B-Bird

FIGURE 3-2.
THREAT CHARACTERISTICS

TABLE 3-1

INFORMATION SOURCE CHARACTERISTICS

Information Type	Discrimination	Location	Symbols
1. Full	All	All	M, A, H, B
2. Outline	All but Airplane/ Helicopter	All	M, AH, B
3. Biological	Bird Only	All	MAH, B
4. Location	None	All	X
5. Left/Right	All	Left/Right	M, A, H, B
6. Default	None	None	D

(4) Information confirmation -- observe and interpret the symbol displayed on the screen when both the time delay and information content are varied for different information types selected.

(5) Action decision -- aggression or avoidance.

Subsystem Monitoring Tasks. The subsystem task required the operator to monitor various levels of the subsystem processes (Figure 3-3) to detect possible events (i.e., "0" symbols) and to act to bring the process into operational status (i.e., "1" symbols). If the operator thought process 6 were down (Figure 3-3A), he might press "6" on the keypad and the status display of the next level would appear (Figure 3-3B) The display might then show that branch 3 were "down" and a press of key "3" would lead to the display of next level, where the branch "4" would be "down," (Figure 3-3C) etc. The operator would continue until all branches were "up", whereupon process 6 would be "up" again.

Speed and errors were recorded on performance data. When the incorrect key was pressed, an error was registered in the system while the display status remained unchanged.

3.3.2 *Displays and Controls*. The simulation used a computer-generated graphic display and an alphanumeric CRT display illustrated in Figure 3-1. The display on the left was the graphic display of the threat handling tasks, for which the subjects had to select the appropriate information for the follow-on actions, evasive or aggressive. The display on the right was of the operator's monitoring tasks, for which the subjects were required to attend to the interactive check-list procedures for subsystem abnormalities and to maintain the system under operational conditions.

Process	1	2	. . .	6
State	1	1	. . .	0

Figure 3-3A. Monitoring Display

Proc 6 / Level 1

Branch	1	2	3	. .	6
State	1	1	0	. .	1

Figure 3-3B. First Level of Process 6

Proc 6 / Level 2

Branch	1	2	3	4	. .	6
State	1	1	1	0	. .	1

Figure 3-3C. Second Level of Process 6

FIGURE 3-3.
SUBSYSTEM CHECKLIST PROCEDURE

The real-time graphics used in the study provided the fidelity in timeliness and sensor data variability. Color was used to differentiate "dynamic" foreground information from the "static" background reference. There were three functional elements in the graphic display -- the moving map display, the situational display, and the outcome display. They are described in the following paragraphs.

Moving Map Display. Spatial relationships of the aircraft relative to the sensed threat environment were presented in the upper-right portion of the graphic display (Figure 3-4). Sensed target types and the approximated position (foreground) were shown as target symbols in a fixed assessment area and acquisition window (background). The display was updated with inputs from information selection keys, own vehicle (joystick) control, and detected threat arrivals. The own vehicle could be moved horizontally within the window, either to avoid the threats or take an aggressive action against one of the threats. The actions open to the operator were primarily decision making in nature, the dynamics of control were minimized since the threat and vehicle velocities were held constant.

Situation Display. The stages of an aircraft mission can be characterized by such factors as danger, difficulty, system reliability, and communications security. These factors vary from situation to situation and have consistently been the primary consideration in airborne information handling. In this study, the situational conditions that vary among experimental phases were:

(1) Degree of danger - this was the distribution of possible threats in a given phase. A different set of probabilities of the four threat types was assigned to each phase.

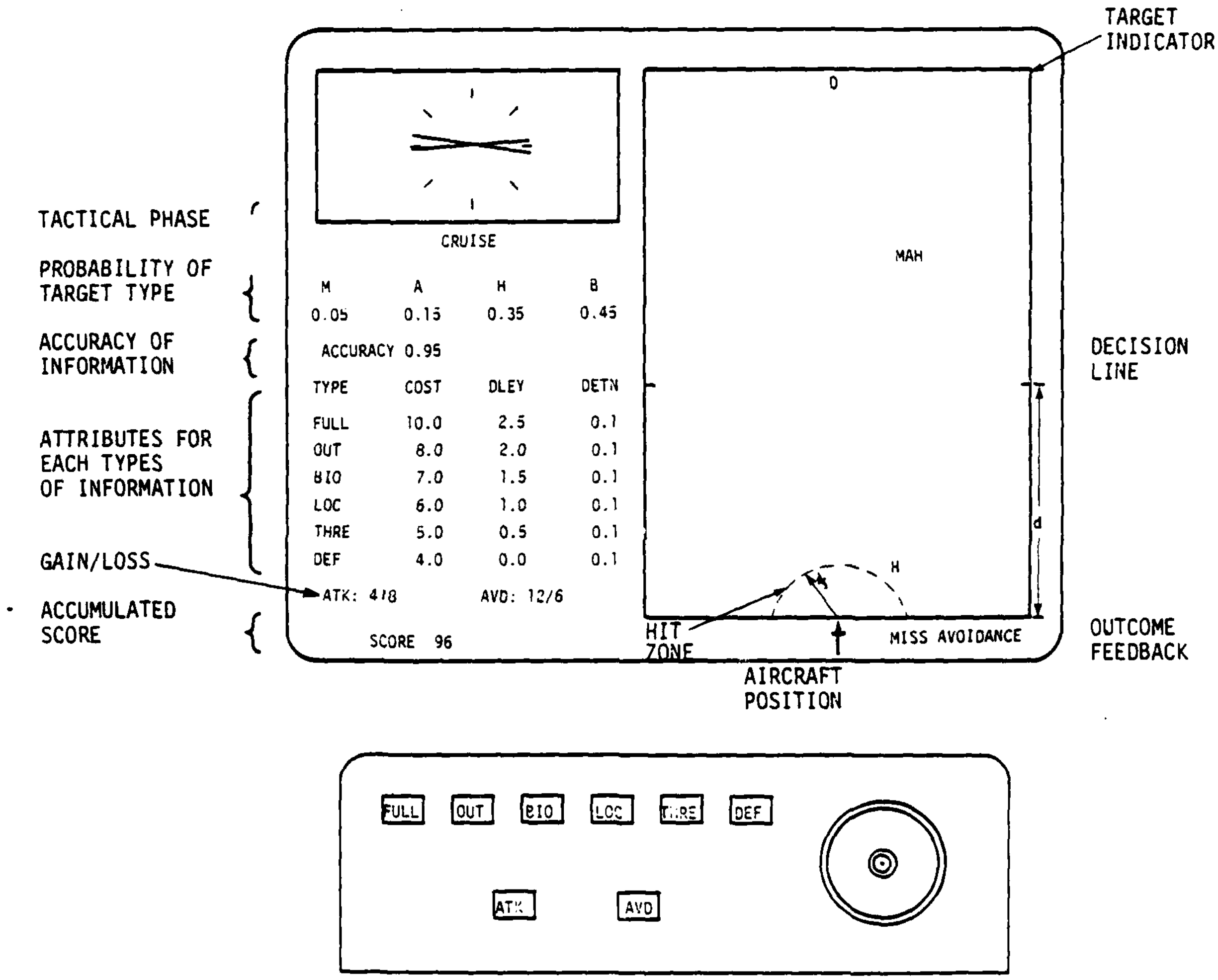


FIGURE 3-4.
MAP, SITUATION AND OUTCOME DISPLAYS

(2) Information accuracy - a percentage of information transmissions that were inaccurate through having random noise added to location content. This indicated the possibility of the location being unpredictable.

(3) Payoffs - different payoffs in points were made for avoidance or damage sustained from the threats, and/or for successful or unsuccessful aggression actions toward the threats. The payoffs for successful and unsuccessful actions were presented by a series of numbers.

The situational conditions that vary from decision to decision were:

(1) Costs - a different and time-varying cost was assigned to each information choice. This was represented as the number of points that the information would cost (by subtracting from the possible payoff).

(2) Delay - the delay in half seconds was presented regarding the time required for acquiring the selected information type. This was equivalent to the portion of the distance the default symbol traveled after the information request and before the "true" target symbol was displayed.

(3) Detection - this was the increased danger on the succeeding decision due to the use of a given information source. A .10 detection projected that a damage would increase by 10% on next decision.

Outcome Display. The element on the bottom of the graphic display represented the immediate feedback to the subjects concerning the outcome and performance score resulting from their decisions. The outcome display was necessary due to the probabilistic nature of the true state and also for motivational purposes. The display consisted of two parts: the outcome message and the performance score. The outcome message includes 'avoid' or 'damage' for avoidance action; and 'hit and avoid', 'miss and avoid', or 'miss and damage' for aggressive action. The performance score was given as an updated number based on the payoffs and cost incurred in each threat intercept. The characteristics of each functional display along with the subsystem display are summarized in Table 3-2.

3.4 Information Handling Model

3.4.1 General. The continued information handling situation faced by the operator is a multiple-stage information-action sequence, as shown in Figure 3-5. The assumption is that the operator sequentially sampled different sources until some confidence level was achieved prior to action execution. Hence, the experimental scenario of combined threat intercept, navigation, and flight management operations can be represented in a cascade of decision tree structures. Specifically, the threat information handling task has been formulated in detailed and explicit selection processes, as shown in Figure 3-6. The decision space is fairly large resulting from the six possible information choices, fourteen message types, two subsequent action choices, continuous range of threat position, and 24 combinations of threat status. A variety of time varying, multi-dimensional consequences result from the various combinations of navigation states, outcomes, costs, payoffs, delays and future impacts.

A purely analytical formulation of this is intractable, just as it is for most operational information seeking decisions. Categorization is

TABLE 3-2

DISPLAY-CONTROL CHARACTERISTICS

DISPLAY TYPE	FUNCTION	CONTROL	ACTIVE ELEMENTS	PASSIVE ELEMENTS	UPDATE EVENTS
MOVING-MAP	Threat - Own Vehicle Relations	Information/Action Selection Keys, Joystick	Threat ID, Threat Position Vehicle Position, and Direction	Assessment Area Assessment Window	Joystick Control, Threat Arrival, Information Selection, Action Selection
SITUATION	Information Options and Handling Attributes	Action Selection Keys	Estimates for Cost, Delay, and Detection	Estimates for Accuracy, Payoffs and Degree of Danger	Action Selection Phase Transition
OUTCOME	Feedback on Selection/Action Outcome and Score	Action Selection Keys, Joystick	Hit/Miss, Avoid/Damage, Score	Anchors	Action Selection
SUBSYSTEM	Operation and Check-Point Status of Subsystems	Alphanumeric Keys	Levels of Status	Anchors	Subsystem Events Checking Procedures

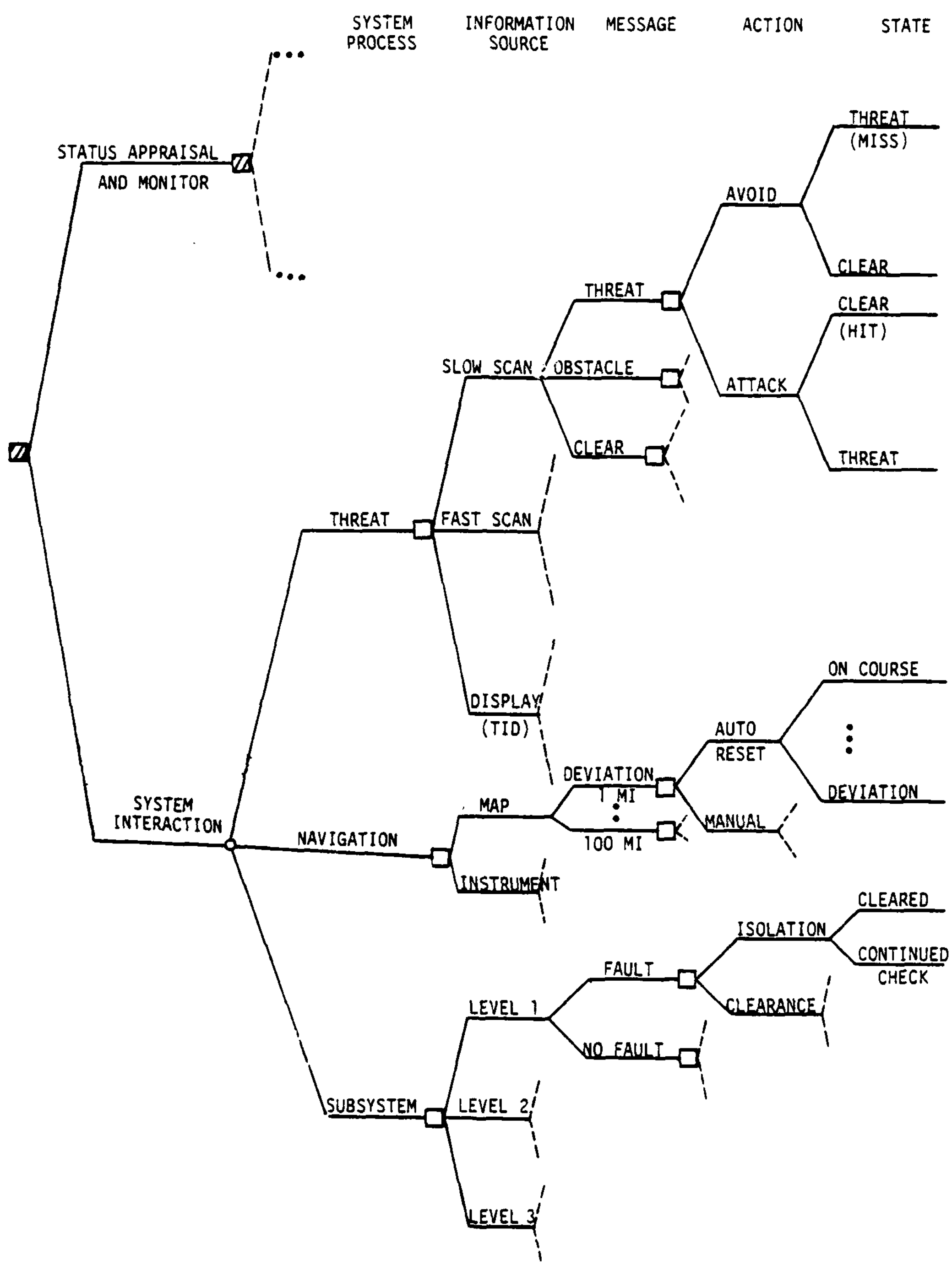


FIGURE 3-5.
TWO-LEVEL INFORMATION SELECTION DECISION TREE

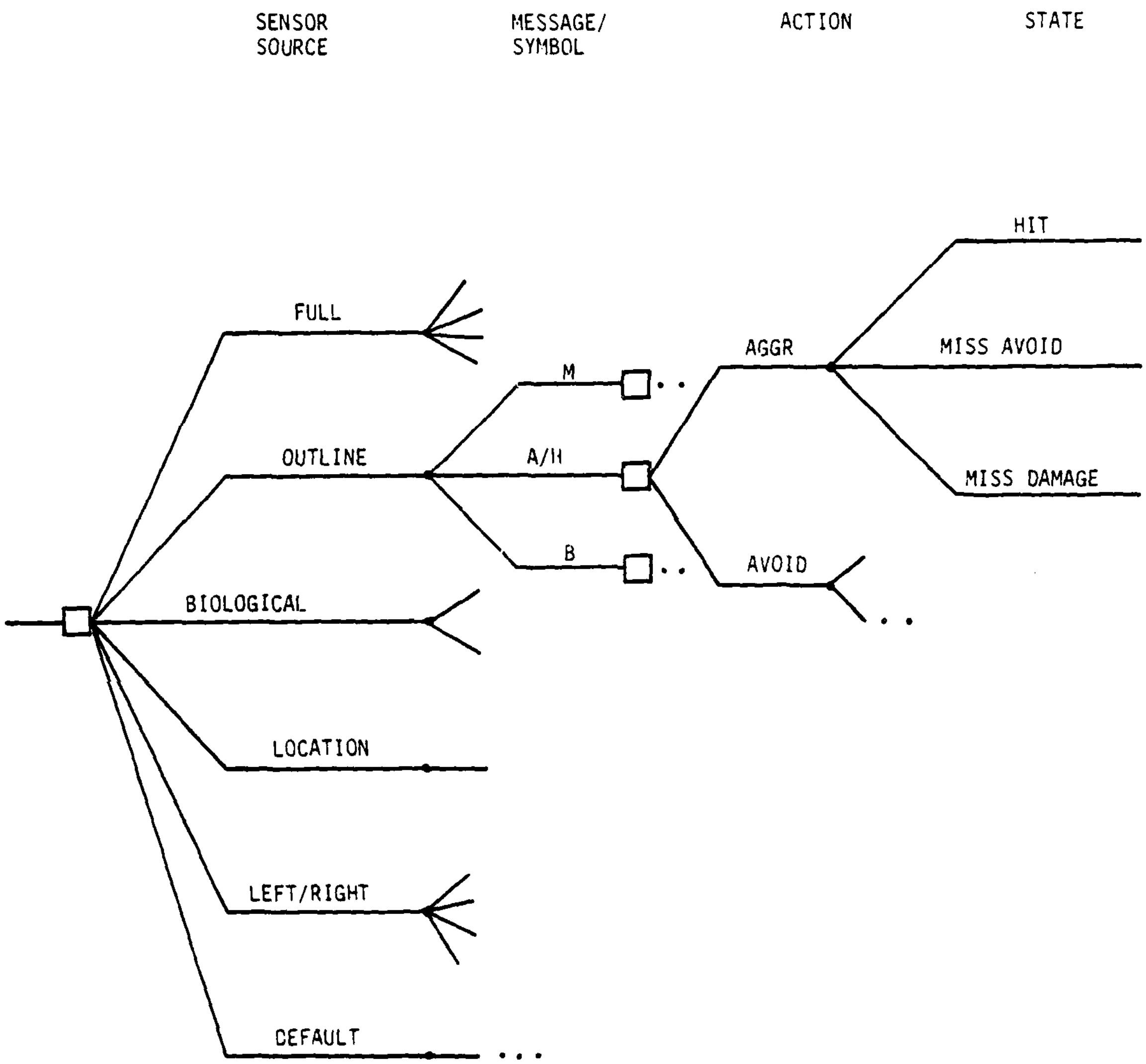


FIGURE 3-6.
THREAT INFORMATION AND ACTION DECISION TREE

an obvious means of reducing the complexity of the decision. Here those elements in the decision similar in consequence can be classified together. For example, the navigational area can be lumped into 22 discrete regions according to the hit and the avoidance probabilities, and the number of threat states can be reduced to four categories by ignoring specific locations. The probability of each message and state can then be calculated from the prior probabilities of each of the threats and the information source characteristics. The actions can be similarly categorized as avoid or attack without regard to location. Probabilities of each outcome type--avoidance, damage, miss and avoidance, miss and damage, and hit--can be established by observed frequency. To do so, a probability estimate must be associated with each combination of information, message, action, and state. After categorization, 48 such combinations are present. These probabilities were determined from a series of pilot system tests, and were intended to be representative of the performance of the typical subject. Estimates specific to each subject were not made. At a given time, the consequence levels (the attribute level vector) associated with a given information choice in a given situation are calculated by folding back the decision tree. The favored action choice after receipt of a given message is determined in a similar manner.

3.4.2 Threat Information Handling Attributes. Five time-varying, consequence-related attributes were employed in the decision model. The attributes are the following:

(1) (X_1) Cost - The cost of the communication in points (costs ranged from 0 to 14.5 points).

(2) (X_2) Delay - The time in seconds before display of the information (delays ranged from 0 to 4 seconds).

(3) (X_3) Detection - Increase in the probability of damage on the subsequent decision (the probability of increase ranged from 1 to 5 percent).

(4) (X_4) Vehicle loss - Expected (probability weighted) level of avoidance damage to own vehicle.

(5) (X_5) Offensive gain - Expected level of damage inflicted on adversary.

X_4 and X_5 are computed according to the following expression:

$$X_4\ (\text{Avoid} \mid \text{Mes}_j,\ \text{Info}_i) = \sum_{\ell=1}^{M\ \text{state}} [P(\text{State}_\ell \mid \text{Mes}_j,\ \text{Info}_i)*$$

$$\tilde{X}_4(\text{State}_\ell \mid \text{Mes}_j,\ \text{Info}_i)]$$

$$X_5(\text{Attack} \mid \text{Mes}_j,\ \text{Info}_i) = \sum_{\ell=1}^{M\ \text{state}} [P(\text{State}_\ell \mid \text{Mes}_j,\ \text{Info}_i)*$$

$$\tilde{X}_5(\text{State}_\ell \mid \text{Mes}_j,\ \text{Info}_i)]$$

where

$$\tilde{X}_4(\text{State}_\ell|\text{Act}_k,\ \text{Mes}_j,\ \text{Info}_i) = P(\text{Avoid},\ \text{State}_\ell|\text{Act}_k,\ \text{Mes}_j,\ \text{Info}_i)*$$
$$\text{Payoff (Phase, Avoidance)} + \{1-P(\text{Avoid},\ \text{State}_\ell|\text{Act}_k,\ \text{Mes}_j,\ \text{Info}_i)\}*$$
$$\text{Payoff (Phase, Damage)}$$

and

$$\tilde{X}_5(\text{State}_\ell|\text{Act}_k,\ \text{Mes}_j,\ \text{Info}_i) = P(\text{Hit},\ \text{State}_\ell|\text{Act}_k,\ \text{Mes}_j,\ \text{Info}_i)*$$
$$\text{Payoff (Phase, Hit)} + \{1-P(\text{Hit},\ \text{State}_\ell|\text{Act}_k,\ \text{Mes}_j,\ \text{Info}_i)\}*$$
$$\text{Payoff (Phase, Miss)}.$$

The payoffs range from -14 to 14 points.

3.4.3 Option Evaluation. The evaluation of each of the 6 information choice is made according to the following equation:

$$MAU\ [I_s]\ \sum_{i=1}^{5} K_i \cdot X_s$$

where MAU $[I_s]$ is the aggregate (multi-attribute) utility of information choice I_s, X_{is} is the level of attribute i associated with information choice I_s, (calculated using Equation 2-3) and K_i is the importance weight of attribute i. It should be noted that the program did not have access to the true state of the environment.

Adaptive estimation of importance weights was employed in the study, using the pattern recognition method described in Section 2.3. Since trial experiences demonstrated that subjects were not able to produce different weight vectors for each phase, but rather followed a single overall strategy, a 5-element vector was maintained for each of the three phases.

3.5 Experimental Procedure

3.5.1 Experimental Variables. The following experimental variables and levels were tested.

(1) Computer aiding - three levels.

(a) Unaided operation - the operator makes the information and control choices without benefit of aiding.

(b) Situation aggregation - the operator makes the information and control choices with the aids of aggregated situational information and display.

(c) Information recommendation and automated selection - the operator makes the information and control choices with the aids of computer recommendations, with the option to override.

(2) Threat arrival rate - two levels.

(a) Low speed stress - threats, including false-alarm, arrived with an average interarrival time of 30 sec.

(b) High speed stress - threats arrived with an average interarrival time of 15 sec.

The low and high speed stress levels were chosen empirically to represent two reasonable extremes of load. The low speed rate was selected to provide sufficient time for trade-off consideration of all factors. The high speed rate was designed to rush the information and action decision somewhat, but not to debilitate the action accuracy.

3.5.2 Subject and procedure. An experiment based on the representation described above was conducted. First, six subjects were used in a preliminary experiment. Those data were used to adjust the situational parameters. Another twelve subjects were recruited from nearby universities for the actual experiment. All subjects represented the type of personnel who might interface with computer-aided information systems. The subject's ages ranged from 18 to 30. All had one or more years of college experience. Six were male and six were female. Four subjects had had experience with computers. The twelve subjects were assigned randomly to the six groups.

Each subject underwent two hours of orientation and practice of both subsystem monitoring and threat intercept tasks. The practice concluded with a high arrival rate manual session, during which aggregated attribute information was given. The experimental sessions consisted of three complete phases of cruise, surveillance and aggression phases, ten minutes in each phase. For each experimental session, the subject was first told the specific tasks to perform, then a 30-minute trial was given, and a questionnaire (in the form that is shown in Appendix III) was filled out by the subject. Each subject experienced all six combinations of conditions in a repeated measures design (Table 3-3). The subjects were paid $6.00 per hour and were given a bonus of up to $6.00 per hour contingent on performance.

3.5.3 Performance Measures. The following performance measures were evaluated in every experimental run:

(1) Threat handling task score. The score was derived from payoffs/penalties and communication costs. The score was presented to the subject as a single index of performance, and the subject's compensation depends to a large extent on this measure.

(2) Average delay in response and service for subsystem events. The subsystem event response time was measured from the time of event occurrence to the time at which an action was

TABLE 3-3

EXPERIMENTAL DESIGN

	LOW SPEED STRESS			HIGH SPEED STRESS		
	MANUAL NO UPDATE	MANUAL UPDATED	AUTO	MANUAL NO UPDATE	MANUAL UPDATED	AUTO
GROUP 1	1	6	4	5	3	2
2	2	3	5	4	6	1
3	3	5	1	2	4	6
4	4	2	6	3	1	5
5	5	1	3	6	2	4
6	6	4	2	1	5	3

Numbers denote sequence of presentation of conditions.

initiated. The service time was measured from the time of last action initiation to the time of action completion for the event. The waiting time was measured from the time of event occurrence to the time of action completion for the event. Waiting time was equal to the sum of response time and service time only when non-preemptive or preemptive-resume disciplines were used and no incorrect action occurred.

(3) Subsystem service errors, i.e., incorrect actions. As the probabilities of both false alarms and missed events were low and were not recorded, the subsystem service errors reerred to the incorrect keys pressed.

(4) Information selection and action times for threat handling task.

(5) Operator time occupancy in terms of the fraction of time the operator was performing either subsystem or threat handling tasks.

(6) Subjective ratings of level of effort required for the tasks and the desirability of computer aiding.

All these measures were obtained by analyzing the sampled and the accumulated data. Except for subsystem status and aircraft stick responses, which were sampled twice per second, all data were sampled as nchronously. The empirical results along with the analysis of variance are discussed in the next chapter.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Overview

This chapter summarizes the results of the experiment performed in the current program year to investigate the efficacy of model-based aiding in information handling. The experimental situation was sufficiently varied and difficult to provide a test of the MAU/Queueing model. The subject learned the task procedures readily, and by the end of the training session, could effectively handle the multiple task demands under different aiding conditions. A variety of subject preferences and strategies were observed and modeled.

The data sampled during the flight information handling experiment was analyzed to obtain the several objective measures listed in the previous chapter. The subjective ratings of the task situations based on the questionnaires answered by the subjects during the experiment were also obtained. For each of these measures, factors of significance were determined using the analysis of variance (fixed effects, within subject design) and the underlying trends of variation were investigated (ANOVA tables appear in Appendix IV). Effects were accepted as significance if $p < 0.05$.

4.2 Task Performance

4.2.1 Task Score. Figure 4-1 shows the performance score attained, averaged across the subjects for the threat intercept task under three modes of computer aiding and the two levels of threat arrival rate. Both experimental variables produced statistically significant effects [$F(2, 22) = 112.10$, $p < 0.001$ for aiding mode; $F(1, 11) = 473.04$, $p < 0.001$ for arrival rate]. The subjects' performance score increased as

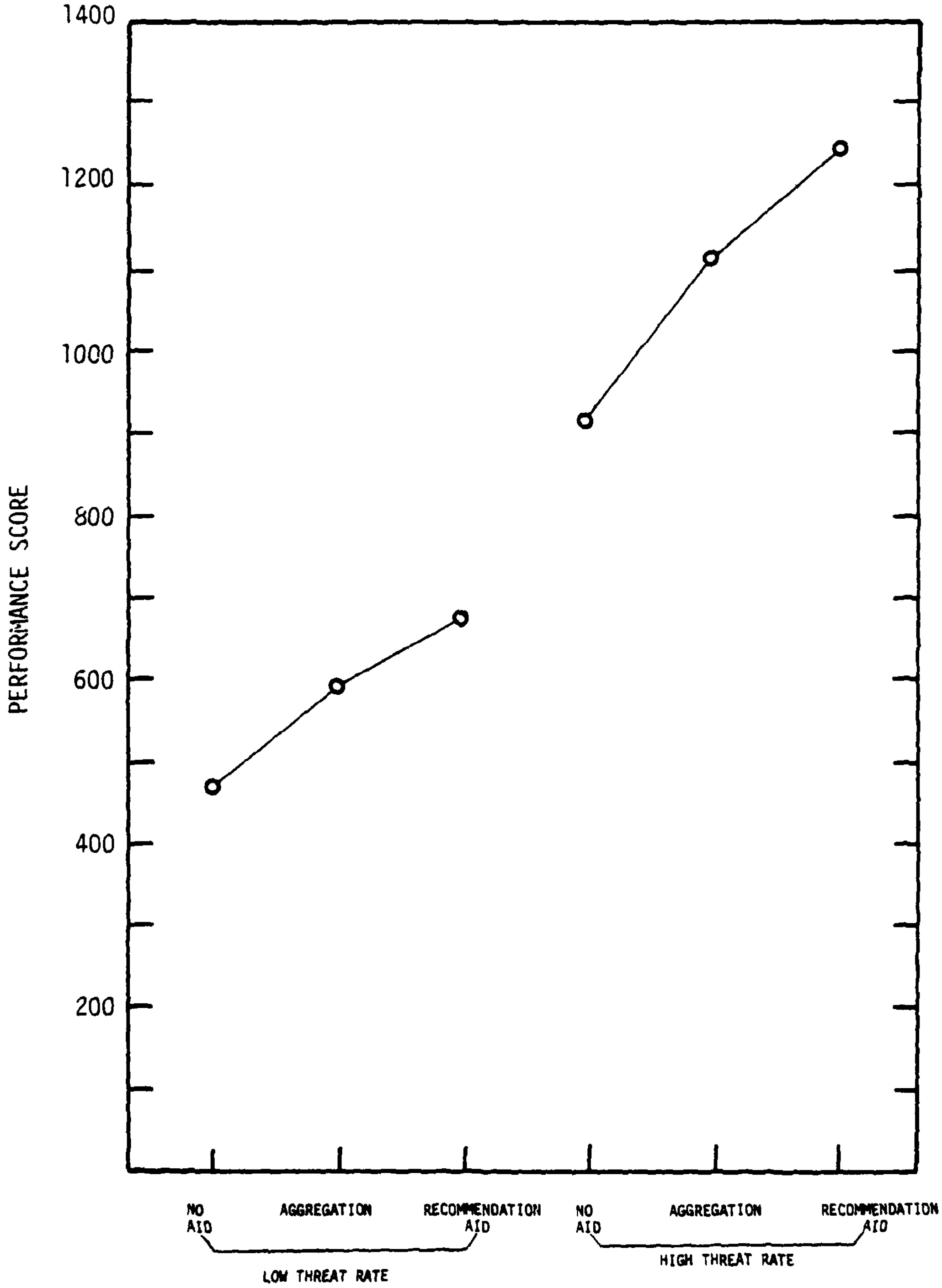


FIGURE 4-1.
AVERAGE PERFORMANCE SCORE

the computer aiding level increased and as threat arrival rate increased. Model recommendation (REC) mode has maintained a 60% improvement and information aggregation (AGGR) mode a 25% improvement over manual (no aiding) mode for both the low- and high-threat-rate conditions.

The score improvements with aggregation and recommendation aids were traceable to differences in both action outcome and payoffs/cost attained. Subjects in both the recommendation and aggregation aided conditions achieved more "avoidance" and "hits" than in the manual, unaided conditions. Although the aided conditions incurred greater information acquisition cost than unaided conditions, the aided conditions resulted in higher payoff scores. The increase in payoffs was more than double the increase in cost expended, resulting in the net performance improvement observed in the aided conditions.

4.2.2 Subsystem Waiting Time and Service Errors. The average subsystem waiting time, shown in Figure 4-2, appears to be independent of aiding level, but increased as threat arrival rate increased [$F(1, 11) = 9.51$, $p < 0.01$]. This may be due to the subject's preemption of subsystem service by the threat arrivals. The service errors, measured as the ratio of the number of incorrect actions to the total number of actions, appear to be independent of both arrival rate and aiding level.

4.2.3 Subjective Ratings. Subjects' ratings concerning the perceived level of effort in performing the tasks, the effectiveness and the desirability of computer aiding, and the ease of interaction with the aiding were analyzed. Individual ratings for different task situations were first converted to a normalized scale (e.g., Guilford, 1954), then these measures of variation among tasks were averaged across the subjects. The resulting effort ratings, i.e., the averaged level of per-

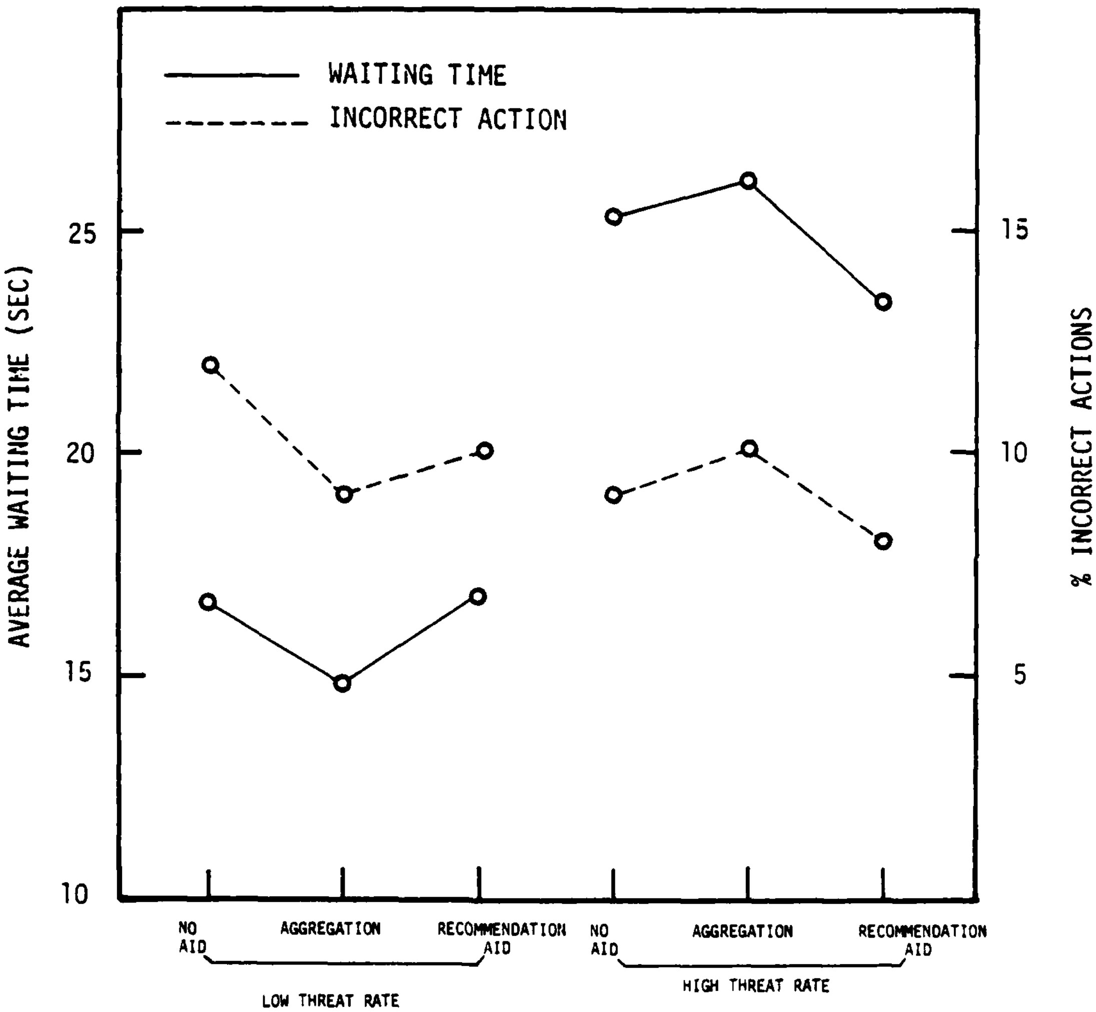


FIGURE 4-2.
AVERAGE SUBSYSTEM WAITING TIME

ceived effort, varied from 'low' to 'high' level (Figure 4-3), and increased as threat arrival rate increased [$F(1, 11) = 29.53$]. Although both of the aiding modes have been shown to produce higher effort level, the effect was not significant. It appears that the subjects had actually settled for lower performance and lower effort levels in unaided situations than those in aided situations.

The subjective ratings of the various aspects of computer aiding also appear to vary among the task conditions. The aiding was considered 'relatively easy' to interact with (Figure 4-4), 'somewhat desirable' by the subjects (Figure 4-5), and had a 'slight improvement' on performance (Figure 4-6). Among the factors of significance, the subjects saw the aiding to be relatively more effective [$F(2, 22) = 5.27$, $p < 0.05$] and more desirable [$F(1,11) = 56.57$, $p < 0.001$] in aggregation mode, and relatively easier to use in high threat rate situations [$F(1, 11) = 8.83$, $p < 0.05$). It is interesting to note that the subjects' perceived desirability of the aiding was more in line with their perception of aiding effectiveness than with their perception of the ease of interaction.

In general, based on the comment from the subjects, it appears that all subjects were quite in favor of both aiding schemes used in the experimental situation. They have preferred the aggregation aid to the recommendation aid, mainly because it took time and effort to override the recommended decisions however infrequently was the override.

4.3 Information Selection Behavior

Each of three aiding modes -- manual, aggregation, and recommendation -- exhibited a different distribution of selections among the six information options. Figure 4-7 shows the frequency of selection averaged

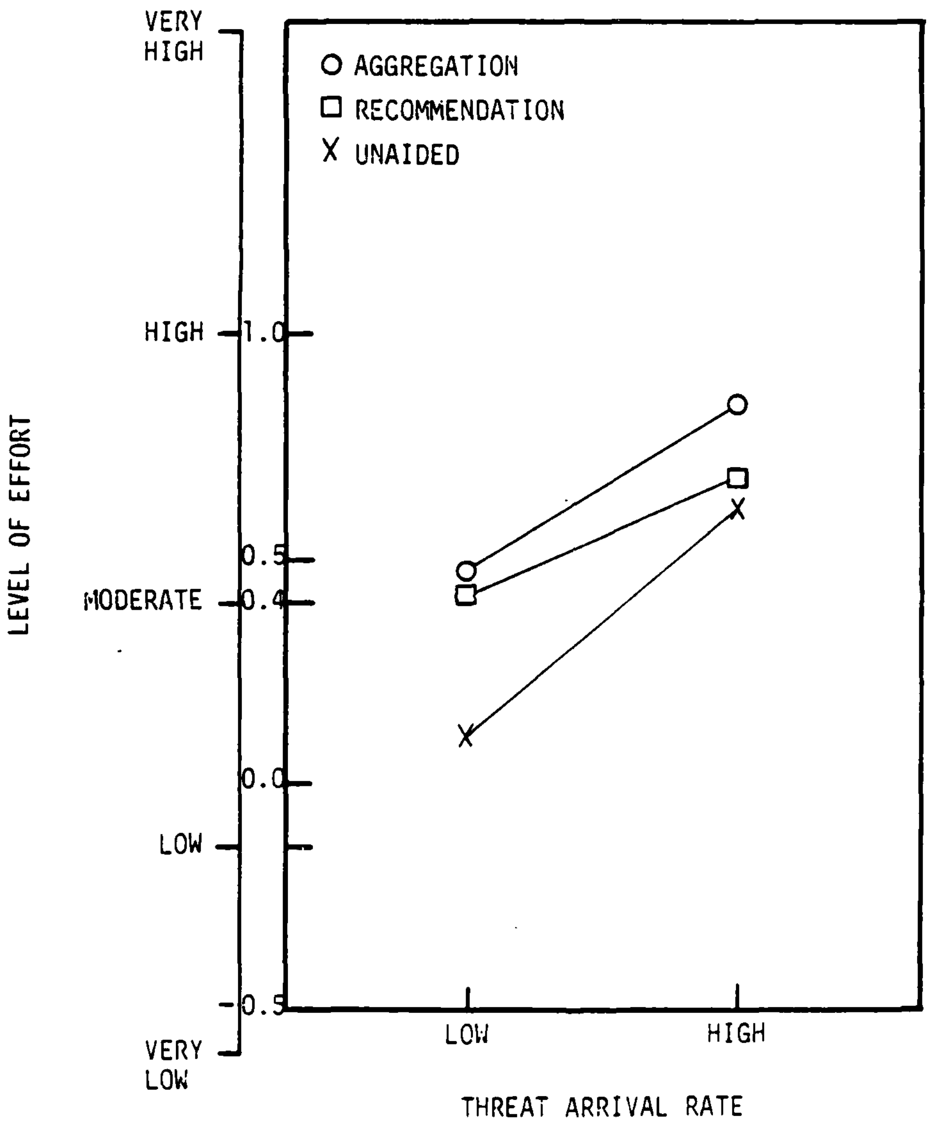


FIGURE 4-3.
SUBJECTIVE RATINGS OF EFFORT

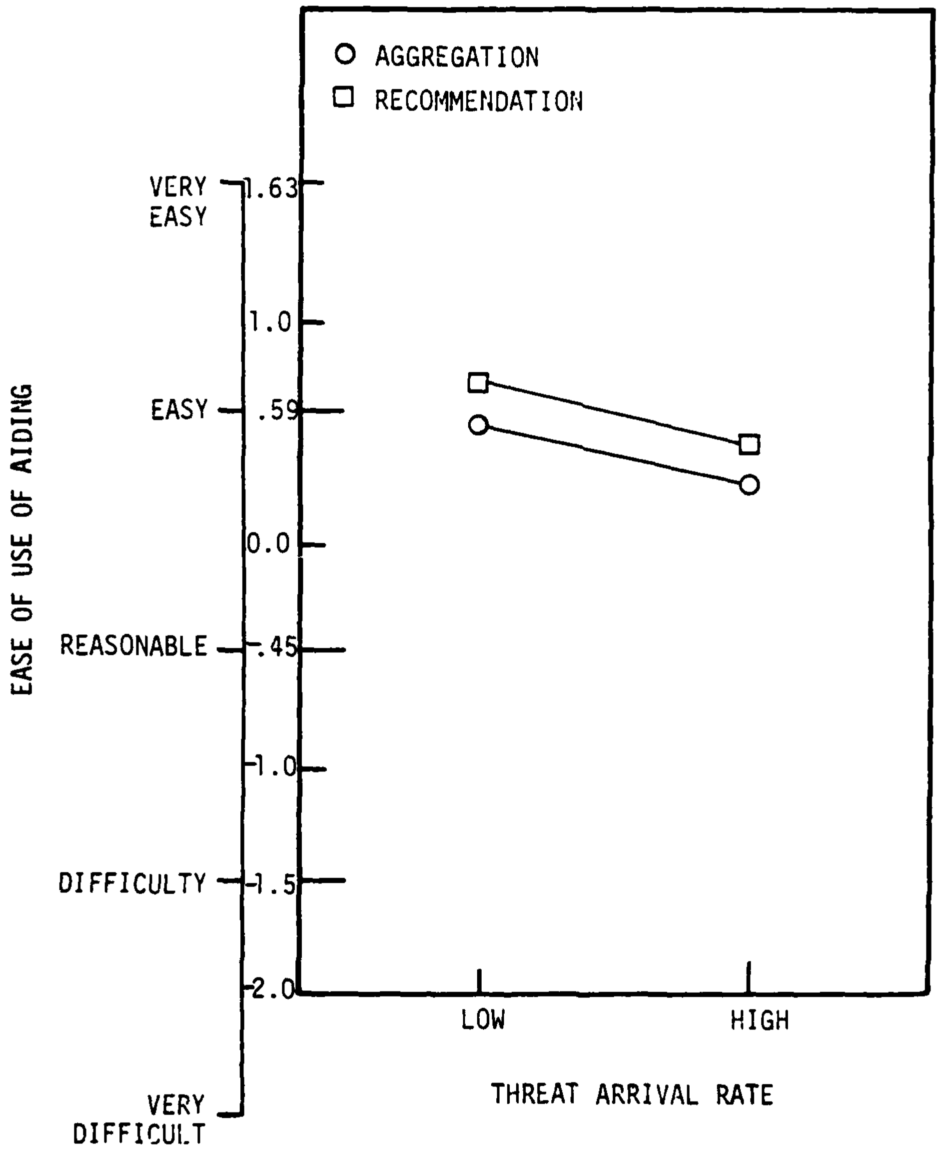


FIGURE 4-4.
SUBJECTIVE RATINGS FOR THE EASE OF USE OF COMPUTER AIDING

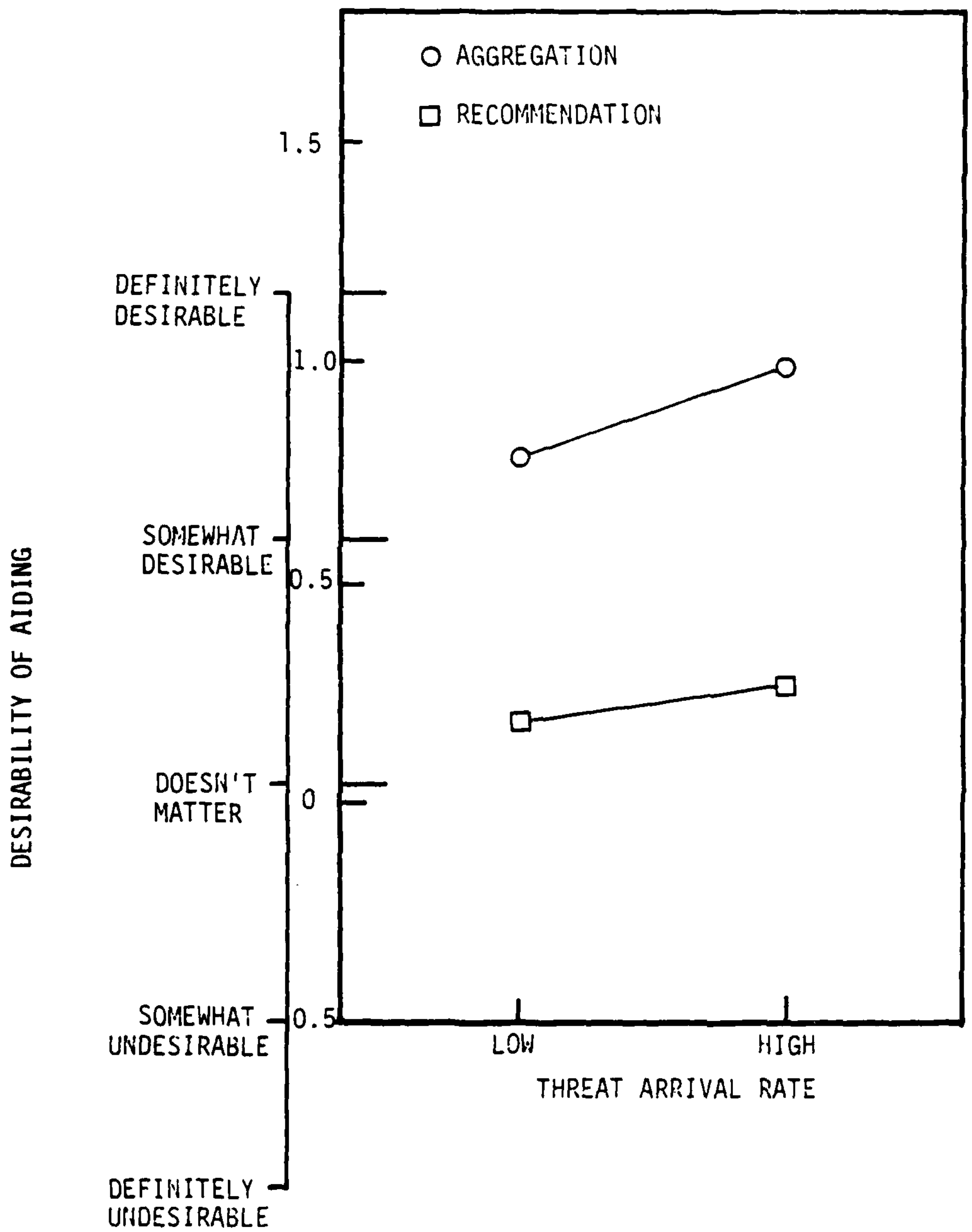


FIGURE 4-5.
SUBJECTIVE RATINGS OF DESIRABILITY
OF COMPUTER AIDING

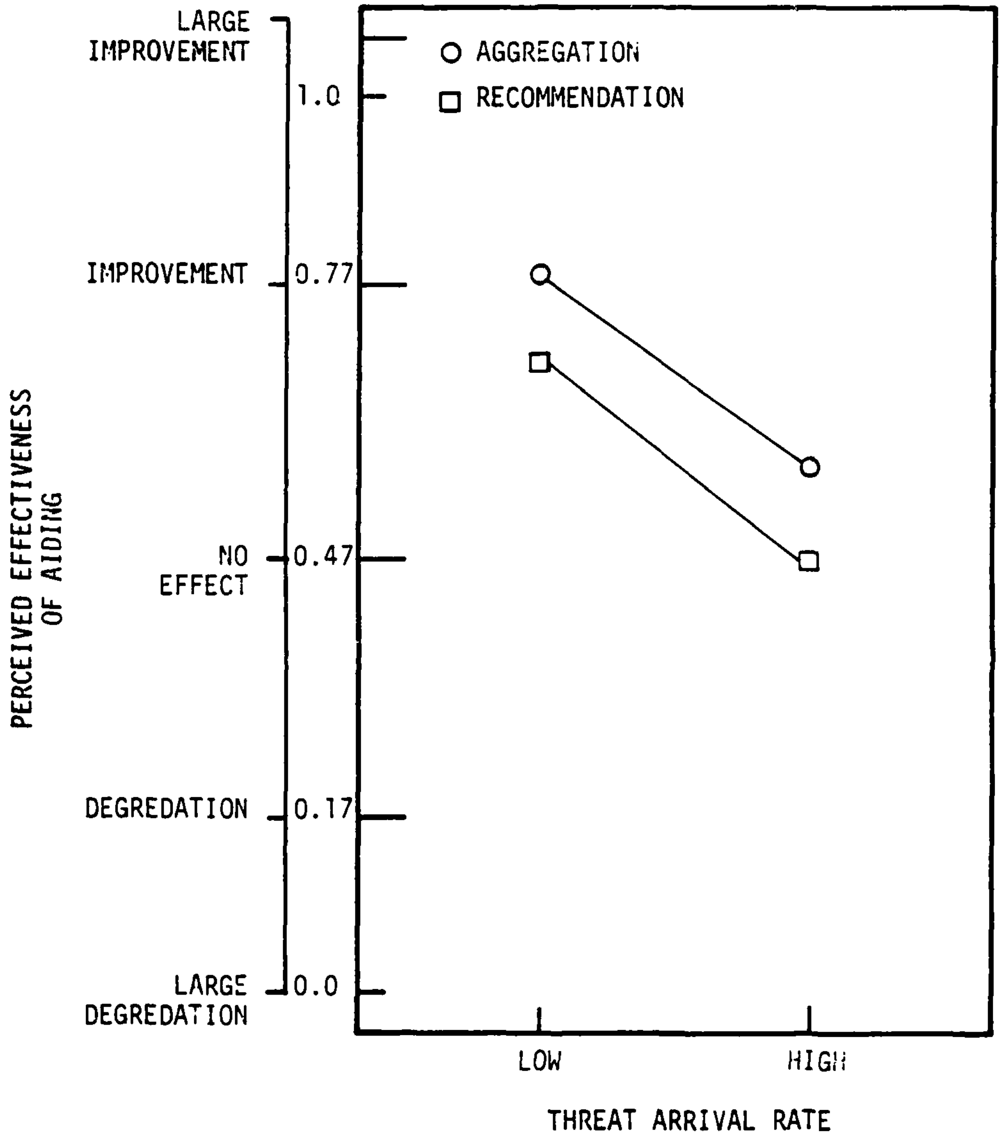


FIGURE 4-6.
SUBJECTIVE RATINGS OF AIDING EFFECTIVENESS

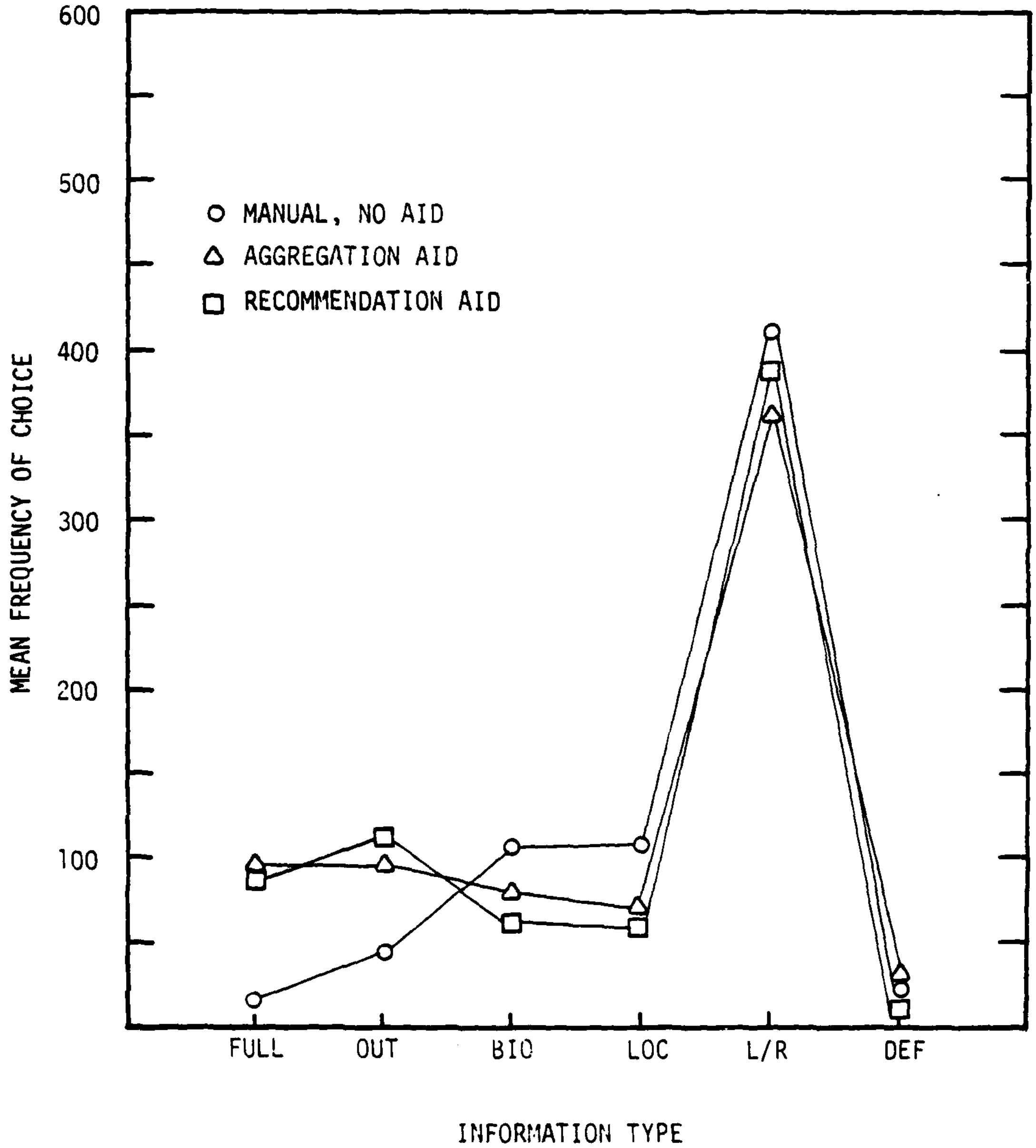


FIGURE 4-7.
INFORMATION CHOICE DISTRIBUTIONS FOR THE THREE SELECTION MODES

across the subjects. The aided (aggregation and recommendation) selections exhibited more diverse use of high-detail/high-cost information such as Full and Outline information than unaided selections. The lack of use of the high-detail/high-cost information in the unaided selections may be due to the subjective emphasis on some sub-optimal objectives.

Subjects' policy in information selection can be observed via the averaged importance weights they placed on the attribute vector, i.e., the cost, delay, detection, loss and gain factors. The averaged policies of the subjects in three aiding modes are shown in Figure 4-8. While the profiles of the three modes are quite similar, the subjects in aided modes appeared to place a greater emphasis on cost (A_1) and aggresive gain (A_5) than they did in the unaided modes. The averaged policies of the subjects in two levels of threat arrival rate are also shown in Figure 4-9. The subjects in low stress situations appeared to place a greater emphasis on communication cost, (A_1), time delay (A_2) and aggresive gain (A_3) than they did in the high stress situations.

In order to ascertain the effect of the aiding mode, speed stress and tactical phase on the subject's policy, a multivariate analysis of variance was performed. The Pillais multivariate test for significance showed a significant effect of mode by speed by phase (df. 4,198, approx. $f = 1.8$, $p < 0.015$). Examination of the univariate f tests indicate that the greatest effect was with cost (df. 4,198, $F = 6.18$, $p < .0001$) and time delay (df. 4,198, $F = 2.98$, $p < .02$), which substantiates the observation that the subjects had placed extra emphasis on these two factors. Multivariate analyses were also performed to examine the effects of specific combinations of mode, speed and phase. These tests show significant differences in policy among aiding modes, tactical phases, and between stress conditions. (MANOVA tables appear in Appendix IV.)

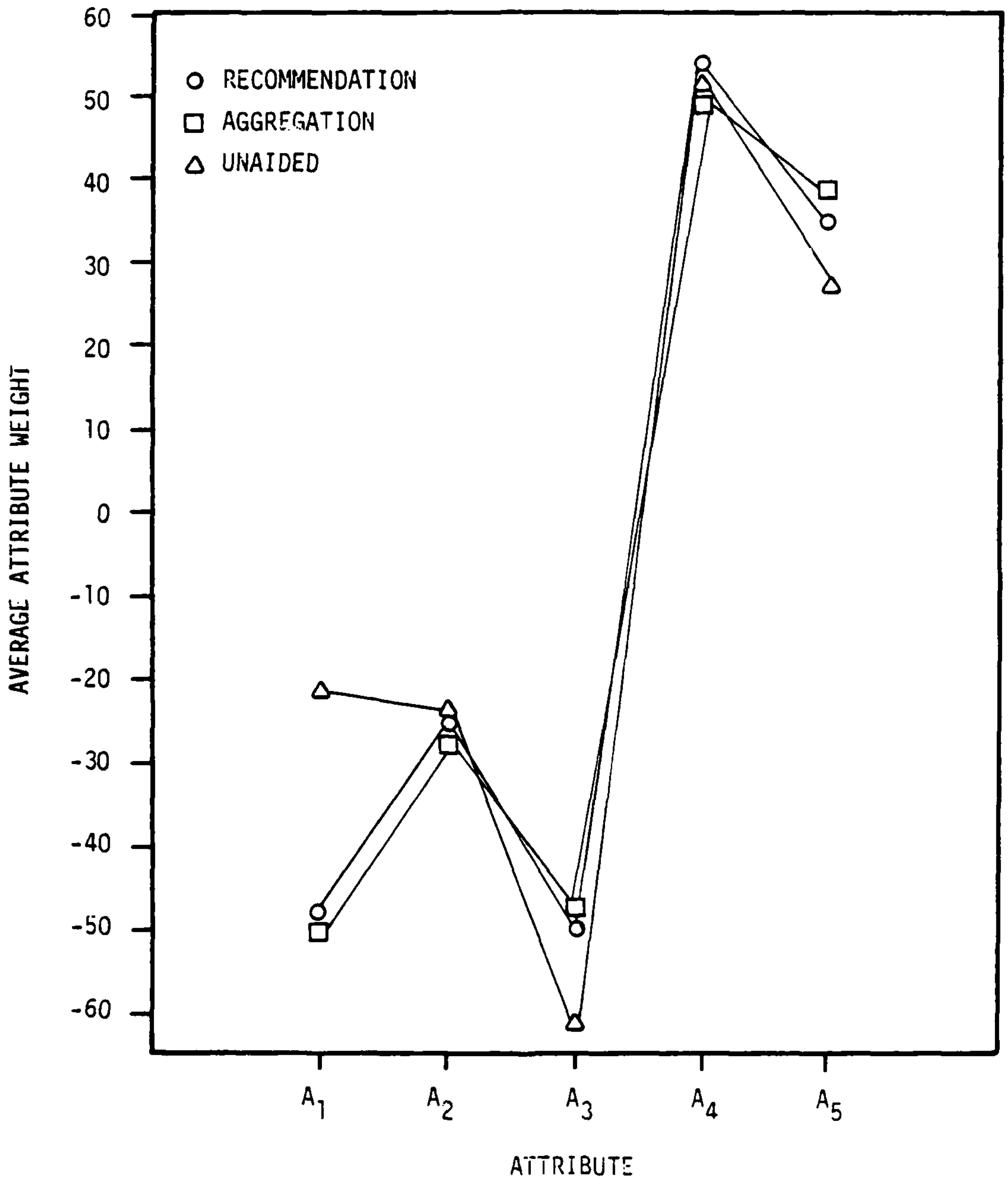


FIGURE 4-8.
AVERAGE ATTRIBUTE PROFILES FOR THE
THREE SELECTION MODES

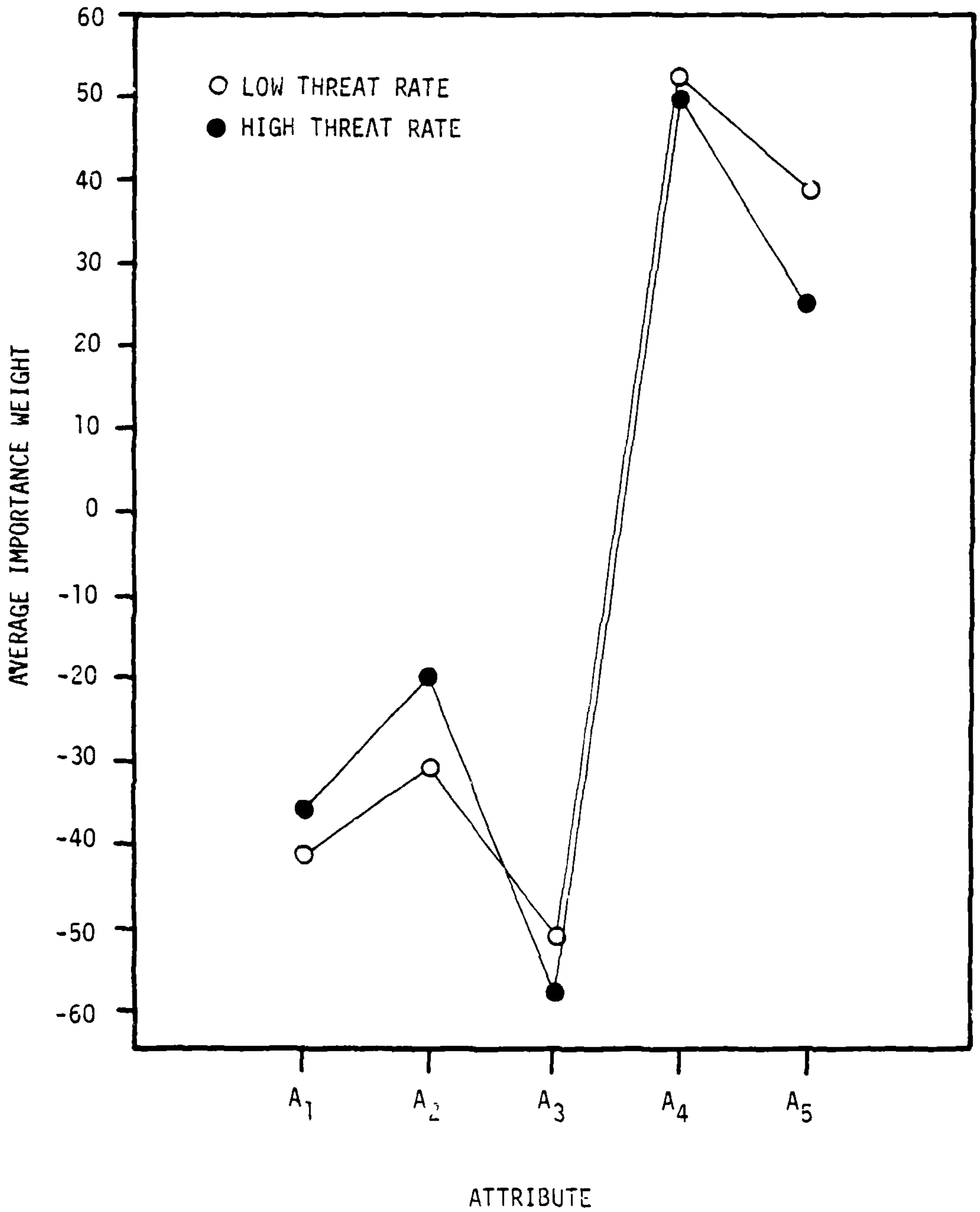


FIGURE 4-9.
AVERAGE ATTRIBITE PROFILES FOR THE TWO THREAT RATES

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Value-Based Model of Information Handling Tasks

The present study demonstrates the potential of on-line, value-based modeling techniques for information source selection in continuous information handling tasks. The techniques employ the multi-attribute utility model to represent the prescriptive aspect and the queueing model to represent the descriptive aspect of the information handling situation. The current year study has used the queueing model as a framework to evaluate the value-based model in a continuous decision and control environment, where the operator is required to make complex and timely decisions regarding information and control options. The model was shown to be useful for capturing, analyzing and assisting the operator's information handling policy.

The experimental studies demonstrated the effectiveness of aiding based on the time-continuous, value-based model of information handling. In terms of performance score, the aiding of model recommendation and parameter aggregation was more effective than the aiding of parameter aggregation alone, and the improvement over unaided situations was substantial in both high and low rate conditions. In support of this, subjects perceived the effectiveness of and expressed the desirability for the aiding, although both aiding conditions had imposed extra loading over the subjects.

In general, the addition of model recommendation was not perceived by the subjects as desirable in the aiding of data aggregation alone. This was due to the frequent requirements of operator overrides in the initial model-training period. It is possible, however, to separate the training periods from the experiment sessions, so that the model recommendation can be better perceived to be "in-tune" with the subjects' own preference. On the other hand, increased accuracy of model recommendation is also possible. The probability estimation programs were frozen throughout the experimental sessions and the attribute weights were reassigned to be unified in the beginning of each phase. Dynamic estimation of outcome probabilities specific to each subject should improve the accuracy of the attribute level estimates and, in turn, result in better information recommendations. Similarly, allowing the continued use of trained weights could update the convergence of weight vector, reduce the model training period, and provide more coherent recommendations.

5.2 Management of Information Handling

The availability of a methodology for quantitative representation of both descriptive and prescriptive aspects of operator information handling opens up the possibility of managing automated sensor-based systems through supervisory man-machine systems; where event sensing, data aggregation, source selection are performed by the machine and problem recognition, event selection, and consequence evaluation are jointly performed by the operator and the adaptive models. Of course, the adaptive modeling approach is not preferred for all aspects of information management. These techniques are specific to the tasks that require complex, subjective, recurrent, and stressed decisions. Therefore, the approach is most applicable to information handling that features some or all of the following operational characteristics:

(1) High Information Load. The operator is in a time-stressed decision task. For each decision he can process only a portion of the available data set and must choose an action within a short time.

(2) Costly Information Transmission. The transmission of data to the operator is subject to cost, risk of detection, or limited transmission capabilities. Immediately valuable information must be selected.

(3) Significant Judgmental Factors. The decision maker must consider the credibility and content of the evidence along with the probabilities and utilities of the consequences associated with each ensuing action.

(4) Multiple Competing Information Sources. A variety of different systems or sensors must be monitored, and each unattended system increases in uncertainty over time.

Among the examples of actual military decision making situations that require such tasks are: (1) supervisory control and decision making in advanced aircraft; (2) air traffic control; (3) remotely piloted vehicle guidance; (4) satellite intelligence coordination; (5) supervision of air, ground, or sea support operations.

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APPENDIX I

EXPERIMENTAL APPARATUS AND SOFTWARE

APPENDIX I

EXPERIMENTAL APPARATUS AND SOFTWARE

The experimental situation is generated by a PDP-11/45 driven multiple-display system which included a Genesco Model GCT-300 programmable color grap system with eight color, 480-640 raster, high speed full graphic display monitor. Also included are the programmable control and selection console, consisting of special-purpose keypad and X-Y joystick interface. The individual hardware components are illustrated as follows:

(1) Computer: A DEC PDP-11/45 with UNIX operating system is used to load and executes the software programs.

(2) Graphic System: The Genisco GCT-3000 color graphic system generates, updates and displays the scenario in real time.

(3) Programmable Control Console: This unit, containing (a) an 8-key programmable control panel and (b) a spring-centered X-Y joystick, is a microprocessor-based intelligent terminal, which polls the subject's inputs, reflects the computer's decision and converts the analog signal of the joystick (using a multiplexed A/D converter). The unit is specificially designed to support the experimental study. It provides two-way sampled signal, power, clock signal, logic-level buffering and conversion. This is shown in the functional block diagram of Figure I-1.

(4) Secondary Display: A CRT terminal is used to display and update the subsystem task status indicators under the control of the computer, and reports the subject's actions back to the computer.

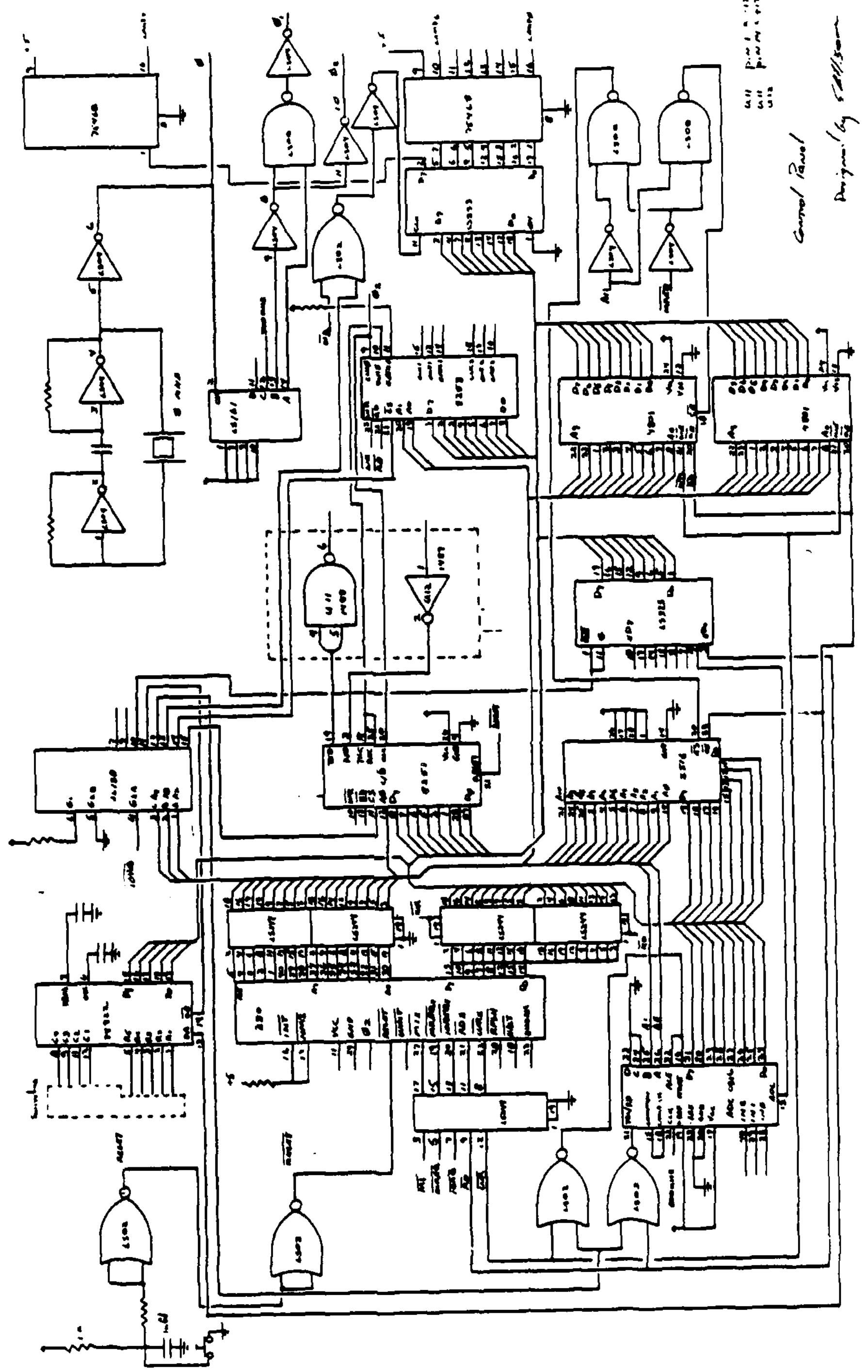

FIGURE I-1.
PROGRAMMABLE CONTROL/DECISION INTERFACE
SCHEMATIC ORGANIZATION

The software was developed based upon the structural programming technique of the C language. Figure I-2 presents a flow chart of the main control software, and the organization of major subroutines, which are described as follows:

MAIN -- This routine monitors and controls the overall system logic flow, and calls all subroutines in a pre-defined sequence. The real-time process queue and interrupt structure is also implemented in the MAIN program.

INITIALIZATION -- This program handles (a) session intialization and (b) phase initialization.

REPORT -- Phase and session reports are generated and stored in the data file for the off-line data analysis and reporting.

SCENARIO -- The real-time presentation and updates of the scenario are made by replacing the outgoing portions of the continuous target paths/terrain with a new incoming target path/terrain on the top part of the display. The messages are also updated accordingly.

MAU -- The MAU model generates the state and the information probabilities, and calculates the attributes. Based upon the highest MAU, the model makes both messages and action recommendations for the next move.

ADJUSTMENT -- The utility weights are adaptively adjusted based upon the subject's decisions and actions.

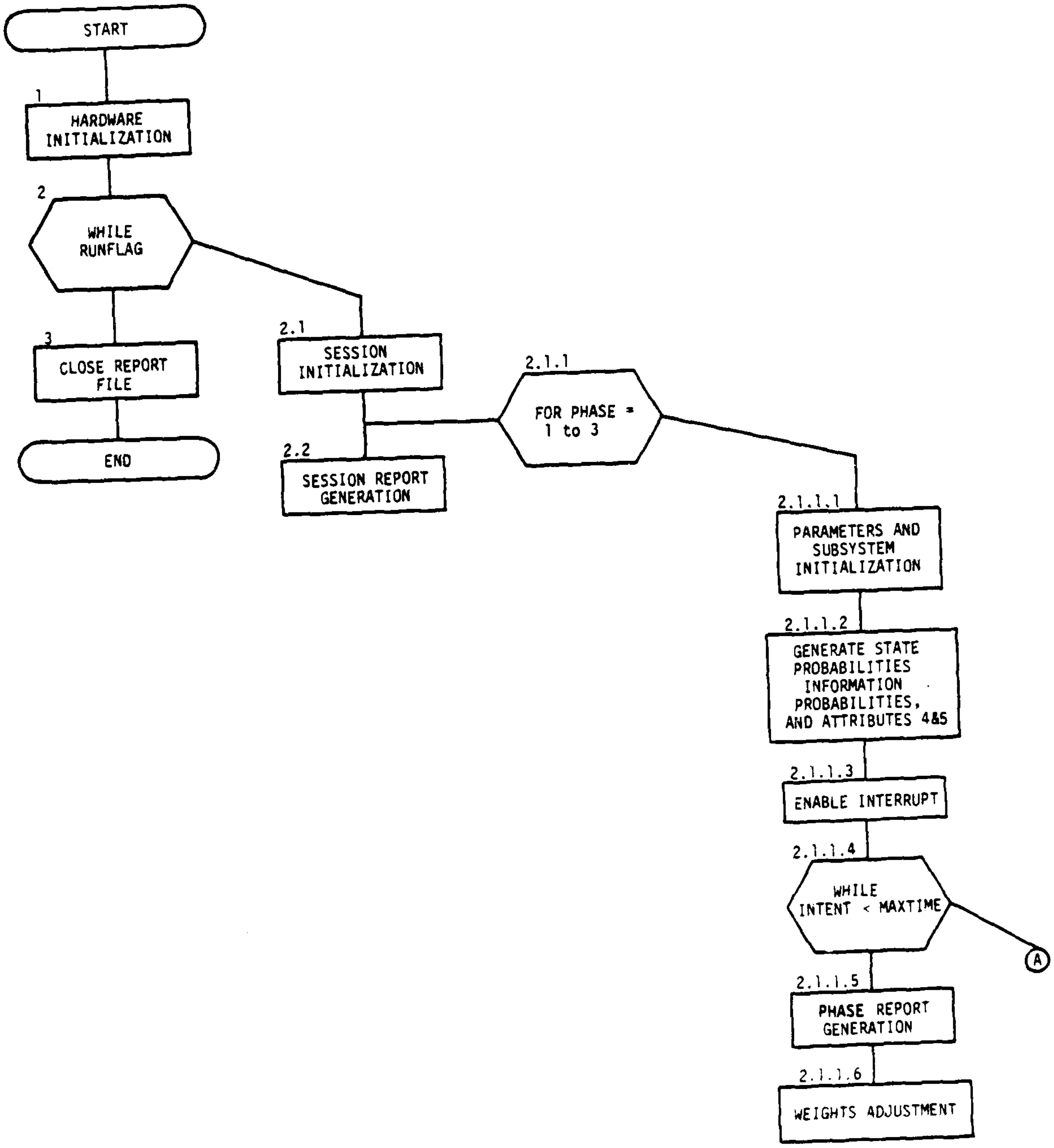

FIGURE I-2.
EXPERIMENTAL SITUATION SOFTWARE PROGRAM ORGANIZATION

AD-A119 067   PERCEPTRONICS INC WOODLAND HILLS CA   F/G 1/3
ANALYSIS AND MODELING OF INFORMATION HANDLING TASKS IN SUPERVIS--ETC(U)
MAY 82 Y CHU, K CHEN, C CLARK, A FREEDY   F49620-79-C-0130
UNCLASSIFIED   PFTR-1080-82-5   NL

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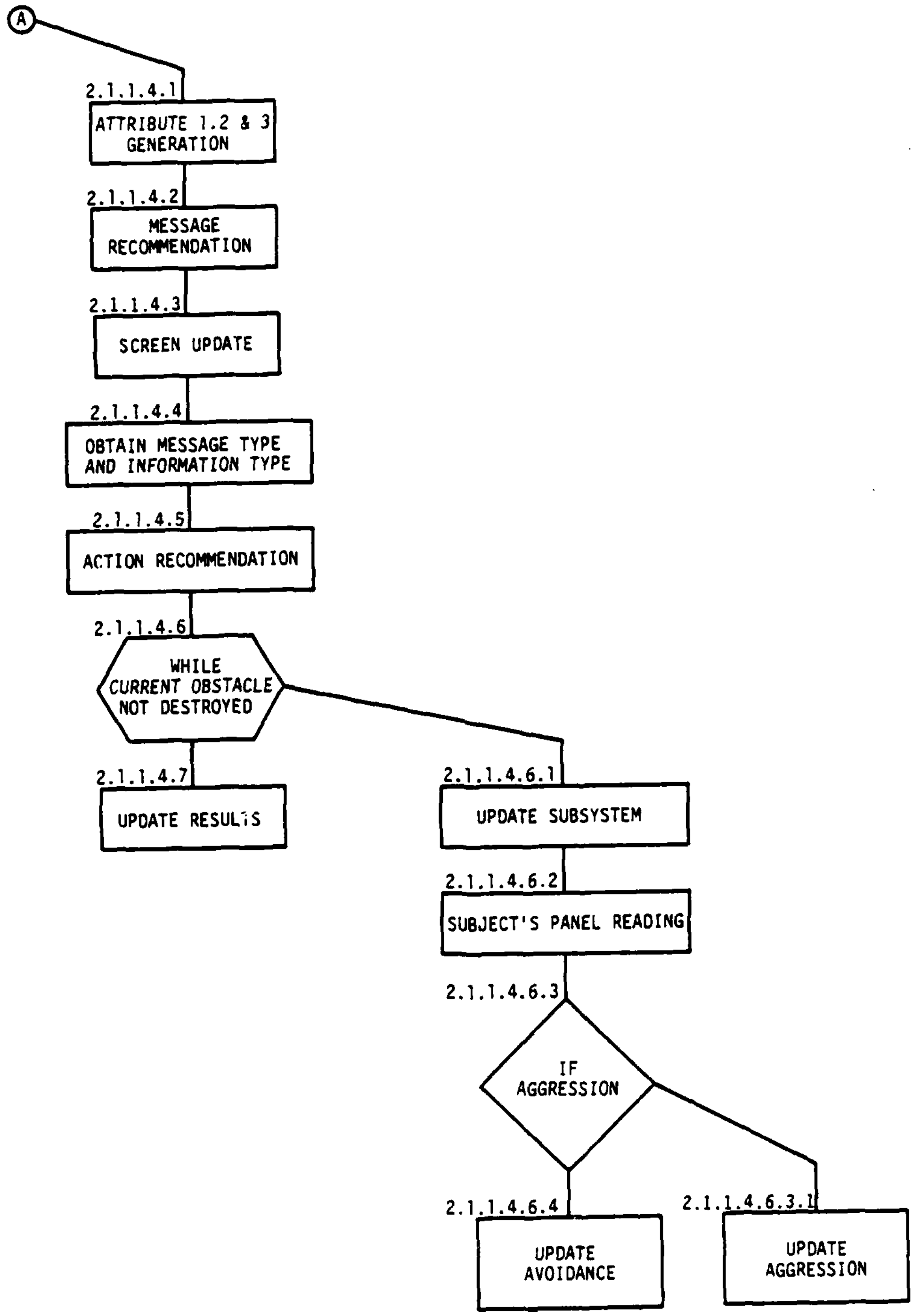

FIGURE I-2. (Continued)

The flight information handling simulation and model-based aiding algorithm plus data collection routine, running under UNIX operating system, requires approximately 74K bytes of core. The program flow including threat assessment and computer aiding is as follows.

First, the sytem is initialized. The experimenter interactively specifies the task conditions and experiment identification to the computer. The appropriate disk file (prepared beforehand) is read in, which contains all the information needed by the simulation program to generate the proper target type display and subsystem event arrivals. (The task is mainly specified by the contents of this disk file, so that experimental conditions can easily be changed.) The data file in which sampled data is to be stored is opened and the time and date are recorded.

The program then enters the main iteration loop for three tactical phase and for the given time period. The program then first updates the attribute weight and attribute level evaluation, the information value and provide message recommendation. During the loop, the program also waits for keyboard/control response from the subject. For example, when a response is made, and a subsystem selected for diagnostic action, one of two things can happen. If no event has occurred in the selected subsystem, a false alarm has been made, and the loop is begun again. If an event has occurred in the sybsystem, the checklist diagnostic procedure is begun. If the subject makes an incorrect response in the checklist procedure, the main loop is immediately restarted. Otherwise, after the response to the event is correctly completed, the subsystem pointer is redrawn (upward), and another event is scheduled for that subsystem, before the loop is restarted.

As the main iteration loop is being executed, the real-time clock is running, and checks are made frequently to determine if it is time to perform a system states and status update. Update of the simulation state is made every 0.50 second. Several things happen during a simulation update. First, a data sample is taken, and stored on the PDP-11 disk. The states of target, own vehicle and the status of each subsystem, control inputs and keyboard responses, and the states of the own vehicle dynamics are sampled. Also included are computer aiding status in the aided session.

Next, a schedule of events is checked, and if an event is to occur at the present time or if a keyboard input is received, the corresponding subsystem indicator is redrawn (downward) on the display.

The threat neutralization procedure is then performed. The positions of the targets are updated, and redrawn on the display. The subject's action decision is examined and outcome determined, and displayed. At this point, the simulation update is complete, and the main iteration loop is resumed.

When the subject has flown over the three-phase mission, the simulation ends. At this time, information such as starting and finishing time of the trial, subject name, experiment identification, date, and subjective pilot comments are recorded in the data file.

APPENDIX II

SUBJECTS' INSTRUCTIONS

APPENDIX II

SUBJECTS' INSTRUCTIONS

This experiment is part of a program of continuing research at Perceptronics in human decision making and information handling. The purpose of this particular experiment is to analyze ways in which a human operator handles multiple information demands and how a computer might aid a human operator in operating a simulated aircraft. You are an integral part of this research since your performance provides the baseline data for predicting overall man-machine system performance and estimating the effectiveness of various aiding techniques.

Task

The primary task is one of navigating a simulated aircraft through a changing, hazardouz environment. The environment contains threats of uncertain form and extent. At each threat, you must either take an avoidance action or an agressive action. The identity and location of the obstacles can be determined by requesting different types of information. The different types of information vary in cost and content. The secondary task is to monitor a subsystems display which simulates status indicators of aircraft functions and interactive check-list procedures which correct malfunctions.

Displays and Controls

The environment and the vehicle are shown as in a moving-map display where incoming threats appear at random, presented with symbol "D" at the upper edge of the screen, and move downward at a constant velocity. You can move the vehicle symbol horizontally to avoid the obstacles, or to fire at the nearest threat. Your range of fire is indicated by 1/3 of dashes (-) placed at the extreme right and left of the screen (see Figure 1).

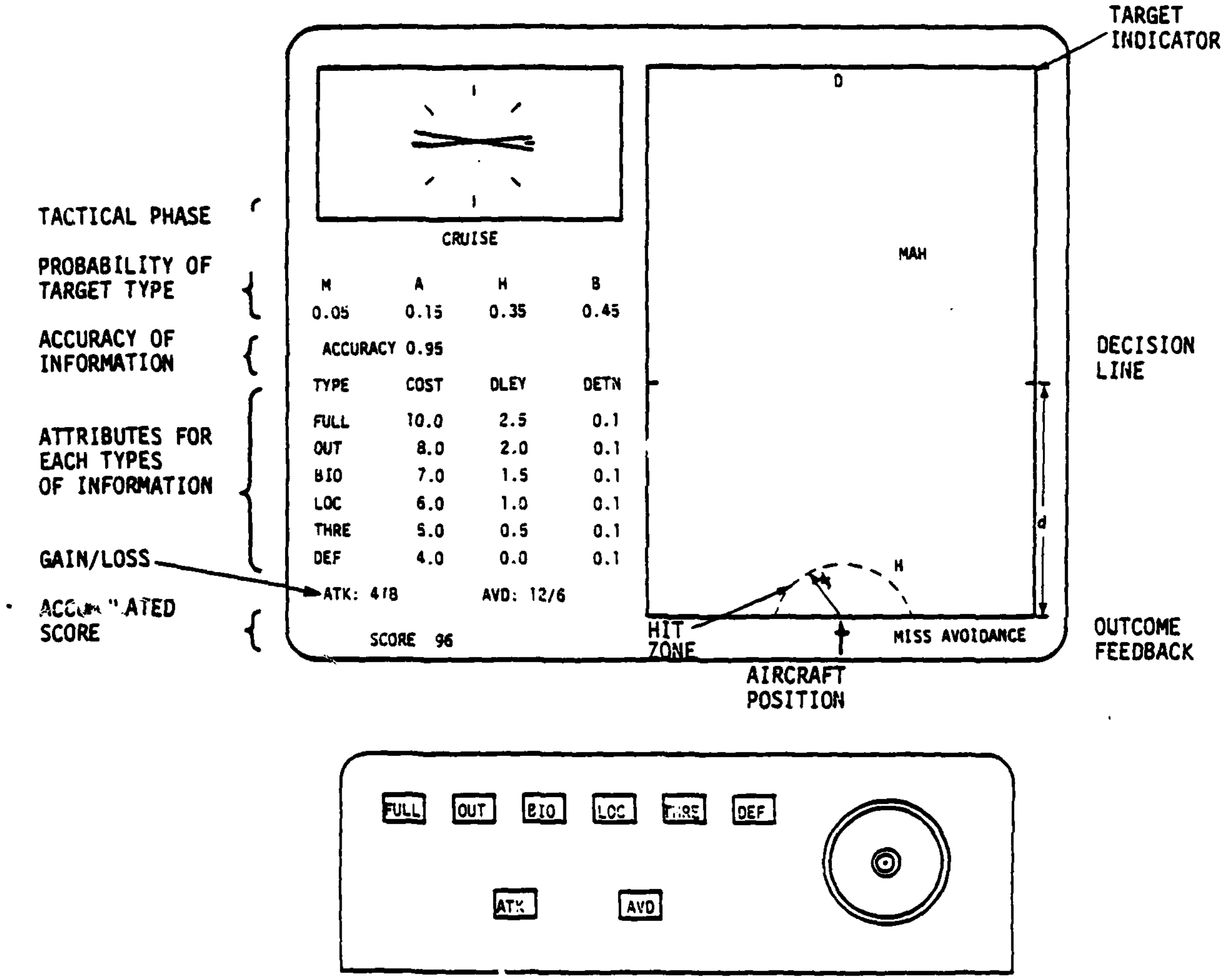

FIGURE II-1.
MAP SITUATION AND OUTCOME DISPLAY

The threats introduce uncertainty to the task. Each type of obstacle has a probability distribution of avoidance. The first obstacle is a helicopter (H). If you pass close to it there is a high probability of damage. The second threat is an aircraft (A), which has a wide area of danger. Again, a pass close to it should be avoided. The third threat is a missile (M), which is safe close to it but not safe far away. Often, it is best to fly through or around it. The fourth symbol, a *bird (B), is a non-dangerous object.* *It cannot damage you and cannot be shot down* (see Figure 2).

After reviewing the mission situation display, and before selecting information, you may decide on taking one of the following actions:

(1) Avoidance - try to avoid the damage; the results will be 'avoid' or 'damage'.
(2) Aggression - try to hit; the results will be 'hit and avoid', 'miss and avoid', and 'miss and damage'.

If no action is taken, avoidance is assumed. The amount of gain and loss (and thus the score) depend on the information costs and payoffs for Successful/Unsuccessful Avoidance and Successful/Unsuccessful Aggression. Payoffs will vary from phase to phase.

The task consists of a series of three phases of aircraft missions: cruise, surveillance, and aggression. Threat probability and payoffs will vary among phases. For example, there is a high probability of a bird in the cruise phase and a high probability of a missile in the aggression phase. To make an information selection, you can press one of the buttons on the control panel. If 'full' information is selected, the differentiated symbols in their proper location will move down the screen. If "outline" information is selected, the missile and bird

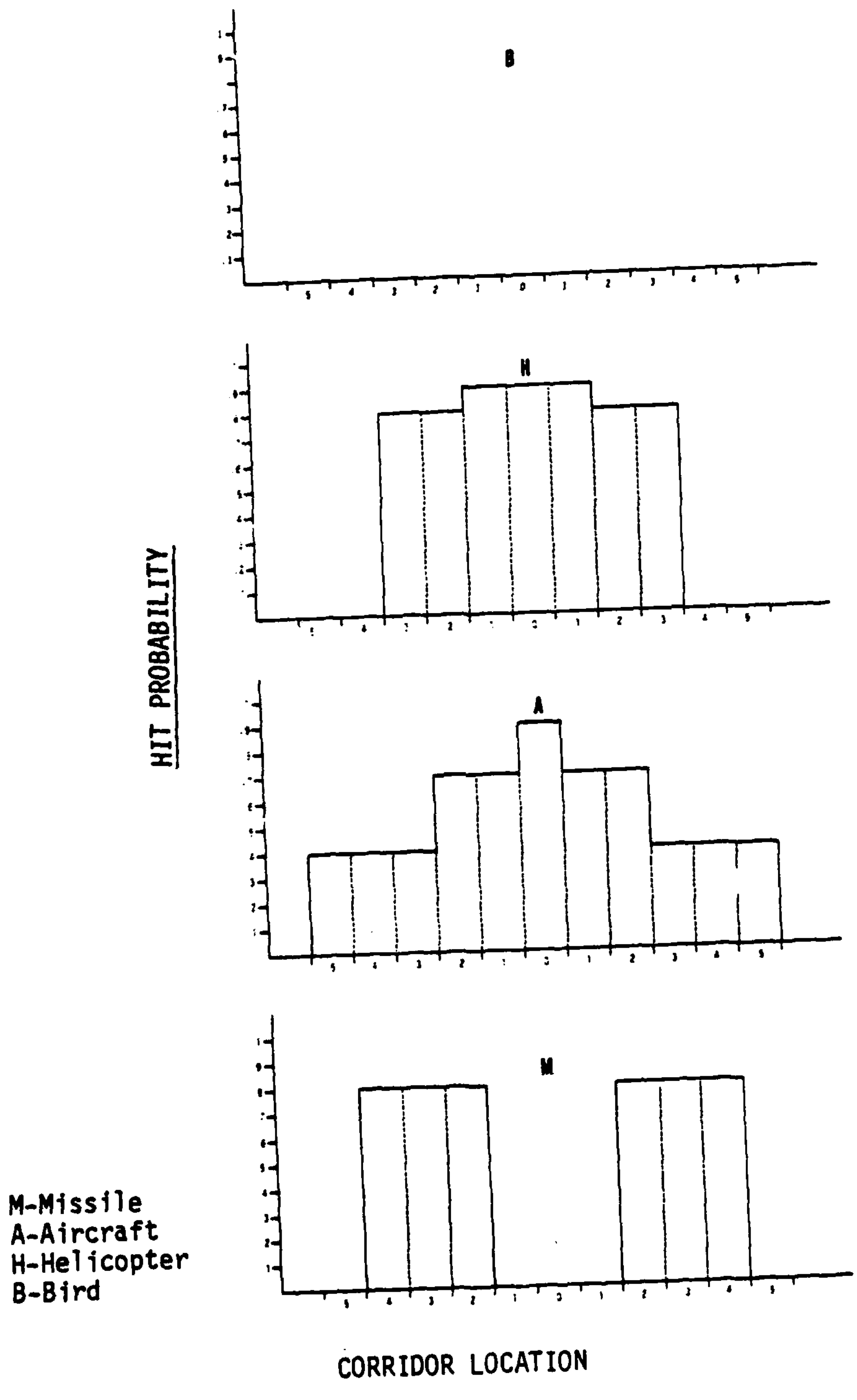

FIGURE II-2.
THREAT CHARACTERISTICS

symbols will be differentiated, but helicopters and airplanes will be represented by a single, non-differentiating symbol (A). Similarly, "biological" information will use a single, non-differentiated symbol, (MAH) to represent either missile, airplane, or helicopter. "Location" information provides no discrimination. A symbol (X) denotes the location but not the identity of threats. "Threat" information discriminates the obstacles using the standard symbols, but locates them only as lying in the left or fight half of the screen. "Default" information gives no target identity nor target location (see Table 1).

Situational Display. The stages of an aircraft mission can be characterized by such factors as danger, difficulty, system reliability, and communications security. The situational conditions that vary among phases are:

(1) Degree of danger - this is the distribution of possible threats in a given phase. A different set of probabilities of the 4 threat types is assigned to each phase.

(2) Information accuracy - a percentage of information transmissions are inaccurate through having random numbers added to location content. This indicates the possibility of the location being unpredictable.

(3) Payoffs - different payoffs in points are made for avoidance of or damage sustained from the threats, and/or for successful or unsuccessful aggression actions toward the threats. Each of the payoffs will vary phase-by-phase. Your payoff for successful and unsuccessful actions are presented by two numbers with a slash between them, for example: 12/6. The first number adds to your score (if successful) while the second number subtracts from your score (if unsuccessful).

TABLE II-1

INFORMATION SOURCE CHARACTERISTICS

Information Type	Discrimination	Location	Symbols
1. Full	All	All	M, A, H, B
2. Outline	All but Airplane/ Helicopter	All	M, AH, B
3. Biological	Bird Only	All	MAH, B
4. Location	None	All	X
5. Left/Right	All	Left/Right	M, A, H, B
6. Default	None	None	D

The situational conditions that vary within a phase are:

(4) Costs - a different cost is assigned to each information choice. This is the number of points that the information costs.

(5) Delay - the delay in half seconds before actual display of the selected information. This is equivalent to the portion of the distance the default symbol travels before the "true" symbol is displayed.

(6) Detection - the increased danger on the succeeding decision due to the use of a given information source. A .10 detection means that a damage will increase by 10% on next decision.

Your score is updated based on the payoff and cost incurred in your decision, i.e., Added Score = Payoffs - Cost. For example, in Figure 1, if the outcome is Miss and Avoid by using Full information, the added score is -8 + 12 - 10 = -6. Therefore, sound selection and tradeoffs between potential payoffs, cost, delay, accuracy and detection are required to achieve high score. In some sessions, computed recommendation on selection will be provided. You may accept or override the recommendation by pressing the buttons, otherwise, the default information and/or the recommended action will be taken by the system.

Subsystem Tasks. The subsystem task requires the operator to monitor the top-level subsystem processes to detect possible events (i.e., "0" symbols) and to act to bring the process into operational status (i.e., "1" symbols). If the operator thinks process 6 is down, he may press "6" on the keypad and the display of next level appears. The display may then show that branch 3 is "down" and a press of key "3" will lead to the display of next level, where the branch "4" is "down," etc. He continues until all branches are "up" whereupon process 6 is "up" again.

Speed and errors will be recorded on performance data. When the incorrect key is pressed an error will be registered in the system while the display status remains unchanged. Remember, it is assumed that the subsystem 1 has the highest priority and subsystem 6 has the lowest. Your overall performance will be evaluated based on the total score achieved in the primary task as well as the speed and errors in the secondary tasks.

APPENDIX III

SUBJECTIVE RATING QUESTIONNAIRE

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SUBJECTIVE RATING QUESTIONNAIRE

At the end of each experimental run, an appropriate version of rating questionnaire shown in Figure III-1 was giv ˀ to the subject. On the rating scale following each question, subjects made a mark indicating their perception of relative effort and quality of computer aiding. These ratings were then quantified and scaled for statistical analysis. Subject's comments were also summarized.

AUTO

Below you will find several questions pertaining to the computer aided task you have just completed. Underneath each question is a line with 5 classifications. Please place a slash at the point you feel best classifies the question. It is not necessary to mark directly at a classification point unless you feel it is appropriate. For example:

How comfortable was the temperature of the room?

very	cool	comfortable	warm	very warm

Her the slash is placed <u>between</u> comfortable and warm, indicating that the room temperature was approximately halfway between comfortable and warm.

If you do not understand the instructions, please ask the experimenter to clarify them. If you do not have any questions then please begin:

1. What effect do you think computer recommendation had in the overall performance?

large degradation	modest degradation	slight degradation	no effect	slight improvement	modest improvement	large improvement

2. How desirable did you find the computer recommendation?

definitely don't like it	somewhat undesirable	doesn't matter	somewhat desirable	definitely desirable

3. How easy was it to use the computer recommendation?

very difficult	difficult	reasonable	easy	very easy

4. Did you feel the recommendations gave you a sense of control in handling the situations?

not at all	somewhat	moderate	more than usual	very much

5. How satisfied were you with the quality of the information recommendation?

not at all	somewhat	moderate	more than usual	very much

FIGURE III-1.
SUBJECTIVE RATING QUESTIONNAIRE

6. What level of effort and/or attention did you have to expend?

very low	low	moderate	high	very high

7. How complicated or difficult is the task?

extremely simple	simple	moderate	complicated	extremely complicated

8. General observations and/or additional comments.

FIGURE III-1. (Continued)

APPENDIX IV

ANALYSIS OF VARIANCE

APPENDIX IV

ANALYSIS OF VARIANCE

Two sets of analyses of variance based on the data for twelve subjects was conducted. The first set consists of repeated-measures ANOVA for task performance measures and subjective ratings, to be presented in Table IV-1 through IV-7. The second set consists of the MANOVA on the attribute weight vector. The results of the analysis are presented in Table IV-8 with the statistics for each effect given separately.

TABLE IV-1

ANOVA ON PERFORMANCE SCORE

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	50753728.00	1	50753728.00	702.57	0.000
ERROR	794637.12	11	72239.68		
M (MODE)	960870.00	2	480435.00	112.10	0.000*
ERROR	94284.00	22	4285.63		
S (SPEED)	5116385.00	1	5117385.00	473.04	0.000*
ERROR	118999.62	11	10818.14		
MS	96370.62	2	48185.31	16.96	0.000*
ERROR	62507.58	22	2841.25		

TABLE IV-2

ANOVA ON SUBSYSTEM WAITING TIME

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	30243.55	1	30243.55	31.90	0.000
ERROR	10427.66	11	947.96		
M (MODE)	11.01	2	5.50	0.31	0.733
ERROR	384.75	22	17.48		
S (SPEED)	1397.17	1	1397.17	9.51	0.010*
ERROR	1616.89	11	146.99		
MS	77.81	2	38.90	0.77	0.476
ERROR	1115.91	22	50.72		

TABLE IV-3

ANOVA ON SUBJECTIVE RATINGS OF EFFORT

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	4948.45	1	4948.45	212.52	0.000
ERROR	256.12	11	23.28		
M (MODE)	28.41	2	14.20	2.05	0.153
ERROR	152.53	22	6.93		
S (SPEED)	79.48	1	79.58	20.46	0.001*
ERROR	42.78	11	3.88		
MS	0.75	2	0.37	0.12	0.884
ERROR	66.85	22	3.03		

TABLE IV-4

ANOVA ON SUBJECTIVE RATINGS FOR THE EASE OF USE OF COMPUTER AIDING

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	5557.73	1	5557.73	488.29	0.00
ERROR	125.20	11	11.38		
M (MODE)	0.00	1	0.00	0.00	0.986
ERROR	63.60	11	5.78		
S (SPEED)	12.91	1	12.91	8.83	0.013*
ERROR	16.09	11	1.46		
MS	2.66	1	2.66	1.16	0.305
ERROR	25.23	11	2.29		

TABLE IV-5

ANOVA ON SUBJECTIVE RATINGS OF DESIRABILITY OF COMPUTER AIDING

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	5135.66	1	5135.66	287.08	0.000
ERROR	196.78	11	17.88		
M (MODE)	216.32	1	216.32	56.57	0.000*
ERROR	42.06	11	3.82		
S (SPEED)	11.11	1	11.11	2.09	0.176
ERROR	58.46	11	5.31		
MS	0.04	1	0.04	0.02	0.897
ERROR	29.30	11	2.66		

TABLE IV-6

ANOVA ON SUBJECTIVE RATINGS OF AIDING EFFECTIVENESS

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	4681.87	1	4681.87	129.90	0.000
ERROR	396.46	11	36.04		
M (MODE)	279.51	2	139.75	5.27	0.014*
ERROR	583.67	22	26.53		
S (SPEED)	1.62	1	1.62	0.21	0.654
ERROR	84.15	11	7.65		
MS	15.86	2	7.93	1.08	0.357
ERROR	161.63	22	7.34		

TABLE IV-7

ANOVA ON SUBJECTIVE RATINGS
OF TASK DIFFICULTY

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	4054.49	1	4054.49	160.22	0.00
ERROR	278.35	11	25.30		
M (MODE)	12.78	2	6.39	1.32	0.289
ERROR	106.89	22			
S (SPEED)	38.57	1	38.57	17.13	0.002*
ERROR	24.76	11	2.25		
MS	4.82	2	2.41	2.01	0.157
ERROR	26.36	22	1.19		

TABLE IV-8

MANOVA ON THE ATTRIBUTE WEIGHT VECTOR

* A N A L Y S I S   O F   V A R I A N C E * * * * * * *

EFFECT .. MODE BY SPEED BY PHASE

MULTIVARIATE TESTS OF SIGNIFICANCE (S = 4, M = 0, N = 96)

TEST NAME	VALUE	APPROX. F	HYPOTH. DF	ERROR DF	SIG. OF F
PILLAIS	.17764	1.83112	20.00	788.00	.015
HOTELLINGS	.19565	1.88315	20.00	770.00	.011
WILKS	.83002	1.86158	20.00	644.38	.015
ROYS	.11823				

UNIVARIATE F-TESTS WITH (4,198) D. F.

VARIABLE	HYPOTH. SS	ERROR SS	HYPOTH. MS	ERROR MS	F	SIG. OF F
ATTRIB1	.16153	1.29318	.04038	.00653	6.18290	.000
ATTRIB2	.12616	2.09841	.03154	.01060	2.97610	.020
ATTRIB3	.16350	6.30078	.04087	.03182	1.28445	.277
ATTRIB4	.03016	4.23385	.00754	.02138	.35266	.842
ATTRIB5	.04479	3.80107	.01120	.01920	.58322	.675

EFFECT .. SPEED BY PHASE

MULTIVARIATE TESTS OF SIGNIFICANCE (S = 2, M = 1, N = 96)

TEST NAME	VALUE	APPROX. F	HYPOTH. DF	ERROR DF	SIG. OF F
PILLAIS	.32126	7.46329	10.00	390.00	0.0
HOTELLINGS	.41116	7.93536	10.00	386.00	0.0
WILKS	.69624	7.69993	10.00	388.00	0.0
ROYS	.25177				

UNIVARIATE F-TESTS WITH (2,198) D. F.

VARIABLE	HYPOTH. SS	ERROR SS	HYPOTH. MS	ERROR MS	F	SIG. OF F
ATTRIB1	.10204	1.29318	.05102	.00653	7.81140	.001
ATTRIB2	.20815	2.09841	.10407	.01060	9.82001	.000
ATTRIB3	.19791	6.30078	.09896	.03182	.10970	.047
ATTRIB4	.18731	4.23385	.09365	.02138	4.37983	.014
ATTRIB5	.12107	3.80107	.06053	.01920	3.15324	.045

EFFECT .. MODE BY PHASE

MULTIVARIATE TESTS OF SIGNIFICANCE (S = 4, M = 0, N = 96)

TEST NAME	VALUE	APPROX. F	HYPOTH. DF	ERROR DF	SIG. OF F
PILLAIS	.39758	4.34841	20.00	788.00	0.0
HOTELLINGS	.49557	4.76983	20.00	770.00	0.0
WILKS	.64226	4.60139	20.00	644.38	0.0
ROYS	.23007				

UNIVARIATE F-TESTS WITH (4,198) D. F.

VARIABLE	HYPOTH. SS	ERROR SS	HYPOTH. MS	ERROR MS	F	SIG. OF F
ATTRIB1	.27546	1.29318	.06887	.00653	10.54407	.000
ATTRIB2	.21962	2.09841	.05490	.01060	5.18065	.001
ATTRIB3	.73556	6.30078	.18389	.03182	5.77870	.000
ATTRIB4	.59242	4.23385	.14810	.02138	6.92622	.000
ATTRIB5	.23068	3.80107	.05767	.01920	3.00406	.020

TABLE IV-8 (Continued)

EFFECT .. MODE BY PHASE (CONT.)

EFFECT .. PHASE

MULTIVARIATE TESTS OF SIGNIFICANCE (S = 2, M = 1, N = 96)

TEST NAME	VALUE	APPROX. F	HYPOTH. DF	ERROR DF	SIG. OF F
PILLAIS	1.03531	41.85489	10.00	390.00	0.0
HOTELLINGS	2.23513	43.13802	10.00	386.00	0.0
WILKS	.22778	42.49634	10.00	388.00	0.0
ROYS	.58747				

UNIVARIATE F-TESTS WITH (2,198) D. F.

VARIABLE	HYPOTH. SS	ERROR SS	HYPOTH. MS	ERROR MS	F	SIG. OF F
ATTRIB1	.76778	1.29318	.38389	.00653	58.77794	0.0
ATTRIB2	.68347	2.09841	.34174	.01060	32.24532	0.0
ATTRIB3	.59460	6.30078	.29730	.03182	9.34261	.000
ATTRIB4	3.47722	4.23385	1.73861	.02138	81.30782	0.0
ATTRIB5	1.74443	3.80107	.87221	.01920	45.43411	0.0

EFFECT .. MODE

MULTIVARIATE TESTS OF SIGNIFICANCE (S = 2, M = 1, N = 96)

TEST NAME	VALUE	APPROX. F	HYPOTH. DF	ERROR DF	SIG. OF F
PILLAIS	.79390	25.67132	10.00	390.00	0.0
HOTELLINGS	3.64301	70.31009	10.00	386.00	0.0
WILKS	.21373	45.12584	10.00	388.00	0.0
ROYS	.78417				

UNIVARIATE F-TESTS WITH (2,198) D. F.

VARIABLE	HYPOTH. SS	ERROR SS	HYPOTH. MS	ERROR MS	F	SIG. OF F
ATTRIB1	3.67601	1.29318	1.83801	.00653	281.41810	0.0
ATTRIB2	.00527	2.09841	.00263	.01060	.24852	.780
ATTRIB3	1.11787	6.30078	.55894	.03182	17.56435	.000
ATTRIB4	.34845	4.23385	.17422	.02138	8.14775	.000
ATTRIB5	.89842	3.80107	.44921	.01920	23.39952	0.0

EFFECT .. SPEED

MULTIVARIATE TESTS OF SIGNIFICANCE (S = 1, M = 1 1/2, N = 96)

TEST NAME	VALUE	APPROX. F	HYPOTH. DF	ERROR DF	SIG. OF F
PILLAIS	.36713	22.50812	5.00	194.00	0.0
HOTELLINGS	.58011	22.50812	5.00	194.00	0.0
WILKS	.63287	22.50812	5.00	194.00	0.0
ROYS	.36713				

UNIVARIATE F-TESTS WITH (1,198) D. F.

VARIABLE	HYPOTH. SS	ERROR SS	HYPOTH. MS	ERROR MS	F	SIG. OF F
ATTRIB1	.30827	1.29318	.30827	.00653	47.19888	0.0
ATTRIB2	.65230	2.09841	.65230	.01060	61.54927	0.0
ATTRIB3	.43023	6.30078	.43023	.03182	13.51982	.000
ATTRIB4	.00167	4.23385	.00167	.02138	.07794	.780
ATTRIB5	.88039	3.80107	.88039	.01920	45.85995	0.0

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