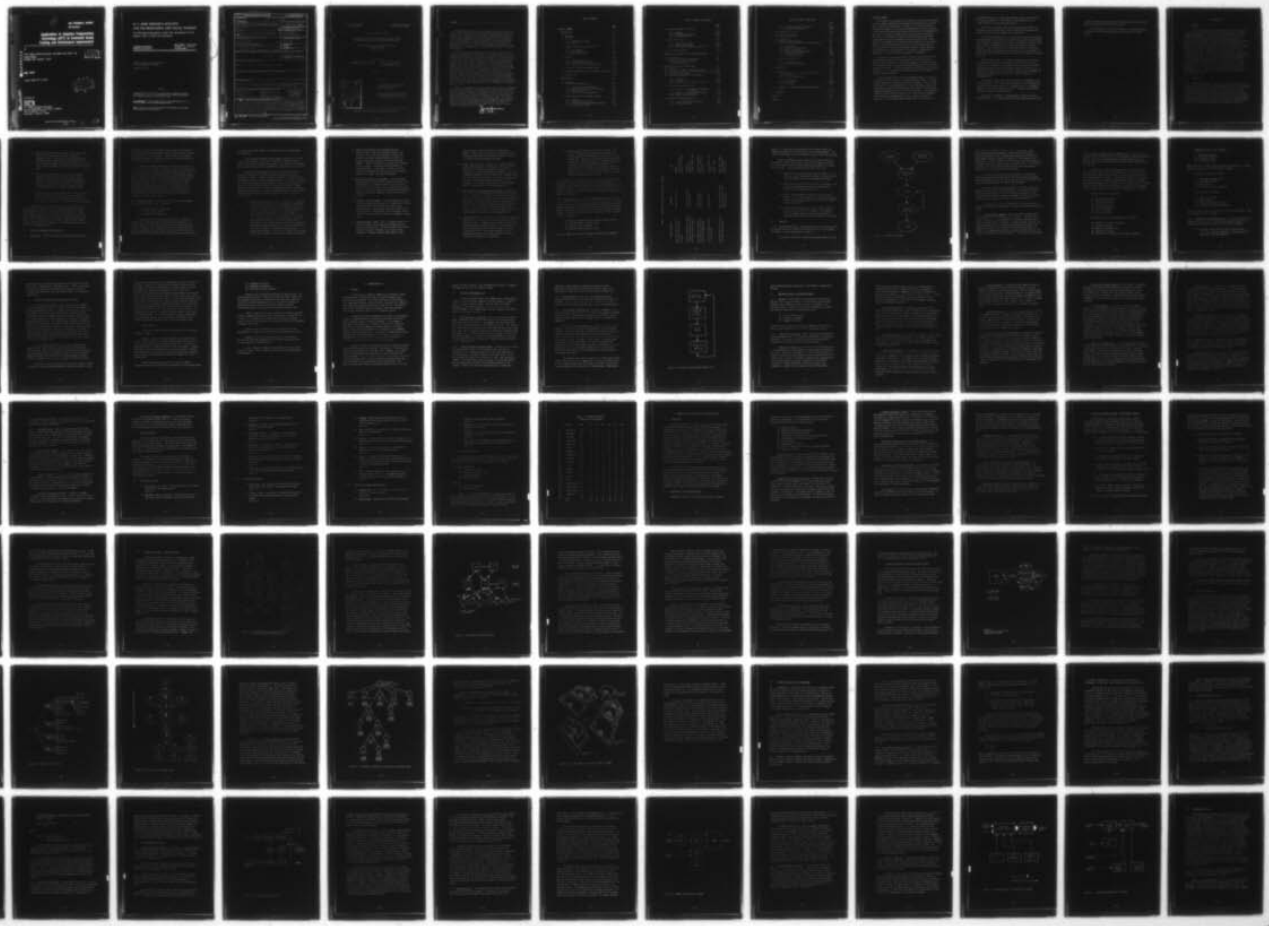
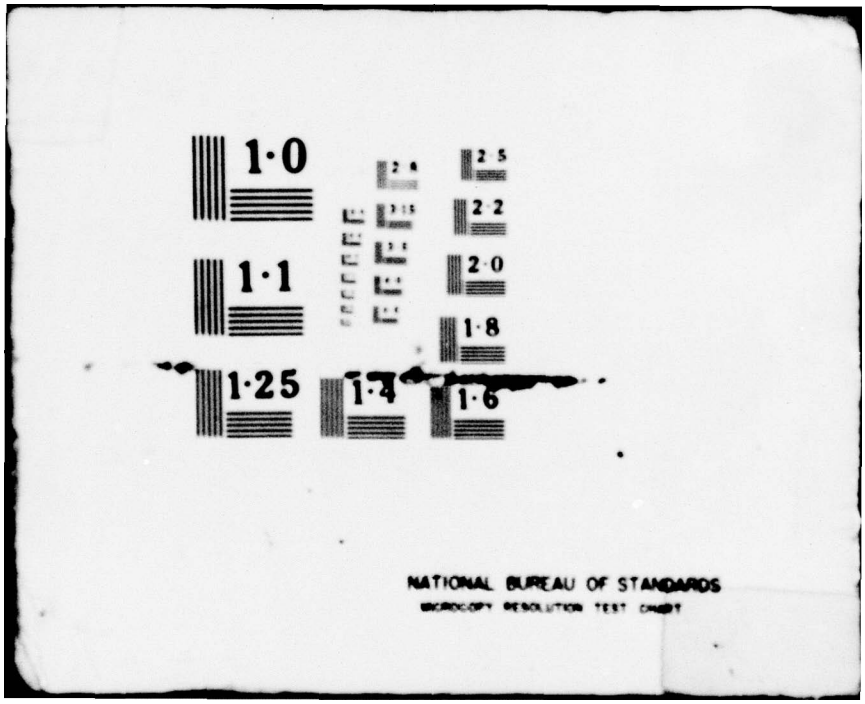
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Applications of Adaptive Programming Technology (APT) to Command Group Training and Performance Improvement

by

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Woodland Hills, California 91367

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This report provides a feasibility analysis and evaluation of the application of Adaptive Programming Technology (APT) to the improvement of command group performance. The final high payoff application area recommended is a situation assessment aid for a division-level G2. APT technology is expected to provide a concept-oriented, interactive aid to integrate the large information volume available into a coherent global situation assessment. A 5-year development program is provided.

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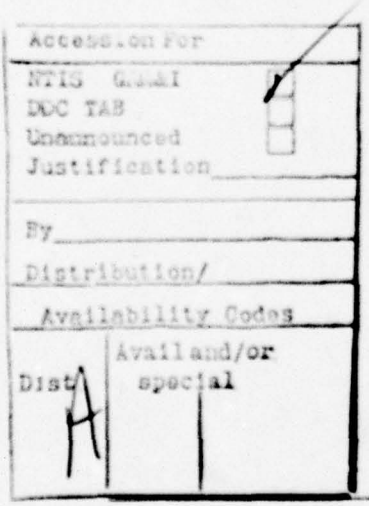
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FOREWORD

The Army Research Institute for the Behavioral and Social Sciences (ARI) conducts research on tactical information systems with particular emphasis on the human factor in battlefield command/control and intelligence functions and operations. The support and extension of human capabilities by computer technology is necessary to meet the challenge of the modern battlefield. Cost considerations call for careful attention to the performance increment attainable for alternative computer applications and aids. The ARI research program in this domain is independently and jointly executed by the Battlefield Information Systems Technical Area in Alexandria, Va., and the ARI Field Unit at Fort Leavenworth, Kans.

The present report describes research concerning technology for improving the flexibility and adaptability of automated systems to user requirements and needs. Because command staff actions occur in a complex, dynamic, and only partially understood environment, it is difficult to describe these actions analytically and to develop decision support which is responsive to user needs. Often, while users may be given improved access to data, few tools are available for easily manipulating and integrating the large volume of information. One emerging area which may provide a basis for flexible decision support tools is adaptive programming technology (APT) derived from research in behavioral decision theory and artificial intelligence. The development of APT has been heavily supported by the Defense Advanced Research Projects Agency in the context of a number of defense programs. Current ARI research analyzes and evaluates potential applications of APT in the context of Army command and control systems in order to determine technical feasibility and operational utility. This effort, representing one phase in the exploration of methods for improving responsiveness of automated systems provides part of the technological base required for the development of effective decision support.

Research on information utilization and decision support is conducted both in-house and augmented contractually with organizations selected for their specialized capabilities and unique facilities. Efforts in this area are responsive to general requirements of Army Projects 2Q162722A765 and 2Q163743A774 and to special requirements of the U.S. Army Combined Arms Combat Development Activity, Fort Leavenworth, Kans., and the U.S. Army Intelligence Center and School, Fort Huachuca, Ariz. This specific effort was conducted under Army Project 2Q161102B74F as basic research related to the above requirements by Contract DAHC19-77-C-0047 by Perceptronics, monitored by both the Human Factors Technical Area and the Fort Leavenworth Field Unit of ARI.

JOSEPH ZEIDNER
Technical Director

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Executive Summary

The objective of this project is to explore the potential contribution of APT to enhance command group performance and provide feasible concepts for its application in advanced C3 systems. One of the main problems with previous attempts at assisting or automating military decision tasks is that the decision making and problem solving tasks of the command group take place in a complex, dynamic and only partially known environment which does not lend itself to analytical or algorithmic formalization. Conventional brute force programming techniques and data base systems tend to be overwhelmed by the complexity and irregularity of the military problem. APT provides techniques that are especially appropriate for such conceptually irregular problem domains and can be made compatible with human expert conceptualization of such domains, even though this knowledge is typically qualitative, uncertain or judgmental.

The promising high payoff area for military C3 application for the transfer and evaluation of APT was found to be a decision aid for a division level G2 performing situation assessment. A preliminary design of a feasible situation assessment system was performed using one of the tested APT techniques: the multi-membership, multi-purpose classification approach. This is a knowledge driven approach based on a generalized Bayesian aggregation model.

It was estimated that a five year development effort is necessary to transfer the APT technology into the military environment. A program plan was developed to accomplish an effective transfer. The first year of the plan is a concept demonstration. The second phase, covering the second and third years will transfer and refine the APT techniques and knowledge representations for the military environment. The third phase, covering the fourth and fifth years, will include primarily knowledge base elicitation, implementation of a test system, and extensive evaluation. The five year program considers the risks involved in a

development effort of such magnitude and requires yearly useful products of increasing complexity. These products allow examination of the systems concepts at regular development phases.

Factors that contribute to the risk of the development effort are addressed in the report and they include technological implementability, technical feasibility and knowledge base considerations.

Technological implementability is concerned with whether the hardware technology needed for a situation assessment system will be available when the time comes to implement such a system. The computing resources needed for an eventual implementation of a situation assessment system were analyzed. It was concluded that the technology that will be available around 1985, when the development transfer effort will be completed, will provide the required computer resources and speed in a compact, militarized enclosure.

Technical feasibility is concerned with whether the APT techniques can indeed effectively handle the complexity of the military problem. The main issue is whether an estimated 5-10 fold increase in the systems knowledge base would cause an unacceptable increase in response time. It is anticipated that being driven by problem-domain-specific knowledge the increase in knowledge base size would not increase processing to unacceptable times.

The problem of correct and complete elicitation of knoweldge is the final risk factor. This is especially significant in the implementation of an APT system, again, because it is knowledge driven. Consequently, attention to the elicitation effort will be a continuous and important part of the complete development effort.

The system is considered to be integratable as part of future C3 systems like TOS. It includes a general military knowledge base but uses

specific knowledge about current tactical engagements available in other data bases, thus avoiding duplication of data.

The final product of the five year program is a complete, working, stand alone and well documented demonstration situation assessment system.

1. INTRODUCTION

1.1 Overview

This report provides a feasibility analysis of the application of Adaptive Programming Technology (APT) to the improvement of military command group performance. The analysis narrowed a list of potential military application areas down to the final high payoff choice, a decision aid for a division intelligence officer (G2) performing situation assessment. APT technology is expected to provide the officer with a concept oriented aid to integrate the vast amount of information available to him into a situation assessment which is coherent, global, and militarily significant. Following requirement analysis for a situation assessment system, this report describes a specific system structure and a set of appropriate mechanisms that will fulfill these requirements. It is estimated that a development effort of five years is necessary to transfer the APT technology into the military environment. The report concludes with a five year plan for the development of an extensive demonstration system. The plan provides yearly demonstrable subsystems and culminates in a comprehensive, minicomputer based, stand-alone, decision aiding system.

1.2 Rationale

1.2.1 The Military Problem. If war breaks out in Europe, the outcome will hinge on the ability of the opposing commanders to assess the situation correctly and respond in the right time, place and manner. The modern military tactical situation represents a complex dynamic environment, involving computerized, accurate and lethal weapons systems, fast ground and air vehicles, electronic sensors, and a surplus of incoming information. A command group must manage its material assets and its information under conditions of severe time constraints and environmental uncertainty.

Because of the increased speed, accuracy and lethality of modern weapon systems, calculating one side's numerical or technological superiority in a given area is meaningless if these advantages cannot be brought to bear at the critical time. Recent modern wars, such as the 6-day war in the Middle East, have demonstrated again that a numerically inferior army can win by mustering its assests at the right place and time. Therefore, in many ways it is more productive to examine and improve the C3 structure which must accomplish these tasks. It is the commander and his staff who accomplish the C3 tasks; the staff makes the analysis, and the commander makes his decision based on the analysis. A failure on either part sows the seed of failure in the war.

The decision making and problem solving tasks of the command group take place in a complex, dynamic, irregular and only partially known environment which does not lend itself to analytical or algorithmic formalization. As a result, the introduction of computer based military C3 support systems met with both conceptual resistance and technical difficulties.

1.2.2 Why APT. Adaptive Programming is an emerging technology which can provide the tools to construct advanced computer based decision aids with the potential for substantial improvement of both command group operational performance and training effectiveness.

Adaptive Programming Technology (APT) is derived from research in Cognitive Psychology, Pattern Recognition, and Artificial Intelligence. The technology consists of models, knowledge representation techniques, algorithms, inference mechanisms and control schemes that allow real time, knowledge based decision aiding systems to be constructed. The following are more specific advantages provided by APT over other conventional programming techniques and data base systems.

The essential difference between conventional data base systems and knowledge based APT systems is that the former are designed to handle a large amount of data organized into a small and rigid number of relations, while the latter can handle a moderate amount of data organized into many, hihgly interdependent relations, compatible with human conceptualization. The knowledge representation methods provided by APT can capture expert knowledge even though it is typically qualitative, uncertain and judgmental, toward the construction of an effective computer based consultation systems. This capability results in the following specific advantages:

(1) The compatibility between the system's knowledge structure and expert's conceptualization facilitates direct elicitation of knowledge from experts without a programming intermediary.

(2) Flexible query language enables the user to request information in a direct and natural format compatible with the terminology and conceptualizations accepted by knowledgeable personnel.

(3) The conceptual compatibility of the knowledge base facilitates debugging and fine tuning, as well as drastic updating by non-programmer experts, even during normal use. Furthermore, such fine tuning may result in systems which conform to the personal cognitive style of the particular user, thus increasing acceptability, use and effectiveness.

(4) Knowledge based systems can also provide explanations in the form of an accessible record of the "line of reasoning" leading to a particular system recommendation. This feature improves system acceptability by the user and gives him an indication of the validity of the answers.

(5) The explanation capability provided by APT can open a new dimension in computer based training. Immediate explanations can be provided during task performance when a problem surfaces. Additionally, exposing the entire line of reasoning enables the student to identify the specific areas where his knowledge is deficient and correct it on the spot.

(6) Military C3 problem domains usually involve a complex network of relations and vast amounts of data, making computer solutions by conventional techniques practically impossible. Such problems can, however, be searched and manipulated efficiently using goal-directed techniques driven by domain specific knowledge provided by experts.

(7) Finally, the high level and natural mode of the man/machine dialog in APT systems can provide an effective detailed record of the decision making process to be used for post-action analysis and evaluation of commander/trainee performance.

In summary, current large-scale military systems must delegate some decision and control functions to computer software to alleviate human information overloads. The quality of computer decision support systems depends heavily on the sophistication and adaptability of their decision making mechanisms. The characteristics and capabilities of APT present the only effective means for computer support of human command functions involving tactical operations, intelligence gathering, resource allocation, and command decisions.

1.3 Adaptive Programming Technology (APT)

1.3.1 Introduction. Adaptive Programming Technology can generally be

defined as a combination of methodology and software techniques that allow the construction of automated, adaptive, knowledge based, problem solving and decision making systems. The technology uses knowledge representation techniques, inference mechanisms, learning capabilities and generalization as its main tools.

Adaptive Programming Technology has evolved as a result of research on computer techniques for automatic perception, cognition, and decision making. This research was performed under the generic titles of Artificial Intelligence, Pattern Recognition and Adaptive and Learning Control. Much of the early work was directed toward the development of general methodologies, rather than toward problem-specific contexts (Asher and Andersani, 1976). As a result, the transition of these techniques to applied problems has been slow. Nevertheless, the methodologies that were developed offer a solid technical basis for computer assistance of decision making functions and have recently materialized into several decision aiding systems with impressive performance in various problem domains.

1.3.2 Major Techniques. The main concepts of adaptive programming fall into three technical areas. These are:

(1) Pattern recognition techniques
(2) Decision making networks
(3) Problem solving techniques

Pattern recognition involves the capability of a computer to evaluate a set of data features and to decide on their meaning, i.e., to which category of events they belong. Pattern recognition may involve learning. Learning is associated with the process of determining the relationship between input data features and the events they represent. Pattern recognition can be used for event classification and environmental

assessment, for example, detection of unusual events or interpretation of sensor data.

Decision making networks involve automatic selection of a course of action by a computer. The process involves an evaluation function, adaptive criteria for evaluating alternatives, and a model for representing the potential gain that can be expected from a particular course of action.

Problem solving techniques consists of control mechanisms for selection and ranking of an action sequence with respect to a given performance criteria, in order to achieve an objective. Problem solving techniques are used for computer strategy planning, for resources allocation, for systems reconfiguration, and wherever a system has to be brought from an initial state to some desired final state with no analytical method available to show the way. A number of computational and representational techniques form the basis for adaptive programming technology. Descriptions of those that are applicable to military decision support systems are provided below:

(1) Production Rule Systems. (Davis and King, 1975). Production rules have been used as the principal method of representing knowledge in many of the highly successful knowledge based systems. A production rules system is generally composed of the following three components: (a) a collection of production rules of the form "IF (condition) THEN (action)". (b) a workspace, and (c) a control mechanism. The system starts with a description of the initial state present in the workspace, the control mechanism then selects appropriate productions and applies them to the content of the workspace. These cause changes in the workspace which make other productions applicable. The process continues until a desired final state is reached in the workspace, namely the solution.

(2) Pattern Classification by Discriminant Function. (Nilsson, 1965). These are evaluation functions that classify a set of input data variables by attaching a weight to each data item and evaluating the data by a linear or nonlinear aggregation of the weighted data elements. Different weights are associated with different classes of events. The weights are established by a training program. In some cases, a system using these techniques can demonstrate learning, even on a previously unseen set of samples (clustering techniques).

(3) Maximum Likelihood Decision Networks. These are methods to represent and solve decision situations in face of risk and uncertainty. The network enables a user to select a course of action on the basis of its probability of success and a loss criterion, inferred from conditional probability parameters and the environmental conditions which bear on the event.

(4) Sequential Decision Network (Fu, 1968; Ben-Bassat, 1978a). These are computational techniques for sequentially selecting information for decision making on the basis of the contribution the information may make toward improving the decision quality. The technique involves concepts such as information feature selection, ranking, and optimal stopping rules.

(5) Semantic Networks (Woods, 1973). A semantic network is a method for representing declarative knowledge about the relations among entities. The major application has been to embody non-syntactic knowledge (e.g., semantics and pragmatics) in natural language understanding systems.

Because of their inherent generality and naturalness, semantic networks have also been used to represent highly interrelated information that cannot be properly processed by standard data-base management techniques.

(6) Frames (Miniskey, 1975). "Frames" are a recent, knowledge representation method of great interest. They provide the capability to include both procedural and declarative knowledge in the same representational formalism. They can accommodate mundane, ad-hoc and idiosyncratic knowledge along with that which is more repetitive or uniform in nature, and they perform plausible reasoning on the basis of such knowledge. This method is appropriate for problem domains where no rigorous, uniform body of knowledge exists.

(7) Multi-membership Multi-purpose Classification (Ben-Bassat, 1977). This is a modified Bayesian classification technique which is applicable to problem domains where classes are not mutually exclusive, not complete and have structured relations among them. The technique avoids the usual requirement of determining all conditional probabilities between events and classes. It also includes a mechanism for an efficient evaluation and classification of partially known samples in a problem domain that displays these characteristics.

(8) Syntactic Methods (Fu, 1976, 1977). A structure of primitive sub-events can be combined in a syntactic manner in order to describe an event. A grammer rule is applied to combine the sub-events into a meaningful structure. The technique is used to evaluate data and classify its meaning in terms of its pattern or class. The syntactic approach is very attractive when describing a complex pattern in terms of hierarchical combinations of subpatterns.

(9) Heuristic Search (Nilsson, 1971; Jackson, 1974). This is a set of computational techniques which allows for a computer evaluation of different possible problem solution alternatives. Heuristic search employs state-space problem representation, heuristic functions, alternative generation, and adaptive alternative evaluation criteria. It is applicable where the problems can be naturally stated in terms of (1) a set of discrete system states, (2) a set of allowable operators on states (actions), and (3) a testable definition of desirable final states.

It is now possible to capitalize on this substantial research effort and apply these successful techniques to the C3 military environment. A relatively modest development effort can lead to a significant jump in the performance, capabilities, and flexibility of future C3 systems. This report is a summary of an effort to identify one method to accomplish this transfer of technology.

1.3.3 Major Applications. Adaptive Programming Technology has been recently applied successfully to a variety of problem domains. The common attributes of these problem domains that made APT applicable and useful were the complexity of the problems, uncertainty and inaccuracy about the premises, and a general lack of rigorous analytical or optimal solution methods. The various applications can be classified into the following four major categories:

(1) Adaptive computer control of dynamic complex processes
(2) Computer analysis of complex data
(3) Decision aids for experts
(4) Automatic problem solving systems

Table 1-1 summarizes a number of successful applications of adaptive

TABLE 1-1. PREVIOUS APPLICATIONS OF ADAPTIVE PROGRAMS

System Functions	Techniques	User
Real-time adaptive control of ballistic missile defense functions	Pattern recognition	BMD/ATC (Leal, 1976; Ben-Bassat, et al, 1978)
Analysis of molecular structure through the evaluation of mass spectrometry data (DENDRAL)	Heuristic programming production rules	NIH/ARPA (Winke, Heller, Feldman, Hydes, 1974)
Development of a computer-based consultant for mineral exploration (PROSECUTOR)	Production rules semantic networks	Office of Resource Analysis, (Duda, et al, 1977)
Control of elevator surface of F-101 aircraft	Learning control	Flight Dynamics Lab U.S.A.F. (Barron, 1967)
Real-time control of steel mill strip and finishing stand	Nonlinear learning control system response acquired through training	Armco Steel Company Ashland-Kentucky (Baily, 1975)

programs. In some cases the performance level of these systems was commensurate with that of top level experts in the problem domain. Such a level of performance was not attainable previously using other techniques.

Much of Perceptronics work to date has focused on interactive man-computer systems, and the utilization of on-line adaptive processes to aid and reduce reliance on routine human decision making in military decision making. There have been four main applications areas:

(1) Adaptive decision aiding in anti-submarine warfare. This includes a scenario generation technique for decision aiding and a methodology for decision performance measurement.

(2) Adaptive decision training for electronic maintenance. This involves a methodology for adaptive instruction and a methodology for performance assessment.

(3) Defense strategy planning in ballistic missiles system defense. This involves automatic configuration of plausible defense strategies and evaluation and selection of optimal response (Leal, 1977).

(4) Classification of objects in a threat cloud of re-entry vehicles for ballistic missile defense. This involves real-time adaptive pattern recognition and learning of known and unknown types of objects (Ben-Bassat, et al, 1978).

1.4 Approach

1.4.1 Current Project Plan. The approach taken in this current project, to identify the most cost effective application for APT in the military environment is shown schematically in Figure 1-1.

The project started with a detailed requirements analysis of the

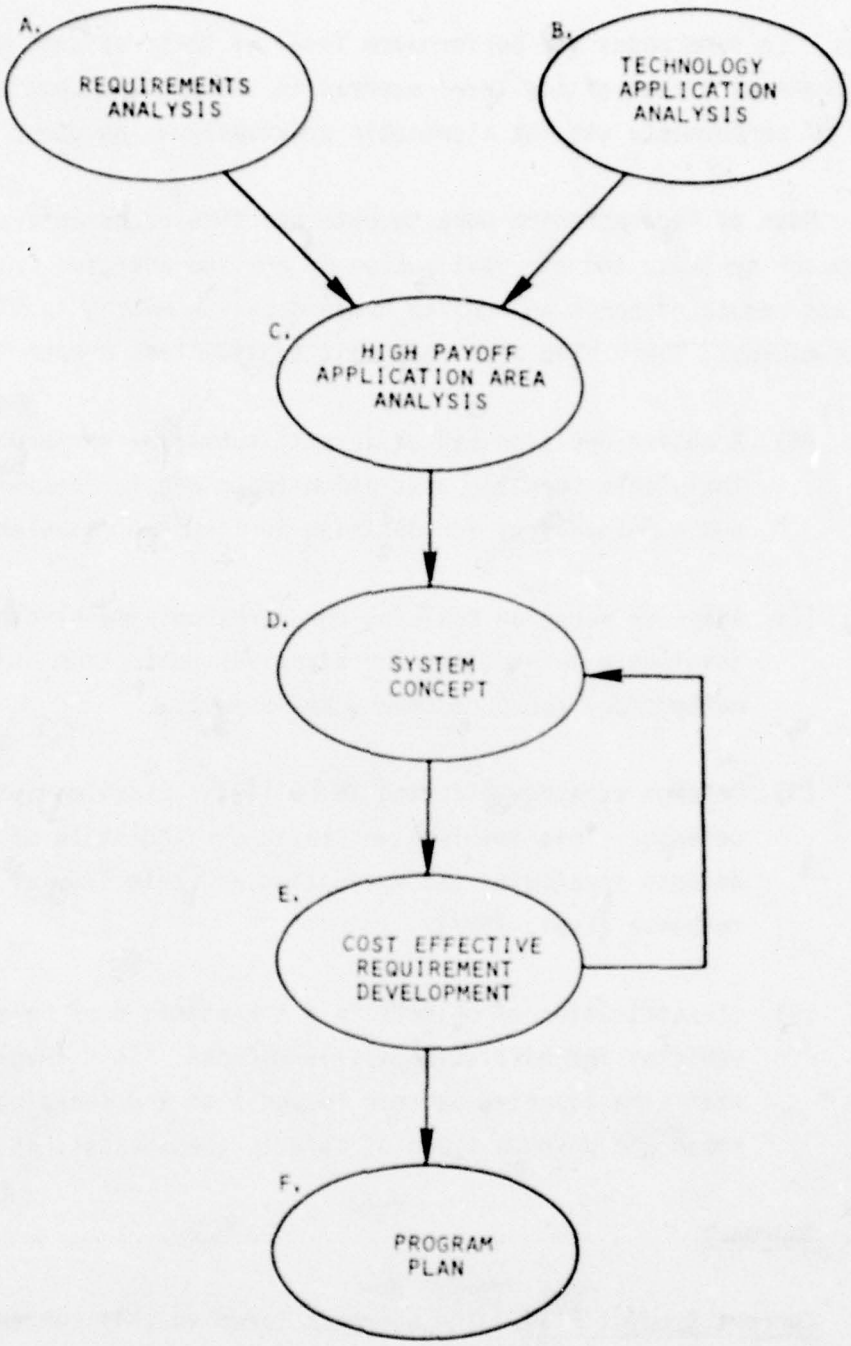


FIGURE 1-1. PROGRAM FLOW DIAGRAM

urgent needs for C3 systems (Figure 1-1 (A)). This analysis used a multi-attribute evaluation method to isolate the most critical and potentially improvable areas in command group operation and determining where computer support is needed. In parallel, a second analysis was conducted (B) to isolate significant APT techniques in previous application development efforts and identify their main characteristics. This analysis resulted in a listing of available APT techniques which have potential applicability to military decision aiding systems.

The result of these two tasks were combined to find the high payoff application area (C) which would have the most impact on command group performance (and training) and, at the same time, be solvable without excessive additional outlays in research and development.

The next step (D) was the development of a system concept that would use the most applicable APT technique in the previously identified military application area. The system concept was evaluated (E) and iteratively modified until a balance was reached in terms of the expected effort versus the expected effectiveness of the resulting system.

The final step (F) was the generation of a five-year plan for research and development program that will produce an operating demonstrable system.

1.4.2 Problem Analysis Summary. The military decision making process is considered here to be a repeated cyclical process. The four phases of this cycle are: (1) Goal and specific objectives determination, (2) Situation recognition and assessment, (3) Battle planning, and (4) Plan execution and monitoring. Considering the information utilized by the command group, Phase I sets the goals of the military operation. In Phase II, the command group assesses the current military situation with respect to the goals and specific objectives. In Phase III, the assessment

of the situation is transformed into a detailed battle plan which utilizes the assets of the friendly forces and takes advantage of enemy vulnerabilities. Phase IV is the actual engagement where the command group monitors the activity, looks for clues of enemy intentions, and gathers information for the next cycle.

This analysis, along with interviews with military personnel at Fort Leavenworth, Kansas, led to the identification of several military application areas where computer aiding, especially systems which utilize APT technology, would be of help. The application areas are divided into two groups: the first is where the computer aiding supports the command group in the performance of its various functions, and the second is computer aiding in the military training environment. Within the area of command group performance support, the following three subgroups were indicated:

Tactical decision aids including:

(1) Alternative formulation
(2) Alternative evaluation
(3) Alternative selection
(4) Battle plan generation
(5) Scenario generation
(6) Resource allocation

Information processing and management aids including:

(1) Evaluation of incoming information
(2) Situation assessment
(3) Detection of unusual events
(4) Production of displays
(5) Identification of areas of insufficient information

Communication control aids including:

(1) Message dissemination
(2) Information filtering
(3) Information pacing

Within the area of military training systems, the introduction of adaptive aiding was considered in the following two subgroups:

Battlefield simulations including:

(1) Subordinate commander actions
(2) Evnironment simulation
(3) Enemy actions
(4) Individual initiative simulation

Trainee monitoring including:

(1) Event history logging
(2) Behavior tracking
(3) Automated performance assessment
(4) Instructional strategies adaptation

This list of applications is the baseline of the selection process. They are explained in detail in Chapter 2.

1.4.3 Evaluation Criteria and the Choice. The selection among all the alternatives was done using a multi-attribute evaluation method. The evaluation criteria can be grouped into the following categories:

(1) Attributes of the military problem to be solved are: criticality, magnitude, frequency, improvement potential, generality, future and aidability.

(2) Attributes of the research effort required are: availability, transfer, leverage, risk, research, support, experts and tools.

(3) Attributes of the solution system are: compatibility, effectiveness, acceptability, technology and cost.

These attributes are further defined in Chapter 2, and the values assigned to the different application areas are given.

The result of this evaluation and further consultation with ARI led to the selection of Situation Assessment (SA) as the target application area for the development effort. It was also estimated that the expected improvement of command group performance is well worth the investment of the required development effort.

1.5 A Proposed Situation Assessment System

Situation assessment, a decision aid for a division level G2 officer, was chosen as the specific application area for further development. The support provided by such a system to the G2 officer is to propose global interpretations for the data available and to verify or reject these possible interpretations through knowledge driven evaluation of large volumes of information.

The feasibility of a situation assessment decision aid is demonstrated essentially by explicity showing how it can be achieved. APT techniques, which have been used successfully in similarly large and complex problem domains, are utilized to perform both the representation and the processing of knowledge. The system structure, its main mechanisms and the processing flow diagrams are explained in Chapter 4.

The complex military knowledge base is represented as a multi-hierarchy of information structures. In each aspect of the military situation, such as terrain, weapon systems or deployment, the structure is based on two basic concepts: features and classes. The observation of features (or indication) in the battlefield suggests the existence of a corresponding class.

A multi-membership, hierarchical, recognition process is used for the situation assessment algorithm. This algorithm and its processor obtain information interactively from the G2 officer, uses the military knowledge base, and generates and maintains a set of temporary models of the situation. This set of temporary models is modified successively as more evidence is available. The objective of the process is to obtain a single, global, integrated interpretation of all the available data. Such an integrated picture is the situation assessment. The output of the situation assessment processor is formatted by a summary generator into a document similar to the Intelligence Estimate Report.

For the elicitation of knowledge, a detailed methodology was developed by Ben-Bassat (1977b). The process is pattern-directed and is aimed at obtaining the class-feature relations necessary for the knowledge base. Thus, the expert is required to provide patterns and estimates of probability of occurrence for a wide spectrum of possible situations in the battlefield. The elicitation process proceeds in three stages that are repeated until convergence is obtained. Stage 1 is class characterization, where all the related classes are identified; for each, the set of significant features are indicated together with the appropriate conditional probability. Stage 2 is class differen iation. The experts are requested to list the observable features that differentiate between each pair of classes. Stage 3 is feature characterization. For each feature, all the classes for which it was significant are listed and verified against the previous information given. The results of this

three-stage process are then tested against some recognition cases and the process is repeated until convergence occurs. Finally, a top-level system design integrates the main functional components in terms of structure, main algorithms, data used, output formats, and intermodule communication.

1.6 Computer Implementability and Database Utilization

To arrive at a reasonable estimate of the resources needed to develop and implement the proposed system, a review was conducted of existing knowledge base systems. A comparison of five such systems, with applications in such varied and complex fields as medicine, mineral exploration, and natural language processing was made to establish the preliminary estimate of resource requirements. The types of information reviewed and compared were: the computer power required, the amount of memory used, the capability of the final system, the response time, and the amount of research effort involved in each project. It was estimated that a five-year development effort, using a dedicated mini-computer available today, capable of 0.5 MIPS (Million Instructions per second) speed, with about one-half magabytes of memory and a fast disk system, can provide a reasonable system for the initial first year development of the situation assessment system.

For the final fieldable SA system, it was estimated that a computer with 5-10 MIPS speed and 2-4 million bytes of direct memory would be needed. Analysis has shown that around 1985, when the five-year development program will be completed the state of the art in computer hardware technology would provide all the computing power and memory capacity to implement such a system in a compact militarized enclosure.

The impact of the proposed system on existing or proposed military C3 computer systems and Database Management systems was evaluated. Within

the decentralized organization of the proposed TOS system, the situation assessment system can be integrated with relatively little difficulty. The situation assessment system contains an internal general military knowledge base. Within this knowledge base, there are a set of descriptors that characterize the content of other external military data bases. These external data bases (such as TACFIRE) contain the specific data about the current on-going situation. The situation assessment system, when in need of some specific fact, will formulate a specific query and will send it over the computer communication network. The response will be analyzed and integrated into the situation assessment picture. This type of organization will not require duplication of the content of the other data bases, with all the complex problems of ensuring consistency and validity of data. It is also not expected to place a large demand on the computing resources in the external C3 system because of the indigenous stand-alone computer of the situation assessment system.

1.7 Report Outline

This report follows essentially the progression of this project as shown in Figure 1-1.

Chapter 2 presents the problem statements, describes the main cyclical decision process of a command group in action, and lists with a short description the key problem areas identified. The potential application areas for computer aiding are listed in two groups: command group decision aids, and computer aiding of training systems. Finally, the criteria by which the application areas were evaluated to select the one with highest military payoff for further development, are listed and explained.

Chapter 3 presents a process analysis for the situation assessment and then lists and discusses requirements in the following areas:

(1) Knowledge elicitation
(2) Knowledge representation
(3) Situation assessment mechanisms

Chapter 4 gives the detailed description of the SA system. The structure and function of a situation assessment algorithm is given, then the knowledge representation techniques are discussed and a method for elicitation of expert knowledge presented. The technical approach is completed with a description of the top-level modules, and their structure and function in a stand-alone situation assessment system.

Chapter 5 addresses the specific problems of resources and effort needed in hardware/software and military expert support to complete such a system. It also addresses the problem of connecting the proposed system to other existing data bases, and effectively utilizing the detailed information they contain.

Chapter 6 gives a detailed five-year program plan for the development of a situation assessment decision aid demonstration system.

Appendix A discusses the generalizability of the different functions and algorithms developed for the situation assessment system to other important C3 system functions.

Finally, Appendix B summarizes the features of five successful APT-based systems. These are applied in medical and mineral exploration problem domains.

2. PROBLEM ANALYSIS

2.1 Overview

To identify ways to improve command group performance a better understanding of their function, both in actual performance and in training, must be attained. This chapter provides an overall model of the command group function, isolates specific key subtasks and summarizes their evaluation as potential application areas for APT. The important subtasks were identified through a literature survey and interviews with military and ARI personnel at Fort Leavenworth, Kansas.

The application areas considered can be divided into two general groups: (1) computer aiding for performance enhancement in the field; and (2) computer aiding for training improvement. In performance enhancement, the computer can aid members of the group in performing their function, improve communication between members of the group, improve availability and presentation of information to the commander and aid his decision making tasks. In the area of command group training the application of APT can improve the effectiveness, timeliness and efficiency of the training system, improve training methodology, and aid in validating and evaluating present methodologies.

Section 2.5 presents the evaluation criteria by which the highest payoff application areas were selected. The evaluation criteria and the results of the evaluation are given here only in summary. The criteria can be classified into three broad classes: 1) those related to the military problem, itself; 2) those that address the availability of proper solution techniques; and 3) criteria related to the effectiveness and ease of transfer of these techniques to the military domain. Six application areas were initially selected and then the six were narrowed

down to one final selection. The choice application area is a situation assessment aid for a division level G2 officer.

2.2 Battlefield Management Cycle

The decision making process of a command group in battle may be viewed as a cyclical process composed of four main phases, as shown in Figure 2-1 (see also Anderson 1976). The four phases are largely overlapping in any actual situation; they are the responsibility of different members of the command group, but they represent the essential function of the group as a whole.

2.2.1 Goals and Specific Objectives. In the first phase, the overall goals of the battle are determined according to the mission directives handed down from higher echelons. The commander then translates these goals into a detailed priority list of specific objectives. For instance, the overall goal may be the destruction of an enemy military force in the area. The specific objectives by which this goal may be achieved include for example: (1) cut off the retreat routes of the force; (2) destroy its anti-aircraft weapons; (3) destroy its air support capability; (4) push it into a destruction zone; (5) destroy its tank force; and (6) destroy its main infantry force.

2.2.2 Situation Recognition and Assessment. In Phase II, the situation is recognized and assessed. The recognition aspect includes the identification of the detailed components of the enemy configuration. For example, what is the defense posture of the enemy forces, or what are the connecting routes of his forces to his rear? Once the various elements of the situation have been recognized, an integrated picture must be composed which provides a goal-oriented assessment of the situation. Phase II also includes the determination of enemy goals,

intentions, likely targets, and alternative courses of action. Additionally, identification of enemy vulnerabilities leads to the determination of the best courses of action for the friendly forces.

2.2.3 Battle Planning. Phase III is the planning phase where alternative courses of action are outlined, transformed into plans, and evaluated. Then an optimal plan, which best utilizes the available resources and the situation opportunities, is chosen for implementation.

2.2.4 Plan Execution and Monitoring. The actual engagement is the last phase of the cycle (Phase IV). It involves plan execution and enemy reaction, with the command group monitoring both the friendly and the enemy performance, and collecting information about the outcome of the engagement.

As a result of the engagement the situation will probably have changed. The specific aims must be reconsidered in light of the new situation. Those which have been achieved are eliminated from the list, some new ones may have to be added, the rest are re-evaluated, and perhaps modified with a new priority rank; as a result, a new prioritized list of specific aims is obtained. This is Phase I in the subsequent cycle, and it continues with Phase II, situation recognition and assessment, etc. It is worth noting that for a given battle, the overall goals are not likely to be changed, although this is also possible, particularly after several cycles have taken place and the situation has changed significantly.

This general, top-level view, may help in isolating more specific potential decision aids for a command group. The next section describes a list of potential application areas where the computer can be used to improve performance of key functions of a command group. Additionally,

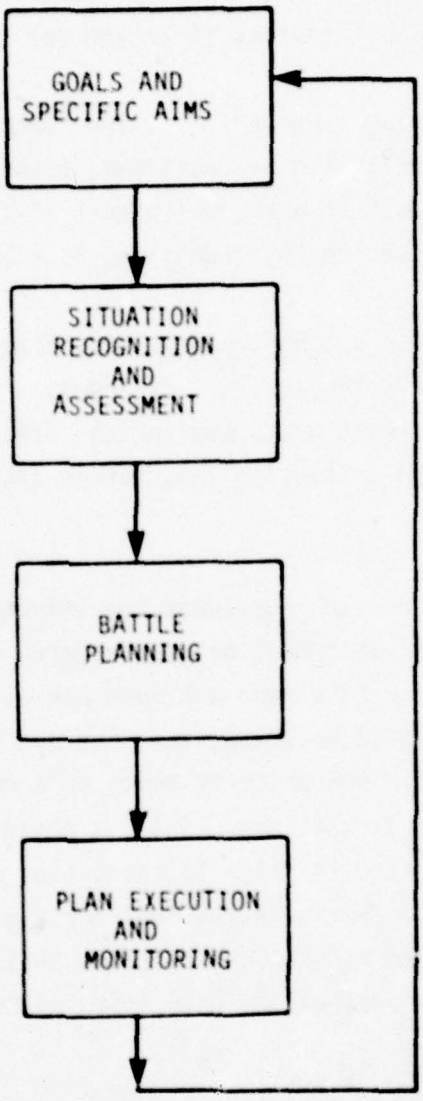


FIGURE 2-1. THE BATTLE DECISION MAKING PROCESS CYCLE

we will indicate potential application in the domain of command group training.

2.3 Application Areas in Performance Support

2.3.1 Overview. The following is a point-by-point discussion of a detailed list of application areas in tactical decision making where computer aiding, supported by APT, will have a high payoff. Each application area is a specific function that can potentially be aided. The areas are categorized into three general groups:

(1) Tactical decision aiding
(2) Information management
(3) Communication control

The discussion will mention key issues and comments given by military officers interviewed during a visit to Fort Leavenworth, Kansas.

2.3.2 Tactical Decision Aiding. Battle decision making includes the following commander tasks: (1) alternative formulation; (2) alternative evaluation; (3) alternative selection; (4) battle plan generation; (5) battlefield simulation; and (6) resource allocation.

Alternative Formulation. The first step in the planning phase is the determination, by the commander, of the available alternatives for action. Alternative formulation is a highly creative process, it requires imagination to take advantage of all the peculiarities of the given tactical situation. Alternative formulation was considered to be of high importance and a potential contributor for considerable improvement in command performance. There are, however, grave acceptability problems with an automatic alternative formulator.

Identifying the alternative courses of action in the battlefield is considered the heart of the command function and is performed in a highly personalized manner. Commanders are unlikely to delegate this function to an automatic, or even interactive computer system. To overcome this problem it was suggested that a possible aid would give only tentative recommendations or suggestions to the commander, who would make the final selection himself.

Alternative Evaluation. An alternative evaluation system would analyze and evaluate each plausible alternative using an exhaustive set of military and operational criteria and would present a meaningful summary of the results to the commander. Psychological research has shown that people evaluate well from a single criterion, but aggregate the results of multiple criteria in a very unsatisfactory manner (e.g., Beach, 1975; and Einhorn, 1974). This function was considered very important, amenable for automation, and potentially more acceptable to users.

Alternative Selection. This function is the final step in making a decision: choosing the best alternative. The computer can apply different decision rules and present the results to the commander for final approval or disapproval. For example, lowest risk choice, choice of highest expected gain etc.

Battle Plan Generation. This includes the commander's various planning functions such as task force disposition, tactical maneuvers, specification, communication plans, weapon system deployment, and support requirements specifications. The computer can aid in presenting plan alternatives, in attending to the standard repetitive details of complex plans, evaluating alternative plans, and performing optimization calculations. Here again acceptability problems may rise, but with proper design, the commander would provide overall plans and general directions and the computer will develop the plans to the fine details required.

Scenario Generation. Simulation systems capable of realistic battlefield simulation can enable the military analyst to explore probable consequences of alternative courses of action, estimate enemy reaction, and test outcomes of planned engagements. The computer models of the battlefield must take into account interactions between military forces, weapon systems, environment, weather, etc., in order to estimate tactical enemy reaction to a given situation. Such a "what if?" capability was considered very valuable for improvement of commander plans.

Resource Allocation. This is a major function which is part of all command group tasks. It deals with an efficient allocation of limited resources to maximize their effectiveness in the battle. This includes, among others, the following specific tasks: (1) allocation of major weapon systems, (2) support fire allocation and management, (3) logistics planning, (4) task force planning, (5) order of battle reconfiguration, and (6) communication planning.

2.3.3 Information Processing and Management. Battlefield information management for the command group and its individual members includes the following main components: (1) evaluation of incoming information, (2) situation assessment, (3) detection of unusual events, (4) production of displays of information, and (5) identification of areas of insufficient information. Each of these components can be accomplished at different task levels. The orientation of an information management system should be toward an integrated conceptual picture of the situation rather than manipulating the data in raw form. Thus, functional systems discussed should provide the commander with meaningful information which he can use directly, rather than just a retrieval of data as it was entered into a data base.

Evaluation of Incoming Information. This process is concerned with quality, reliability, and accuracy of the source of a piece of information while considering other supportive evidence for it, and while checking its consistency with the currently assessed overall picture of the battle situation. Such an aid will process the incoming information and will provide an estimate of the validity and accuracy of messages.

Situation Assessment. This process involves the computer generation of an operationally evaluated summary of the current situation. This calls for the integration of all the detailed information available into a coherent overall picture of the situation. The orientation of such an assessment would be to identify the goals and current aims of the enemy and to identify aspects of the situations that support or hinder the attainment of the friendly specific objectives. This assessment also includes the position of friendly and enemy forces, plus a comparison between them ir terms of fire power, mobility, morale, motivation, training, and terrain. The situation assessment report should be presented at a comfortable level of detail and the commander should be able to obtain the details through an interactive exchange in strict military terms.

Detection of Unusual Events. This application area deals with the early detection of significant events in the battlefield. Significance is not always related to size or centrality of an event. Sometimes subtle changes in the situation may lead to very significant changes later on. This may include an unexpected opportunity caused by enemy vulnerability, it may also be a negative clue which suddenly exposes a friendly weak spot, etc. An early identification of such unusual events is a very important aid for the busy commander who can hardly attend to the more urgent aspects of the battle.

Display Production. This application is concerned with the retrieval and display of tactical information. The key requirement of such systems is the use of knowledge in human perception to facilitate speed, accuracy, and comprehension of the tactical information presented to the commander. The system would have a hierarchy of conceptual levels at which the information is available. It would present it from the top-down level. The commander would first get clear presentations of the overall situation but would be able to obtain details to any level if he desires. The details will be stored hierarchically in the aiding system and will be produced upon request.

Insufficient Information. In the large volume of information traffic going through a command post, it is hard to find where there are large gaps in the information. An automatic system is needed, specifically one that would understand what has to be known about the various aspects of the situation, would find what is available, and would indicate where more information is needed. This could improve substantially the information collection process. Such a system can directly produce detailed Information Requests for the information collecting sources.

2.3.4 Communication Control. Communication within a command group and among command posts in the military hierarchy includes the following functions which can be potentially aided: (1) message dissemination, (2) information filtering, and (3) information pacing.

Message Dissemination. This function is the direct transfer of unmodified messages between sender and receiver. Automation in this function can increase transger speed, reliability, safety, and accuracy. Message dissemination may take place within a command group, vertically in the command hierarchy, or horizontally to neighboring units. The experimental TOS has shown the value and potential for improvement brought about by automation in this area.

Information Filtering. This refers to a mechanism that unloads irrelevant information from the analyst and channels to him only what he wants to know and can use effectively. This is necessary since the sheer volume of information that descends upon a command group increases continously with the development of military technology. The filtering mechanism should be made adaptive to the function and the changing needs of an analyst, and be responsive to the level of details he wants at any given time.

Information Pacing. In current and future C3 environments, the command group members are likely to be overwhelmed by the sheer volume of information flowing in. There is an optimal rate for information comprehension by a human being (Samet, et al, 1977), and the information presented should be paced to this optimal rate. An automatic pacing system should adapt the presentation rate to the specific user, to the features (length, etc.), of the message, and to the dynamics of the situation. Such capabilities can be expected to improve the amount of information actually comprehended by the member of the command group.

2.4 Application Areas in Training

2.4.1 Overview. The following is a point-by-point discussion of specific application areas in the military training domain. The application areas can be classified into the following two categories: (1) Battlefield Simulation, and (2) Trainee Monitoring. The type of training environment to which application areas are pertinent is exemplified by the CATTS system.

2.4.2 Battlefield Simulation. This application area includes the simulation of the behavior of both friendly and enemy forces, the environment, and the interaction of all three in combat. The major

components are: (1) subordinate commander functions, (2) environment, (3) enemy actions, and (4) independent human initiative. Most of these capabilities in a battlefield simulation system were considered important by the interviewed military personnel, except the enviornment simulation which was thought to be a simple task for the simulator controllers. The environment, however, is an essential and integral part of the simulation of fighting forces and its impact on the battle should be integrated into the system.

Subordinate Commander Functions. This concerns simulation of the tactical behavior of lower-level friendly commanders. Current simulators demonstrate poor performance in the tactical behavior of simulated subordinate commanders when they execute the trainee commands. Improvements in the modeling capability of such systems can improve the realism of the whole training system. The improved realism would make the trained command group more prepared to handle communication problems tactical mistakes of subordinate units, and unexpected delays of plan execution caused by the environment and the enemy.

Enemy Actions. This simulation is concerned with the tactical behavior of low-level enemy forces in response to terrain, weather, and friendly forces maneuvers. Realistic tactical behavior of enemy forces and direct responses to trainee actions, with the possibility of entering military doctrines at the conceptual level, was considered highly important and desirable. The future value of such a training aid and its acceptability were also high.

Individual Initiative. Incorporation of individual initiative into the simulation was considered critically important. It relates mainly to simulated individual's capability to "read" the tactical situation and adapt his actions accordingly. This also includes other characteristics

of the simulated human commander (both enemy and friendly) such as intelligence, morale, motivation, training, freshness, errors, and similar characteristics of the fighting men.

2.4.3 Trainee Monitoring. There are several levels at which the behavior of the trainee can be monitored and the information used in the training process. The following areas are some possibilities in order of increasing complexity: (1) event histories logging, (2) behavior tracking, (3) automatic performance assessment, and (4) instructional strategies adaptation. These four levels are sequential steps in the automation of training systems.

Event Histories Logging. Such system would log event histories and keep track of events that have occurred during a training exercise so that important questions can be answered at a later time. Currently, the CATTS system reports only the basic facts. A more advanced capability would be the automatic generation of a summary of the situation and the main events that occurred. This was regarded as a very desirable improvement in the effectiveness of the debriefing which comes after an elaborate and long simulation exercise.

Behavior Tracking. This refers to on-line adaptive modeling of trainee behavior. This would enable detailed evaluation of trainee performance while performing his task, rather than using separate tests. Note that the validity of independent tests is not strictly established. The adaptive model can then be analyzed and the weak skills isolated affording great improvements in training effectiveness.

Automatic Performance Assessment. Automatic performance assessment of the trainee behavior, using computer-accumulated objective measures, was considered by the interviewed military personnel to have a large potential for improvement in training effectiveness.

Instructional Strategies Adaptation. Instructional strategies adaptation allows automatic modification of scenarios and training strategies according to recognized weak spots in trainee performance. This high level of system automation was, however, deemed unrealistic at the current state-of-the-art in training, theory, and methodology.

2.5 Selection Criteria

This section describes the specific criteria that were used to evaluate the cost-effectiveness of a developement effort to transfer APT techniques to the military domain. The situation assessment function was found to be the area with the highest potential payoff. The remainder of this report is a detailed analysis and a description of a proposed design for a situation assessment system.

The evaluation criteria can be grouped into the following categories: (1) attributes of the military problem to be solved, (2) research requirements, and (3) attributes of the solution. With each of the different attributes, a scale of either 1-5 or 1-10 is associated. These scales are used to evaluate the potential application areas using a linear multi-attribute evaluation technique. The value 1 is most undesirable while 5 or 10 is most desirable. The two scales provide a simple weighting mechanism.

2.5.1 The Military Problem.

(1) Criticality. How critical is the problem area to the proper functioning of the command group?
Scale 1-10.

(2) Magnitude. What is the extent of military value that is at stake when specific problematic functions are performed

nonoptimally by the members of the command group?
Scale 1-10.

(3) Frequency. How often is the problem encountered in the actual military environment?
Scale 1-5.

(4) Improvement Potential. Compared to current level of performance, how much can performance in this area be expected to improve with aiding?
Scale 1-5.

(5) Generality. If and when the problem is solved, how easy would it be to transfer the results to other similar military problem domains?
Scale 1-5.

(6) Future. Will the problem identified resolved or aggravated be with expected future developments of military technology and practice?
Scale 1-10.

(7) Aidability. Can significant aspects of the problem be aided by an external automatic and/or interactive system?
Scale 1-5.

2.5.2 Research Requirements

(1) Availability. Have applicable techniques been developed and tested in other domains? How applicable are they?
Scale 1-10.

(2) Transfer. What is the extent of research effort necessary to transfer the available technology into the military domain?
Scale 1-10.

(3) Leverage. Would the specific technology, after being transferred to the military domain, be useful in other military problem areas?
Scale 1-5.

(4) Risk. How certain is the prospect of finding an effective solution to the problem?
Scale 1-10.

(5) Research. How much additional research is needed to solve the complete problem (on top of the transferred technology)?
Scale 1-5.

(6) Support. How much military support is needed for the development in terms of military resources?
Scale 1-5.

(7) Experts: Are experts available who know how to solve problems in the domain, are there accepted methods, do the experts have an articulatable model and are they motivated to support a developement effort?
Scale 1-5.

(8) Tools. Are there appropriate tools available to use in the development process, i.g., programming languages, operating systems, utilities, elicitation methods, etc.
Scale 1-5.

2.5.3 The Solution System Characteristics

(1) Compatibility. Is the solution system compatible with existing or planned C3 systems?
Scale 1-10.

(2) Effectiveness. How much can the particular solution be

expected to improve command group performance?
Scale 1-5.

(3) Acceptability. Will the aiding system be acceptable to commanders in actual use?
Scale 1-5.

(4) Technology. Is the technology available to implement the solution in the field?
Scale 1-5.

(5) Cost. What is the estimated resource requirement for the implementation and maintenance of the aiding system?
Scale 1-10.

2.6 The Selection Results

Through discussions with ARI personnel, the list of 22 application areas described above was cut down to six potential candidates. The six areas chosen for more detailed considerations were the following:

In performance enhancement:

(1) Situation assessment
(2) Detection of unusual events
(3) Scenario generation
(4) Resource allocation

In training:

(5) Battlefield simulation
(6) Trainee monitoring

Table 2-1 is a detailed breakdown of the values we assigned to each evaluation criteria for each of the six application areas. The sum totals are shown at the bottom and it is clear that situation assessment accumulated overall the most points in its favor. It was thus selected as the application area most appropriate for further development.

TABLE 2-1 ATTRIBUTE VALUES FOR
POTENTIAL APPLICATION AREAS

	Criteria	Scale	(1)	(2)	(3)	(4)	(5)	(6)
(1)	Criticality	1-10	9	8	6	7	5	5
(2)	Magnitude	1-10	10	7	7	8	5	6
(3)	Frequency	1-5	5	1	3	4	3	3
(4)	Improvement	1-5	4	4	5	5	4	3
(5)	Generality	1-5	5	2	2	4	2	1
(6)	Future	1-10	10	8	6	10	6	8
(7)	Aidability	1-5	4	4	5	4	5	3
(8)	Availability	1-10	9	7	8	8	8	4
(9)	Transfer	1-10	8	8	9	9	6	7
(10)	Leverage	1-5	5	2	3	4	3	1
(11)	Risk	1-10	6	4	8	8	8	6
(12)	Research	1-5	3	2	3	4	2	4
(13)	Support	1-5	4	5	4	3	4	2
(14)	Experts	1-5	4	2	4	5	3	1
(15)	Tools	1-5	5	5	3	3	3	2
(16)	Compatibility	1-10	7	5	4	6	9	9
(17)	Effectiveness	1-5	5	3	3	4	5	3
(18)	Acceptability	1-5	4	3	5	5	5	4
(19)	Technology	1-5	5	5	4	4	5	4
(20)	Cost	1-10	3	5	4	3	5	5
	TOTAL		115	90	96	108	96	81

3. KNOWLEDGE ELICITATION AND SYSTEM CONSIDERATIONS

3.1 Introduction

Situation assessment is a complex process involving many elements and interactions among the wide variety of battlefield components. A large number of data items are included and used in this process, many of them implicitly. It is not a simple task for a commander to verbalize and spell out the reasoning process which guided him in the analysis of a certain situation. On the other hand, a basic requirement from any intelligent computer system for military command is a systematic and structural representation of military knowledge. The transfer of knowledge from expert human beings to a computer system requires, therefore, two elements. The first is the development of an information structure to accommodate the experts' knowledge. The second is an elicitation technique by which the necessary military knowledge is extracted from expert commanders, manuals, and existing data bases. Of course, the information structure must be designed with the elicitation requirements in mind so that an optimal military knowledge base will emerge.

The elicitation of military knowledge presents unique problems which stem from the fact that recent years have seen very few real large-scale battles in which the United States was directly involved. As a result, statistical battle data is not available, and the number of officers with actual battle experience is decreasing. This implies that a military knowledge base can rely only to a limited extent on previous experience. Rather, it will have to rely extensively on subjective and judgmental understanding of the overall doctrine of the opponent.

3.2 Knowledge Elicitation Requirements

Knowledge elicitation is an essential part, and is of great

influence on, the success of a knowledge based system such as that which the APT techniques produce. The requirements from a technique for knowledge representation and elicitation include:

(1) Group elicitation
(2) Modularity and efficient integration
(3) Literature-assisted elicitation
(4) Cohesiveness and conciseness of information requests
(5) Attractiveness to military personnel
(6) Ease of update
(7) Computational efficiency
(8) Ease of interface with situation assessment algorithms
(9) Adherence to reality

Group Elicitation. To avoid any personal bias, mistakes, or lack of knowledge of a given individual, each component of the knowledge base must be produced by a team of experts. Group elicitation techniques, and their characteristics and requirements, have been extensively discussed in the literature, e.g., Huber (1974), Linstone and Taroff (1975), Keeney and Raiffa (1976) and Dalkey (1977). The available techniques should be examined, and perhaps modified, to create a reliable and efficient technique for our purposes.

Modularity and Efficient Integration. Because of the versatile aspects of the system knowledge base, its establishment would require several teams of experts, each of which excels in one aspect of the battlefield. It cannot be done by a single team. This implies a modular elicitation approach by which each team is assigned a module within the framework of its expertise. The approach must be systematic so that the various teams can communicate with each other. It should also provide efficient tools for integration of the modules into one, and for conflict resolution.

Literature-Assigned Elicitation. A great deal of the required knowledge base already exists explicitly or implicitly in textbooks, field manuals or computerized data bases. A few examples include the FM 30-10 for geographical analysis, FM 30-11 for weather analysis, FM 30-102 handbook on Agressor, the USAICS Handbook on the Soviet Ground Forces (Sup R69720, August 1971), and the TOS computerized data base currently under development. The elicitation techniques should make provisions for utilizing as much as possible this kind of literature and data bases, thus saving duplicate efforts and accelerating the establishment of a high quality knowledge base.

Cohesiveness and Conciseness of Information Requests. The cognitive processes by which experts provide subjective information has been thoroughly researched, e.g., Tversky (1977), survey by Hogarth (1975) and no concensus exists. It appears, however, that well-formulated, cohesive and concise information requests usually produce more reliable and accurate results. Also, cohesive and concise requests reduce the amount of variability between experts, facilitate and accelerate reaching a concensus (if desired), and contribute to modularity.

Attractiveness to Military Personnel. The cooperation of military experts is a key issue for successful establishment of a realistic and comprehensive knowledge base. The elicitation process is, by its nature, a lengthy process that requires significant intellectual efforts. Therefore, the more that is done in the direction of facilitating the process, the higher the chances are to gain cooperation. A typical example would be a set of computer program tools that permit flexible access to the knowledge base for purposes of review and updating.

Ease of Update. It is very likely that a high quality knowledge base will not emerge after the first round of sessions with experts. In order to encompass the entire complexity of the situation assessment

process, the knowledge base will have to pass several "tune-up" iterations in which elements of the knowledge base will be modified or deleted, and others will be added. The knowledge base may also require modifications due to changes in, or better understanding of, the opponent's doctrine. In order to perform these changes frequently, the information structure must provide for efficient and effective updating of the system knowledge base.

Computational Efficiency. The knowledge base constitutes the focal point of the system and is frequently consulted. In fact, all the system activities center around the knowledge base. Therefore, it is important for the elicitation approach to include a computationally efficient representation and storage of the knowledge base. This is important not only because of economic considerations, but also because of human factors of man-machine communication. If every reference to the knowledge base required a significant amount of time, the attractiveness of the system to the user would drop sharply.

Ease of Interface with Situation Assessment Algorithms. The knowledge base is an integral part of the system intelligence. The algorithms that perform the situation assessment task are other components which, together with the knowledge base, complement the system intelligence. An efficient interface between these two components is an imperative feature of the approach. The knowledge base information should be represented in a form directly useable by the situation assessment algorithms.

Adherence to Reality. Because of the difficulties inherent in structuring a human recognition process, adherence to reality must not be sacrificed in favor of an elegant description of the process, nor to a description which is too simplistic to be real.

3.3 Situation Assessment Techniques: Requirements Analysis

The techniques for interactive computer-aided situation assessment should be optimally designed to operate in an adaptive sequential manner which follows the three phase iterative description given in Section 4.2. An adaptive sequential technique offers the following advantages over a "hard-wired" algorithm, i.e., one which always follows a predetermined set of actions ordered in a fixed sequence:

(1) It is capable of modifying doctrinal templates to adapt to specific conditions (e.g., mobility constraints) that prevent the opponent from applying the textbook doctrine.

(2) It selects for consideration only those alternatives that are currently relevant.

(3) It rearranges the information requests as it learns more about their predictive potency in a given situation.

(4) It avoids requesting redundant indications which are either irrelevant to the present situation, or which contain information that has already been conveyed by known indications.

(5) It stops requesting information when sufficient evidence has been collected for a final decision, and not necessarily when a predetermined list of indications is exhausted.

(6) It is able to address specific requests of the user with regard to verifying or denying hypotheses concerning the situation in certain battlefield aspects.

The requirements for the adaptive situation assessment technique

are derived from two basic criteria. First, in order for the system to be practical, it must be able to perform adequately the assessment tasks for real-life situations. Second, the algorithm must interact with the user in a way which will minimize user reluctancy to using the system. These two basic criteria, and the characteristics of the situation analysis task, are translated into the following requirements:

(1) Recognition capability in a hierarchical structure.

(2) Horizontal and vertical communication channels between modules in the hierarchical structure.

(3) Capability of handling probabilistic events and producing conclusions with uncertainty factors.

(4) Capability of filtering out implausible situations. Such a capability will reduce the load from the commander by decreasing the number of situations he has to consider as feasible.

(5) Capability of processing and utilizing information as soon as it becomes available. This is in contrast to programs that entirely control the information acquisition process and are not able to process and utilize information unless it is requested by them. This capability is required for two reasons. First, the user must set the goals - not the computer. The program may be of great help in suggesting goals, but the ultimate decision must be made by the user and the program should be able to follow him. Second, the commander does not control all the information sources which provide data relevant to his tasks, and usually the information flows in a piece-meal manner.

(6) Feature selection capabilities by which the program recommends the next features to be observed, based on cost-effectiveness analysis.

(7) User control. At any stage of the analysis, the program must be under the full control of the user. He should be able to interrupt the process in the middle of a task and to exercise another option. Likewise, he should be able to override the computer recommendations for either further information acquisition or situation recognition.

(8) Capability of goal-oriented analysis. If the commander wishes to concentrate on the exploration of a specific hypothetical direction, the program should be able to join the commander on this "adventure" and to provide him with its regular complement decision aids.

(9) Capability of explaining to the user the reasoning process of the program. For any given system response, the user must be able to request that the system explain itself. This feature of the technique is very significant for enhancing the acceptability of the system and the credibility of its output. This is so because the system's response ceases to be the result of a mysterious process, and also because the computer can provide a validity value of each recommendation specifying what evidence brought it about.

(10) Capability of incorporating negative information as well as positive information.

(11) Capability of coping with changes in the system knowledge base

(12) Capability to handle inconsistencies and even contradictions in the available data.

4. COMPUTER AIDED SITUATION ASSESSMENT

4.1 Overview

This chapter provides top-level designs and descriptions of the basic mechanisms of a development situation assessment system. The proposed system is aimed at meeting the criteria described in Chapter 3. It is based on the multi-purpose, multi-membership Bayesian classification process and is compatible with the concept structure of military experts. A detailed discussion of the knowledge elicitation process is also provided. This approach to a knowledge based system was used successfully in the medical environment (Ben Bassat 1977b). The system developed was MEDAS, an emergency room diagnosis system. Other APT techniques, such as production rules, can be applied but lack the built in orientation around probability and uncertainty that the multi-membership model provides. Although the APT represents a maturing technology, it has not advanced to the point where it is in common use and the techniques are thoroughly understood, especially the issue of system's behavior when the application increases substantially in size. Thus, a program aimed at transferring this technology to the military environment should be considered an advanced research and development program rather than an implementation program. With this caution in mind, the proposed situation assessment system will be described.

Within the overall cyclic process of decision making in the battlefield, situation assessment is the stage that follows goals determination and precedes battle planning (see 2.1). Situation assessment may be viewed as a multi- rspective hierarchical recognition process in which the staff officers collect and integrate a set of findings and indications (features) to infer the situation which exists in each perspective of the battlefield. This process is hierarchical,

since in many cases final decisions cannot be made from raw data. Rather, raw data is used to recognize basic indications, which, in turn, are used to recognize higher level indications, until a comprehensive understanding of the opponent's course of action is reached.

The development effort of an intelligent computer-aided situation assessment system consists of two major tasks. The first phase is concerned with the elicitation and computer representation of the necessary knowledge for situation assessment. The problem focuses on capturing the essence of the situation assessment process in a systematic and structural fashion, which can later on be used by a mechanism for computer-aided assessment.

The knowledge base derived in the elicitation process is focused on the specific problem domain at hand (military situation assessment), and is the essential part that provides APT systems with their power, flexibility, and "intelligent" capabilities. The considerations guiding the elicitation process and the recommended techniques are described in Section 4.8 after the system and its algorithms are described.

The second task deals with the actual design of the situation assessment mechanism and the environment in which it is used. Sections 4.2 describes the essential processes and 4.6 goes into the detailed computations. Section 4.4 provides, through examples, the logical structure of the proposed military knowledge base. Section 4.5 shows how these logical structures and the probability information associated with them will be represented internally. The rest of the chapter describes the system itself. In 4.4, the top-level system block-structure is given, and 4.7 provides a more detailed description of each sub-system's function and main activity.

4.2 Situation Assessment - The Basic Process

Situation assessment is technically viewed here as a multi-perspective hierarchical recognition process. The process cycles through three main phases. Phase I does the interpretation and integration of information, Phase II is concerned with selection of what additional information is necessary and which is the best information source to employ to acquire it. This is required in case the available information is incomplete or is insufficient for a reliable assessment. In Phase III, the conclusions of the situation assessment process are summarized and presented to the user.

Phase I is a bottom-up, multi-perspective, hierarchical, recognition process. We will use Figure 4-1 to explain these terms. It shows the contents of a part of a hypothetical military knowledge base which is used by the recognition process. The recognition process is "multi-perspective" in the sense that the overall picture of the situation is constructed from elements recognized in various perspectives of the battlefield. In each of the interrelated perspectives, the situation can be classified under one of the alternatives associated with that perspective. For example, in Figure 4-1, an enemy attack can be one of the following types: deliberate, hasty, spoiling, or an ambush. Similarly, there are several alternatives for THRUST, TARGET, TACTICS, etc.

The recognition process is "hierarchical" in the sense that low-level indications are used as the building blocks of higher level indications or courses of action. For instance, information regarding the presence of trees, their height and density are features that contribute to determining cover and concealment. Boulder size and soil type contribute to determine tank trafficability. Together they

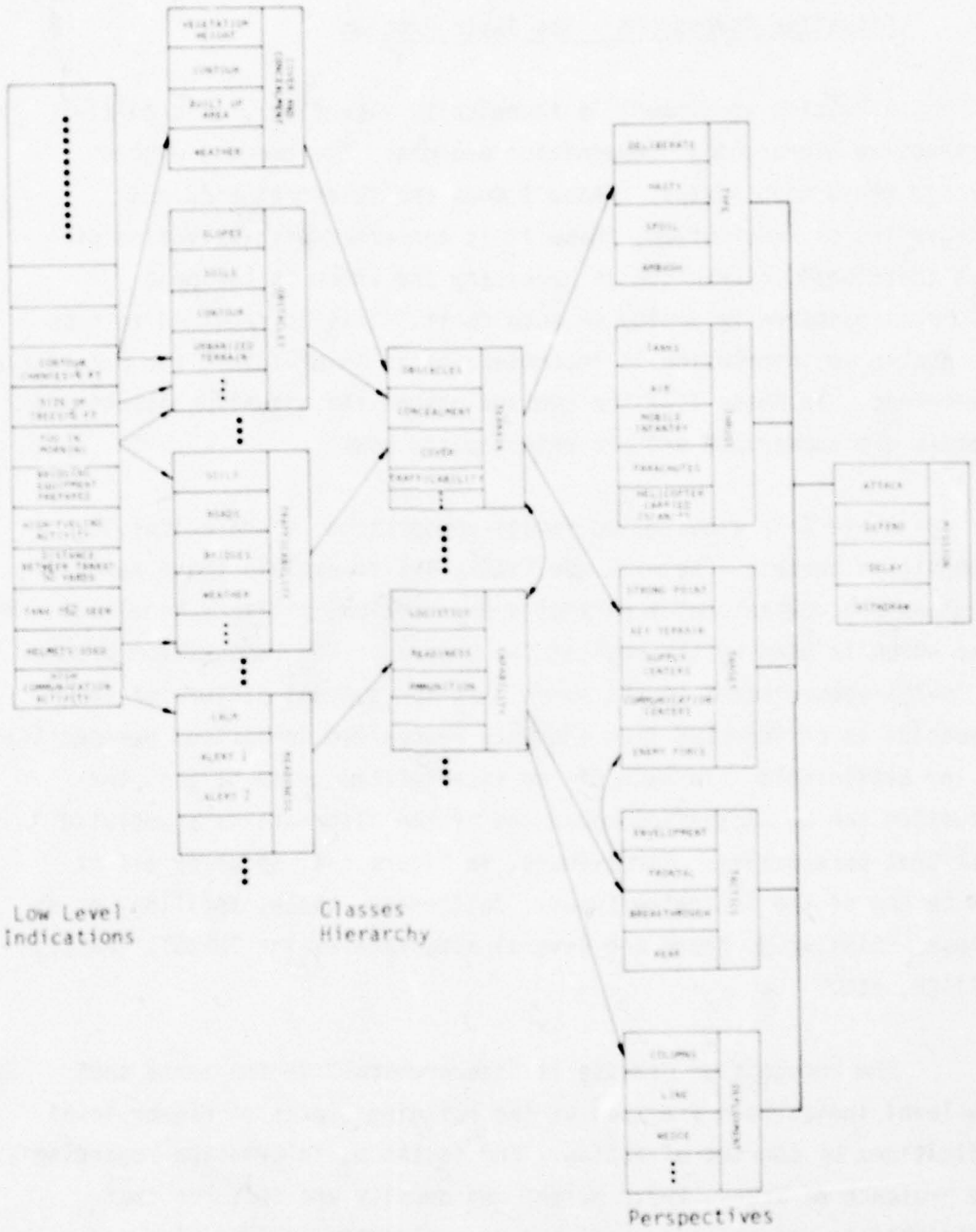


FIGURE 4-1. MULTIPERSPECTIVE HIERARCHICAL STRUCTURE OF THE SITUATION ASSESSMENT PROCESS

contribute to terrain analysis. The results of TERRAIN CAPABILITY and other factors contribute, in turn, to the determination of what tactics the enemy may choose, his deployment technique, and even influence the choice of a target.

Figure 4-2 shows in a schematic form the same hierarchical structure and the relations between indicators and classes. It is an example of the data structure used by both the recognition process (Phase I) and the verification process (Phase II). For example, the low-level indications #1, #3, and #21 point to class C1. At the same time, #1 and #21 are also indicators for class C2. Thus, the same indicators may refer to different classes which may be true concurrently. If C1 or C2 are recognized as being true, this is an indication for the higher level class C23.

Phase I starts with the user (a member of the G2 staff) providing the system with specific facts about the situation. These facts may have been observed in the field or they may have been passed to the G2 through the command channels. They may have come from higher echelons, from parallel units or from subordinate units. They include also indications or responses to information requests that have been placed previously by the G2 and collected by the various information collecting agencies at his disposal. The user needs to format the facts into one of several rigid formats (or key-word patterns) that the system recognizes using pattern-matching techniques. This large set of recognizable patterns form the bottom layer of the hierarchical structure of Figure 4-2. The low-level indicators that were observed and entered into the system trigger an upward moving chain of events. Notice that any subset of the larger set of low-level indicators can be entered initially - the system does not specify any of the indicators to be designated as starting points. Any fact that is available can trigger the recognition process.

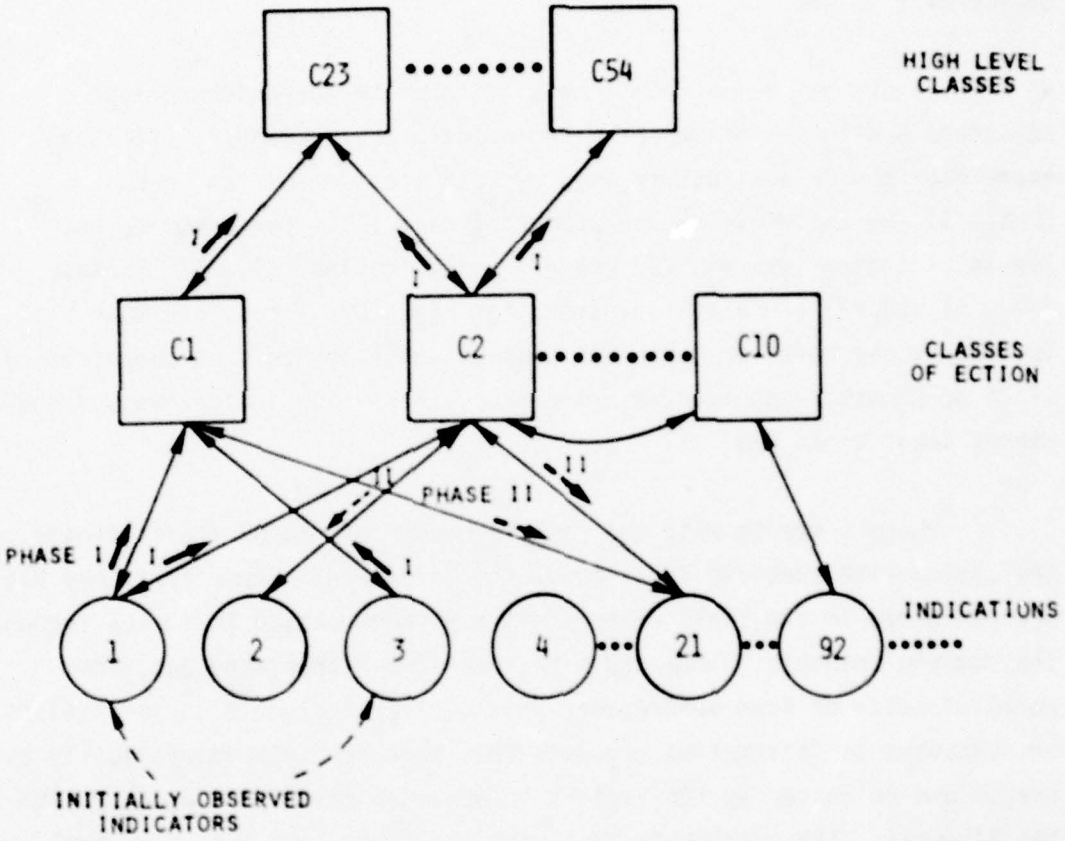


FIGURE 4-2. THE TWO PHASE RECOGNITION PROCESS

This gives the approach great flexibility. As the available facts are entered, the system generates and updates a list of tentative classes that may be true about the situation. All the evidence available, which is relevant to the truth of a particular class, is utilized in assessing the class validity. The facts provide supporting evidence for some classes and refuting evidence for others. The calculations are based on the multi-membership Bayesian model discussed later.

Let us look more specifically at Figure 4-2. Suppose indicators #1 and #3 were initially observed in the field and entered to the system. These indicators, following the links in the hierarchical structure, provide evidence for classes C1 and C2 (only relevant links are present in the structure - resulting in great reduction of the structure's complexity). This is shown in the figure by the small solid arrows pointing upward from indicators #1 and #3. C1 and C2 are entered into the list of tentative classes. They in turn trigger the high level classes C23 and C54, which are added to the tentative list, too. The function of Phase II, the verification phase, is to weed out this list until only the true ones are left.

Phase I is mostly a bottom up process. Occasionally, however, correlations between indications at the same level may provide horizontal evidence as well. For instance, recognizing the size of an attack may suggest evidence regarding the target of the attack and vice versa. This is indicated by a horizontal link such as between C2 and C10. Moreover, it is also possible that certain indications provide evidence for other indications at lower levels. For instance, if indications associated with "precence of a reconnaissance battalion" clearly indicate that a division level attack is anticipated, this may increase the likelihood that an observed and previously hard to interpret column of tanks is a part of the division attack, and even its target becomes easy to determine.

When the upward triggering process propagates as far as the relevancy links permit, a complete list of all the triggered classes are assembled and the evidence available for each is aggregated. The aggregation used is a modified Bayesian model. At this point a choice is made, some classes have been verified (beyond some reasonable threshold of confidence) and others have been totally refuted by the evidence (below some lower threshold). These classes are dropped from the tentative list. This is done for each class for which enough evidence is available. The process then tries to see if some global, top level class was positively asserted (the termination test). If one was asserted, it can be used as a skeleton for a global situation interpretation; otherwise, more information is necessary and the process goes to Phase II.

Phase II, the verification phase, is mostly a "top down" process, using the same data structure that Phase I does. It decides what additional information is necessary to settle conflicting classes, which observations will be most effective in providing the needed information, and which are the best collecting sources to perform the observations.

Phase II starts with the list of tentative classes that were assembled and edited by Phase I. It includes all classes in the different perspectives of the battle that have not been settled yet (either definitely verified or definitely refuted). The process looks for making these decisions in the next cycle of Phase I. The relevancy information is, again, contained in the same data structure of Figure 4-2. Following the dashed arrows pointing downward it can be seen that indication #2 is relevant for settling class C2, and indications #1 and #2 can settle a conflict between C1 and C2. A complete subset of the indicators so selected is the base for generating information requests. Some of these requests will be answered by the user directly, some have to be formulated

as queries and sent to other TOS data bases for answers, and some are turned into Information Requests (IRs). This transformation is done as follows: The available sources of information that may provide required observations are evaluated in terms of cost (financial, logistic, availability, and risk) against expected information gain (i.e., uncertainty reduction). As a result of this evaluation, an optimal request for information related to additional indications is made. The acquisition of new information from these sources ends Phase II of the current iteration. Thus, Phase II generates specific information requests for all sources: the user, other accessible data bases, and for the information collection agencies.

When the answers to these requests are entered again into the system, Phase I is restarted to evaluate, interpret, and integrate the new evidence. The iterative process terminates when either (1) all the triggered classes are settled to some threshold of validity (positive or negative termination) to permit proceeding to situation assessment summary, or (2) temporal considerations force the system to terminate even though certain battlefield aspects may not be entirely clear -- a non-optimal decision is sometimes better than no decision.

The process described above shows how the hierarchical data structure, which is the embodiment of expert knowledge, drives the recognition and verification process. This is the reason for APT techniques being called "knowledge driven." The links in the structure point explicitly to relevant classes or features, and there is no need for major search efforts.

Phase III in the situation assessment process is the summary generation. Situation assessment summary is the process of composing the individual decisions made for separate battlefield aspects into one

complete and coherent picture that leads to tactical planning. The result of this process is the Intelligence Estimate document which is currently produced manually by the intelligence officer.

4.3 Top Level Structure of Situation Assessment System

This section describes the functional top level building blocks of the proposed situation assessment system. The system is based on the multi-membership multi-purpose Bayesian recognition process, and is designed to address and be compatible with all the requirements of an advanced Knowledge Based System outlined in Chapter 3. The target application for the system is aiding for a division level G2 (intelligence officer) in his information collection, integration and final summarization. Figure 4-3 is a block diagram of the system at the top level. The main functions of each block in the diagram are described below.

The heart of the system is the Situation Assessment Processor. It performs cyclically Phases I and II using information and data structures obtained from the blocks around it. In Phase I, the information recognition and integration, it obtains specific indicators (facts about the current situation) by interacting with the G2 through the man/machine dialog subsystem. It then uses the hierarchical data structures contained in the Military Knowledge Base to build a multi-perspective interpretation of the situation. In Phase II, it directs requests for more information to the user through the Information Request Evaluator.

The objective of this process is to obtain a single integrated interpretation of all the available data and events in the form of a unified situation assessment. The output of the Situation Assessment

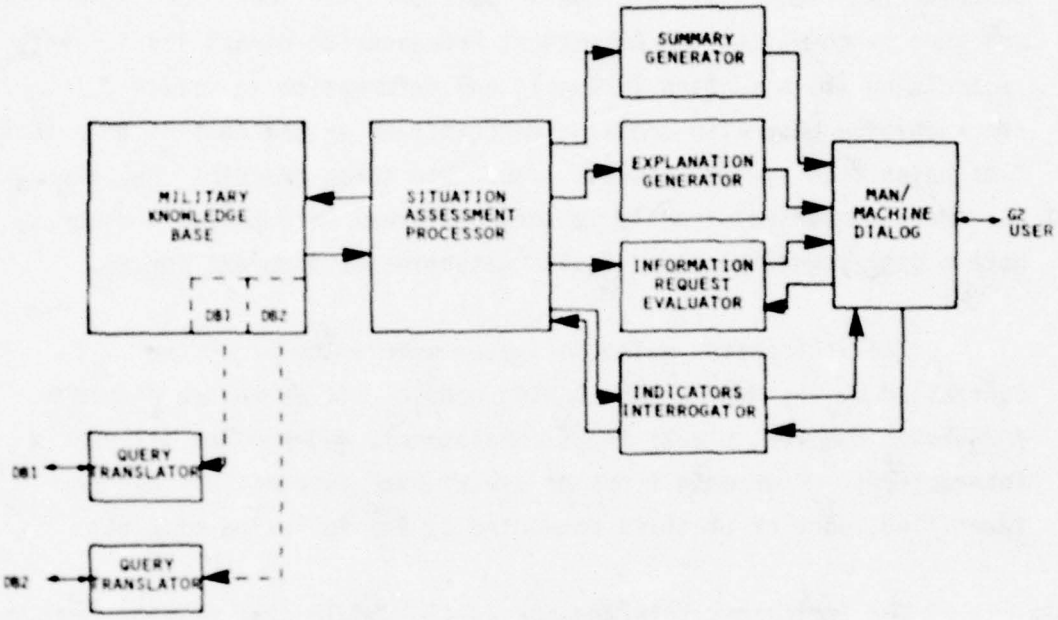


FIGURE 4-3.
DECISION AID FOR DIVISION G2,
SYSTEM BLOCK DIAGRAM

(Phase III) Subsystem is formatted by the Summary Generator into a document similar to the Intelligence Estimate Report.

The Military Knowledge Base contains the explicit representation of military expert knowledge. This information is derived from the literature and from experts and is kept in data structures such as those described in Figure 4-1, 4-2 and in Section 4.4. These data structures are used by the Situation Assessment Processor to direct its activity of recognizing the situation (Phase I) and information acquisition (Phase II). The knowledge base also contains descriptions of the content of external data bases such as TOS, TACFIRE, etc. Via these descriptions, the system may address queries directly to these external data bases in order to obtain data regarding a particular situation or opponent forces.

The interaction with the system user - the G2 officer - is controlled by the Man-Machine Dialog module. It generates displays, formulates queries, checks input consistency, and handles all user interactions. Four main types of system-user interactions may be identified, each of which is conducted by the following modules:

The Indicators Interrogator is the module that elicits from the user the facts about the situation and translates it into indicators as required by the situation assessment processor. The information is elicited through fixed-format queries (e.g., if tanks were observed, the system responds by asking for the number, location, type, activity, etc.). These details are transformed to an appropriate internal representation.

Using predetermined structures (for attack, defense, etc.), the Summary Generator produces a detailed analysis of the situation in light of the chosen interpretation. It completes Phase III of the process. This analysis is given in the format and structure of the Intelligence

Estimate Report commonly provided to the commander by the G2. The summary is centered around enemy intentions and his most probable courses of action.

The Explanation Generator allows the system to produce answers to "How" and "Why" questions issued by the user. For example, "How did the system arrive at given conclusions?" "Why is the system requesting specific information?" "What is the evidence supporting a given interpretation?" This module also permits retrieval of any portion of the system knowledge base for purposes of "on the job" education (e.g., "which are the indications that characterize a certain course of action?").

The Information Request Generator analyzes the capabilities and costs of the various information collection resources available to the G2.

4.4 Logical Data Structures

A division level deliberate attack will be used as an example to show the type and organization of different data structures required in the knowledge base. The information in these data structures is general, showing what is the typical relation between size, location, weapon systems, distribution, etc., of the different units. It also contains probability information about the expected rate of occurrence of different events in various circumstances. Finally, it contains low-level indications which are the observable facts in the field that would indicate the probable occurrence of some higher level events. The next section will show on an abstract level, how these structures are used in the recognition process. It should be emphasized, however, that the examples discussed in this section were developed to show the kind and flavor of the information necessary for the APT system and are not necessarily complete.

Figure 4-4 represents the general information associated with each enemy unit. Each extension is a "slot" that must be filled with the appropriate kind of specific data. Thus, SIZE contains DIVISION and LOCATION contains information about the CP location and the dispersion of the division's subunits. This structure is hierarchical in that each unit is a part of the order of battle of the unit above it. It has a function to perform in that unit's plan, and it is located within the higher level unit's sector. The most important aspect to recognize for situation assessment is the enemy's intention or mission. There are several perspectives in which a mission can be analyzed, and each of these is a hierarchical structure by itself. Together, they specify the mission the unit is engaged in. In Figure 4-5, they are represented as nodes eminating from the DELIBERATE ATTACK slot. They are the following: TARGET, PLAN, FUNCTIONAL STRUCTURE, etc.

Figure 4-5 shows a simplified hierarchy of mission types. It represents the range of alternatives that can fill the MISSION slot in Figure 4-4. Naturally, this hierarchy would be different for units of various sizes, reflecting the range of missions typical to that particular unit. Thus, an AMBUSH is a typical mission for a platoon but is quite uncommon for a division. In Figure 4-5, the various perspectives are again indicated as tip nodes, which together define a specific type of attack (e.g., the DELIBERATE ATTACK).

The various perspectives provide structure by which indicators in the field can be combined and interpreted. The structures for PLAN, FUNCTION and DEPLOYMENT will now be discussed.

Figure 4-6 shows a simplified plan or tactical scenario of a division level deliberate attack. It gives the sequence in time of the main events of the tactical scenario. It starts with the planning

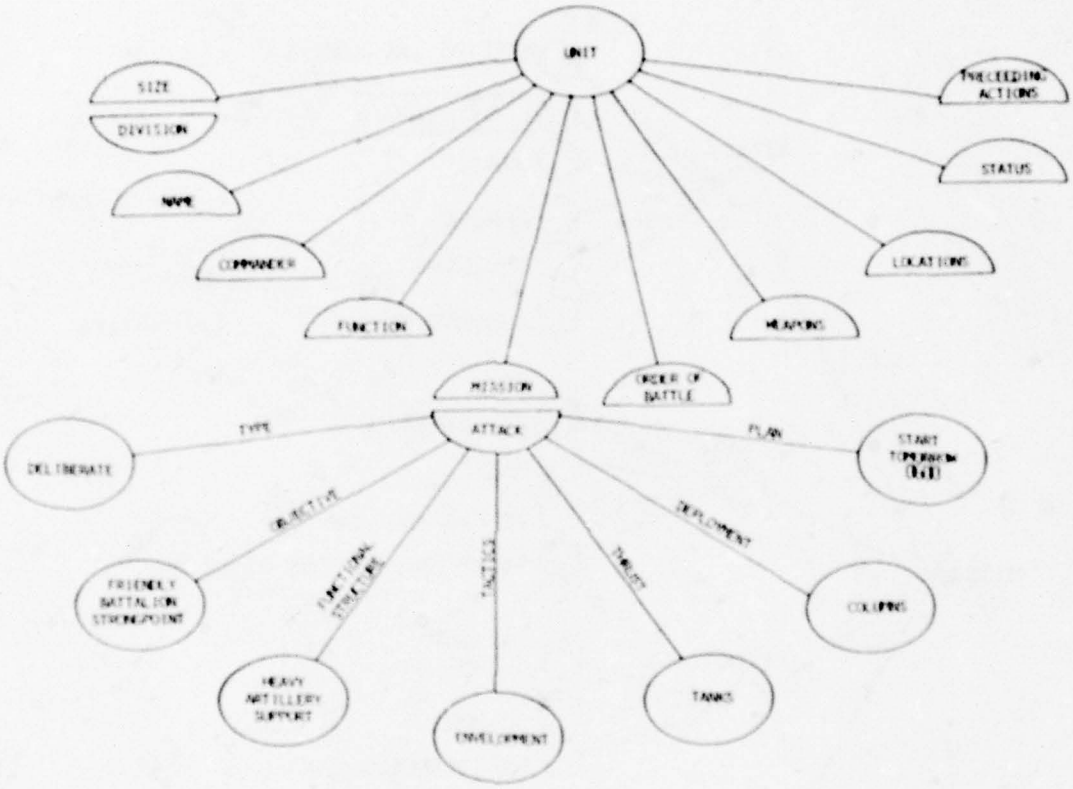


FIGURE 4-4. A SIMPLE UNIT DATA STRUCTURE

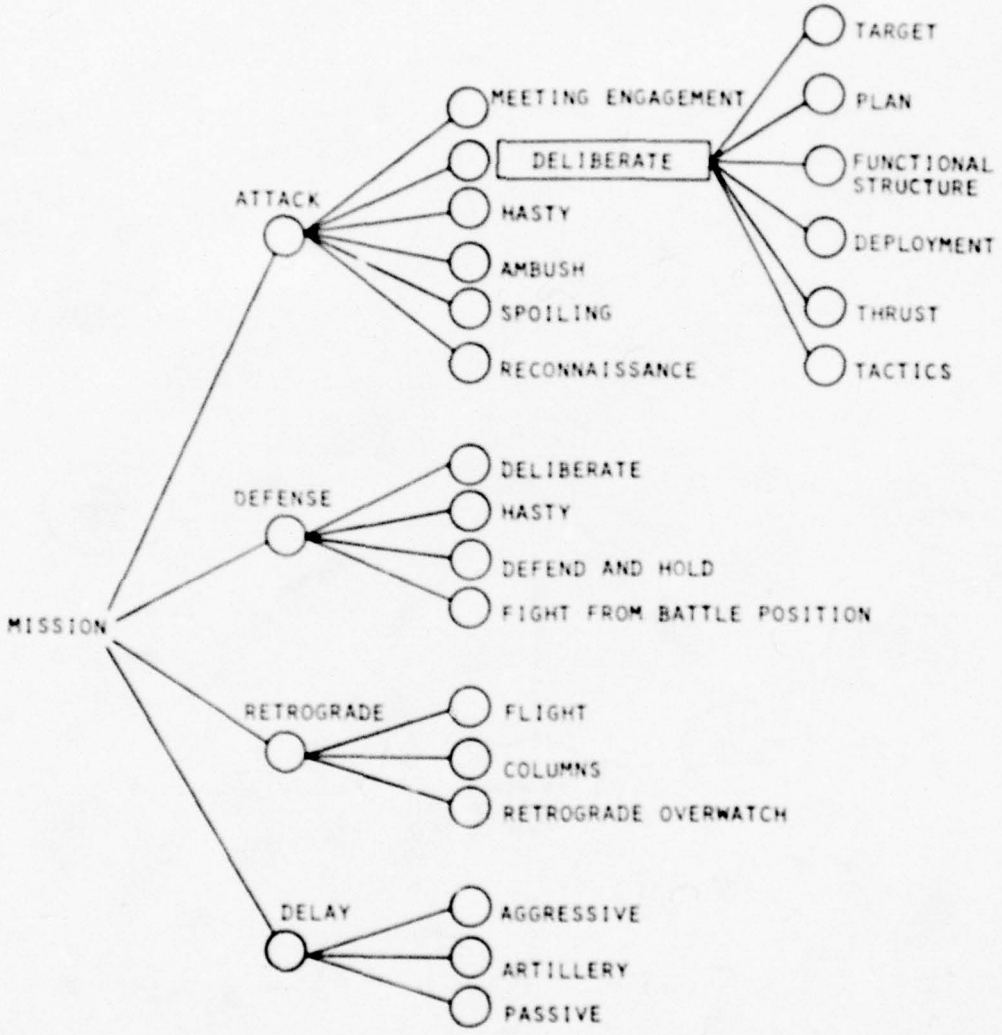


FIGURE 4-5. HIERARCHY OF MISSION TYPES

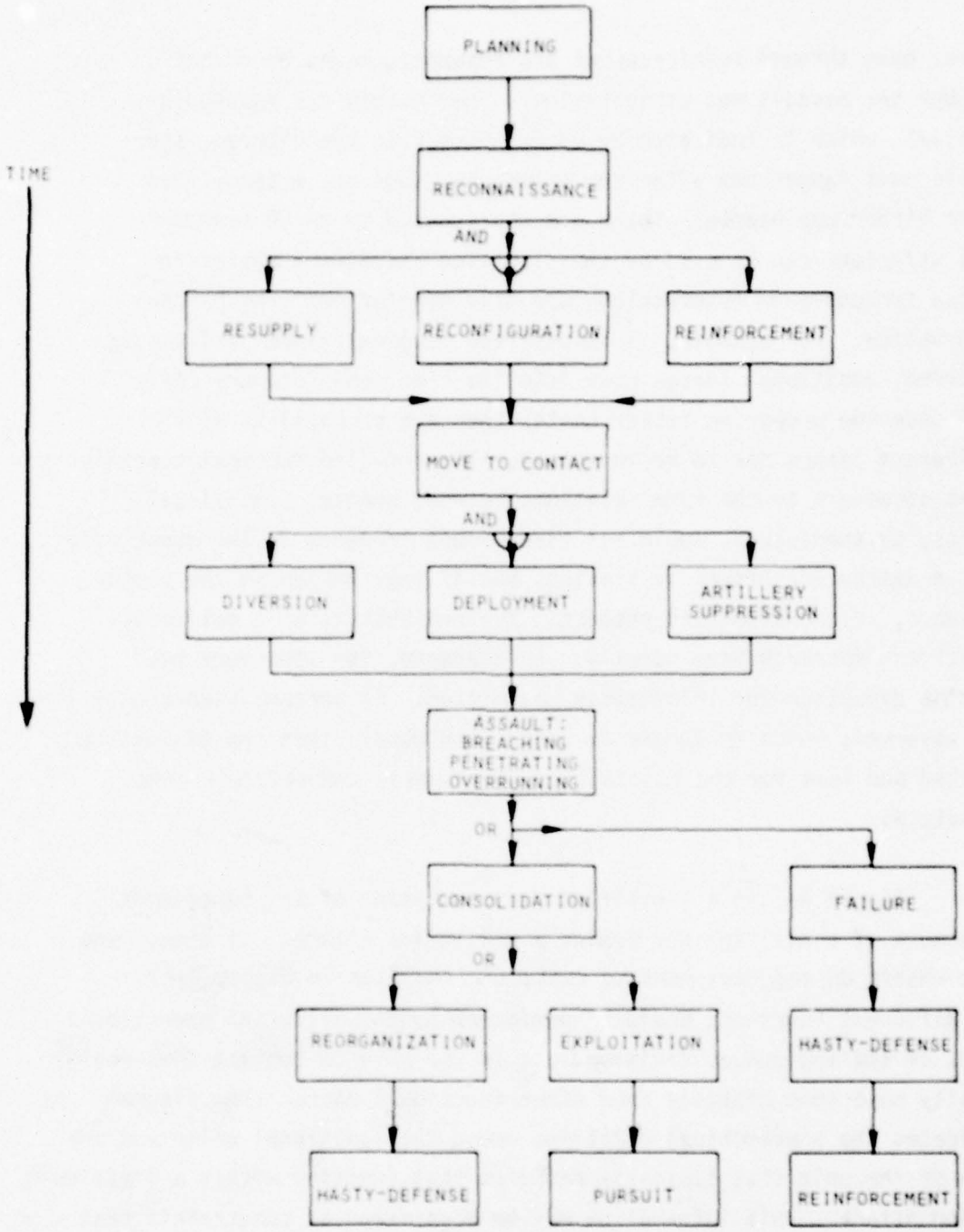


FIGURE 4-6. THE PLAN OF A DELIBERATE ATTACK

phase, goes through reinforcement and resupply, moves to contact, through the assault and exploitation. Some events can happen in parallel, which is indicated by an AND branch in the diagram. some events must happen one after the other, and some are alternatives where either may happen. These are represented by an OR branch. This structure can be used by the situation assessment system to impose structure on observations and draw conclusions from partial information. For example, if intensified reconnaissance activity was observed, additional forces came into the area, and infantry units were observed preparing rubber boats; then the probability of a deliberate attack has to be increased. The detailed tactical scenario gives structure to the time relations between events. Individual events, by themselves, would not give enough credence to the hypothesis that a deliberate attack is brewing, but if they happen in the proper sequence, as the structure predicts, the probability of a deliberate attack can increase very quickly. Furthermore, the structure can provide direction for information collection. If reconnaissance activity was observed, which is larger in scope than usual, then the G2 must be alerted and look for the possibility of resupply and reinforcement activities.

Figure 4-7 is a simplified representation of the functional structure of a division performing a deliberate attack. It shows "who does what?" during "movement to contact" (see plan in Figure 4-6). The different functions would be performed by the different operational units of the indigenous division, but in the move to contact they would usually move some distance from other functional units. The diagram indicates the hierarchical relations among the functional units and the size of the unit that typically performs that function within a division during attack. This information may be considered as constraints that must be met by a unit if it is to fill the proper function in the diagram.

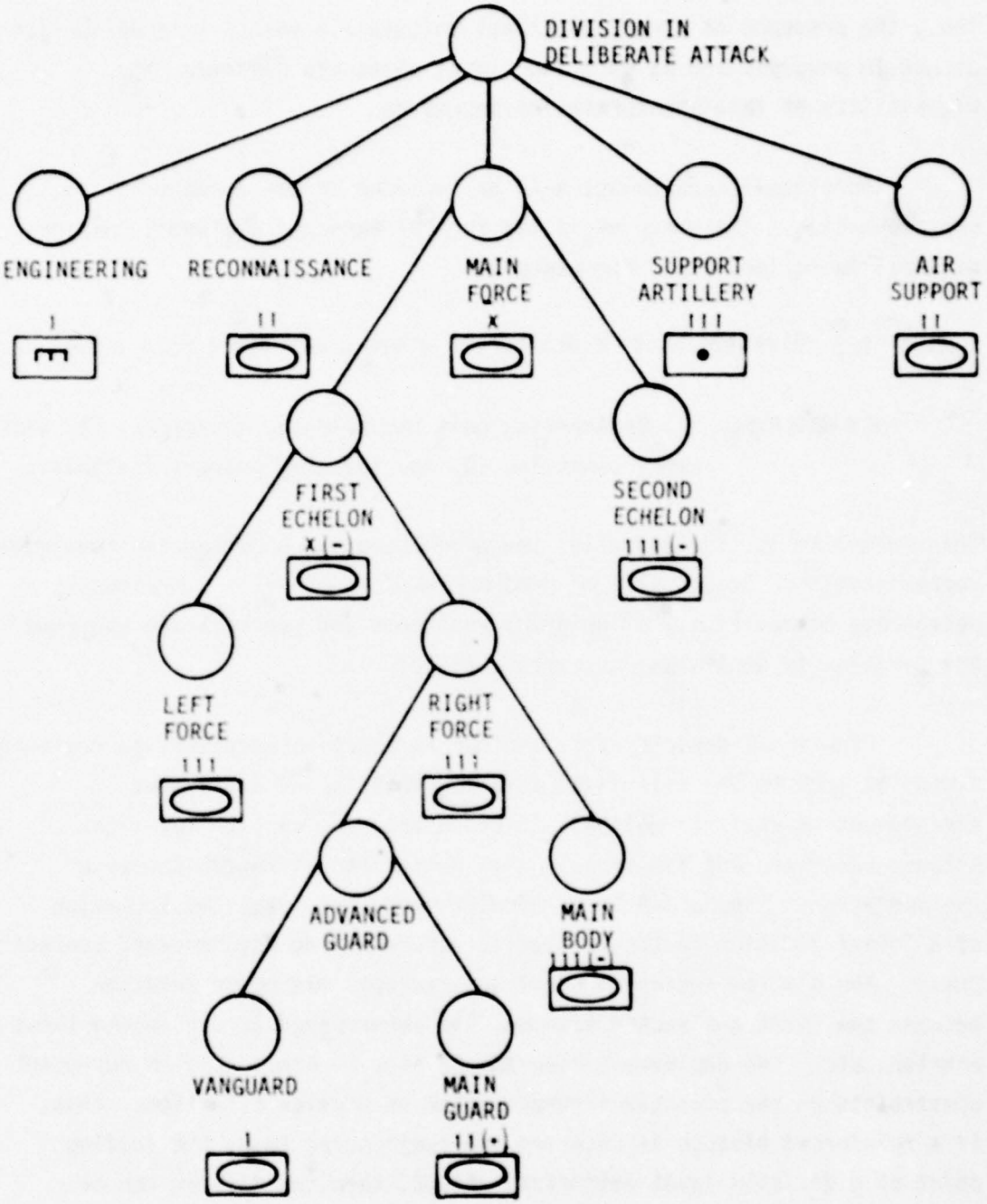


FIGURE 4-7. FUNCTIONAL STRUCTURE OF A DIVISION IN A DELIBERATE ATTACK

Thus, the presence of these functional units again points to a deliberate attack in progress and as more functional units are observed, the plausibility of this interpretation increases.

Additional constraints will be included in the computer representation. These may be in the form of expected equipment, weapons, external formation, etc. For example:

IF: Division is in a deliberate attack, and there is a river ahead

THEN OBSERVE: (1) Engineering unit has bridging equipment, (2) Tanks carry snorkels, (3) and infantry prepare liefboats.

This formalism is, incidentally, the production rules method for knowledge representation. It can also be used backward to activate a hypothesis of deliberate attack (i.e., if bridging equipment and snorkels are observed, the division is on its way to cross a river).

Figure 4-8 depicts still another perspective necessary to represent a mission such as the deliberate attack. This is the deployment arrangement of units in motion. It represents the spatial relation between the different functional units during the different phases of the operation. Figure 4-8 in particular shows the idealized formation of a Soviet division in the deliberate attack during the "move to contact" phase. The diagram conveys the echelon concept, the power relation between the first and second echelon, the two-pronged thrust in the first echelon, etc. The deployment diagram can also be considered to represent constraints on the possible interpretation of a given situation. Thus, if a reinforced platoon is observed and conjectured to be the leading point of a division level deliberate attack, then the diagram can be used to identify supporting evidence. One to one-and-one half kilometers

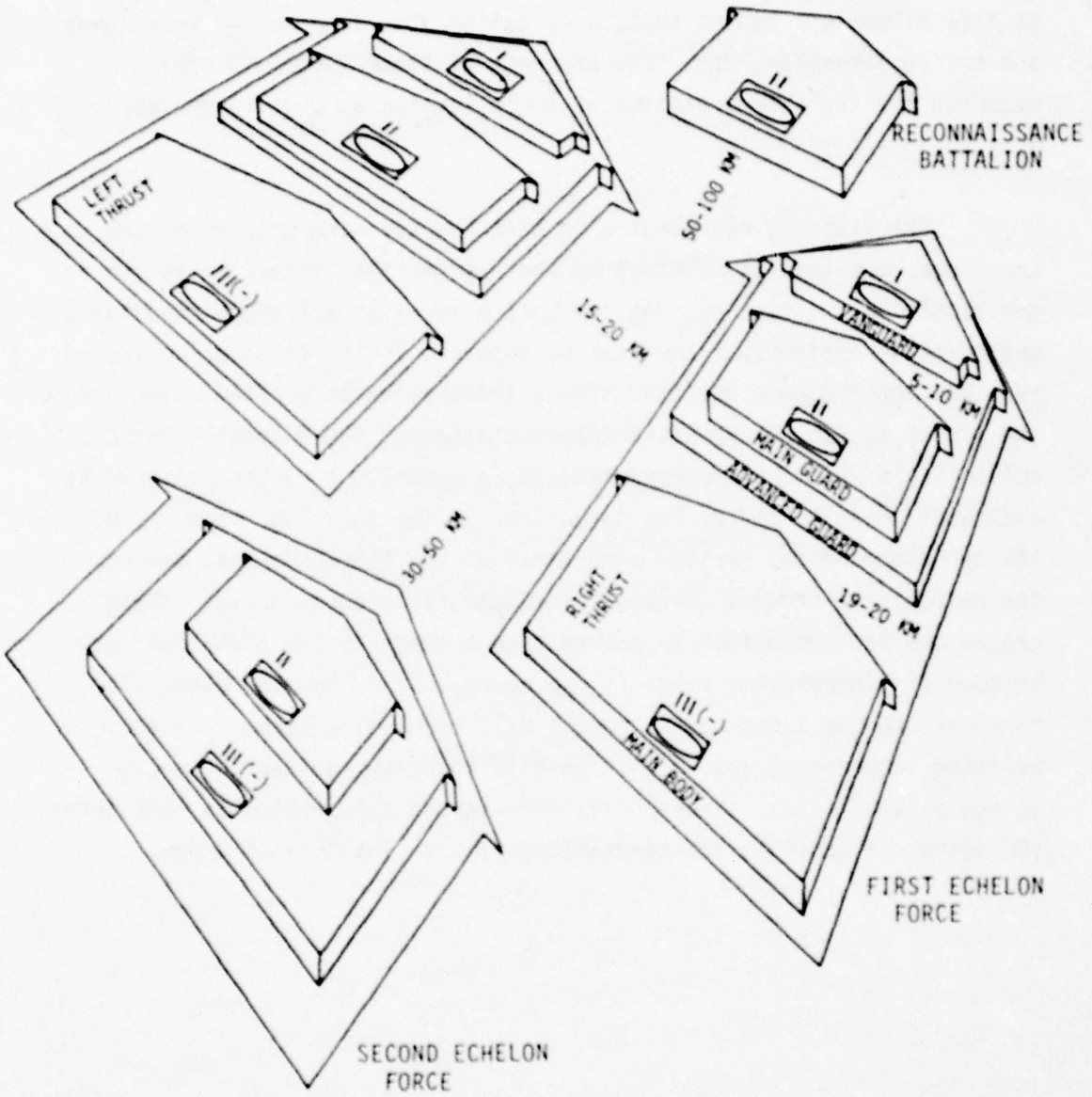


FIGURE 4-8. THE DEPLOYMENT OF A DIVISION IN "MORE TO COMBAT"

behind the point platoon there should be a reinforced company. Three to five kilometers behind that, a battalion should be moving in columns and battle formation, etc. The presence of these forces is strong evidence for the interpretation of the situation as a division level attack.

The diagrams represented in this chapter make up part of the knowledge base that is utilized by the recognition process to assess the battlefield situation. At the bottom level of all these structures are specific indications that can be observed in the field or collected by other intelligence sources. These indications direct the attention of the system to various possible interpretations. The initially large collection of possible interpretations is weeded out by the constraints and conditions implied by the structures in the knowledge base. Thus, the structure of the various components of the knowledge base direct the recognition process to specific issues to be checked out. These can be checked out either by information already in the knowledge base or specific information requests can be formulated for the user. The responses to the information request will be used to either reinforce existing interpretations, reject some of them, or redirect attention to new possibilities. Eventually, when enough information is considered, the number of possible interpretations will shrink to just a few.

4.5 Technical Representation of Knowledge

4.5.1 Introduction. This section will outline in more technical detail the format in which the logical structures discussed in Section 4.4 will be represented in the system. The representation is based on an extended Bayesian classification model called multi-membership and multi-purpose classification. It deals with two main concepts: features and calsses. The concept structures are hierarchical, for each two successive levels i and i+1, classes at level i are features or information items for the next higher level i+1. Probability and valididty information is associated with each two successive levels.

At the very bottom level (level 1), the features are just specific data items, e.g., events or activities observed in the battlefield. Patterns of these features create the classes of level 2, which describe indications regarding the enemy activities or intentions. The indications of level 2 become the features for level 3 classes, which are either higher level indications or, infact, constitute final recognition of the enemy course of action. Generally, the features that characterize the classes in level i+1 are not restricted to come from the immediately lower level i. They may come from any lower level below. For instance, in Figure 4-1, which illustrates this structure, the level 1 features, such as "size of trees>6 ft", serve as indications for level 2 classes that describe concealment. The possible concealment type of level 2 becomes the features of level 3 classes regarding the terrain. Thus, features at any given level may serve as indications for classes in different perspectives of the battlefield.

4.5.2 Features. The term "feature" represents any piece of information related to the battlefield situation, for instance, volume of communication activity, number of tanks in a given force, road conditions, activity rear area, etc.

A cost is associated with each feature that reflects financial, temporal, and logistic efforts required to obtain the information about that feature. For instance, information that is provided by an in place observing officer would be significantly cheaper than information obtained by a reconnaissance aircraft. This cost is used in the information request evaluator which generates cost-effective information acquisition proposals (see Figure 4-3). (The airborne observer will probably provide more accurate information than the officer, but costs more).

Logical interrelationships between features are also recognized and utilized in the situation analysis model. These refer to interrelationships in which the value of a given feature dictates the value or relevancy of another feature. For instance, if the feature "tank force moving to forward position" is negative, then this automatically implies that features such as "type of tanks", "number of tanks", "configuration of tanks", etc., are irrelevant. Or for instance, if the feature "increased activity in rear areas" is negative then this implies that all the features regarding increased activities, e.g., "Intensified Traffic of Fuel Tankers", are negative.

The features may also be categorized into groups that suggest relevancy to a given battle field. For instance, features relevant to Navy operations are irrelevant to a desert battle far away from any sea or ocean.

4.5.3 Classes and Hierarchical Strucutre. The higher-level units for situation analysis are the classes. The term "class" refers to a combination of features that consitutes a well-defined situation in any aspect of the battlefield. For instance, classes for the possible deployment of a unit in the attack (see Figure 4-1) are: C1: columns, C2: line, C3: wedge, etc. The features that characterize these classes include #1: "dispesal of tanks", #2: "direction of attack", #3: "distances

between tanks, etc. The significance of each feature X_j in a given pattern is described by means of two conditional probabilities, P_{ij} and $\overline{P}_{ij}$, where:

P_{ij} = the probability that feature X_j is positive given that class C_i is the true class.

$\overline{P}_{ij}$ = the probability that feature X_j is positive given that class C_i is <u>not</u> the true class. Namely, the probability that the presence of X_j is attributed to other class(es) except C_i.

The P_{ij} value represents the sensitivity of feature X_j as an item of evidence for class i, while the $\overline{P}_j$ value representes one minus the specificity of X_j as an item of evidence for class i. In other words, the ratio $P_{ij}/\overline{P}_{ij}$ indicates the odds in favor of class i when a positive result is obtained for feature X_j. Similarly, $1\text{-}P_{ij}/1\text{-}\overline{P}_{ij}$ indicates the odds in favor of class i when a negative result is obtained for feature X_j.

When the classes for a given aspect of the battlefield are mutually exclusive and exhaustive, only P_{ij} needs to be estimated for every feature X_j that is relevant to class i. The value for $\overline{P}_{ij}$ is given by:

$$\overline{P}_{ij} = \sum_{k \neq i} P_{kj}$$

where the summation is over the rest of the classes in this aspect of the battlefield. It should be emphasized, however, that the model does not necessarily assume that the classes are mutually exclusive and exhaustive. For instance, for recognizing the type of attack, there

is not need to assume that it is going to be either frontal, or envelopment. In principle, both of them may be simultaneously true.

Features that are not included in the pattern of class i are considered irrelevant for that class. The irrelevance of feature X_j to class Ci indicates that that information regarding Xj does not affect the assessment whether class i is the true class or not. For instance, the feature "Sudden Increase in Communication and Electronic Activities" may provide very little or no information for diagnosing the configuration of a given force. Accurate definition of irrelevant features and probability computations with them are discussed in Ben-Bassat (1978b). The paper shows basically that for any given class-pattern, only the conditional probabilities for the relevant features need to be estimated. This is in contrast to classical Bayesian models in which the class/feature conditional probabilities need to be estimated for every class/feature combination. The result is a major reduction in the number of probabilities that have to be estimated by experts.

As already noted, the terms "features" and "classes" are relative, since a given class may serve as a feature for a higher-level class. For instance, a reconnaissance platoon is a feature for recognizing the pattern of a division level attack. Yet, in order to recognize that a given platoon is a reconnaissance platoon, (and not, for instance, a platoon level attack or the point of a mjaor attack), a pattern of features needs to be assembled. These features are related, for instance, to deployment format, observation equipment, weapon systems, etc.

It is also possible for a given class to serve as a feature for a lower-level class. For instance, if features other than a reconnaissance platoon clearly indicate that a division level attack is anticipated, then this increases the likelihood that a given platoon is the reconnaissance platoon for this attack.

Table 4-1 shows a typical pattern for attack (i.e., the features relevant for its assessment). The indicator list was taken from FM 30-102, while the probabilities were taken from Johnson (1977) Table 1. The $\bar{P}$ values were calculated to be the average over the courses of actions defend, delay, and withdraw.

4.6 Situation Recognition Process

4.6.1 Phase I - The Recognition Probability Calculations. Utilizing the information structures, described in Sections 4.4 and 4.5, multi-membership and multi-purpose classification models (Ben-Bassat, 1977) may be used to drive the two-phase iterative siutation assessment process (Section 4-2). Once a feature X_j is observed, all the classes for which it is relevant are identified. These classes may be in different classification schemes. (Each classification scheme represents one aspect of the battlefield). For a given relevant class i, the present probability is updated using the formula:

$$P(C_i|X_j) = \frac{P(C_i)\ P(X_j|C_i)}{P(C_i)P(X_j|C_i)+(1-P(C_i))P(X_j|\bar{C}_i)} \qquad (1)$$

where $P(X_j|C_i)$ is either P_{ij} or $1-P_{ij}$ depending whether X_j is positive or negative, and similarly for $P(X_j|\bar{C}_i)$ which is either $\bar{P}_{ij}$ or $1-\bar{P}_{ij}$. At the beginning of the process $P(C_i)$ represnt prior probability for class i. The positive probabilities obtained by (1) are compared with two thresholds; VERIFIED and ELIMINATE. If $P(C_i|X_j)>$VERIFIED, we decide tentatiely that class i is the true class for the battlefield perspective it behongs to. If $P(C_i|X_j)<$ELIMINATE, we decide tentatively that class i is not the true class. Once a tenative decision is made for class i, this class is not taken into consideration for future feature evaluation purposes (see below). However, we continue to update the probability of C_i as more features are obtained that are also relevant to C_i. Such

TABLE 4-1. A PATTERN FOR AN ATTACK

Class: Attack

Features	P	$\bar{P}$
· Massing of mechanized elements	0.8	0.3
· Extensive artillery preparation	0.8	0.4
· Artillery position concentrated	0.8	0.2
· Concentration of mass toward either or both flanks.	0.7	0.3
· Location of enemy troops in forward assembly area.	0.8	0.3
· Location of supply and evacuation installation well forward	0.7	0.3
· Increased Air Reconnaissance	0.8	0.4
· Movement of additional troops toward the front	0.8	0.4

an update will either strengthen the tentative decision or raise suspicions regarding its validity. If such an update elevates the probability of an eliminated class above ELIMINATE or decreases the probability of a verified class below VERIFIED, then the corresponding tentative decisions are cancelled. If temporal considerations require that certain actions be taken immediately, then these actions should be taken under the assumption that the tentative decisions are final decisions.

Those relevant classes that are neither verified nor eliminated are designated as active classes which require additional evidence for classification. An additional threshold ACTIVE may be used that will designate class i as active only if $P(C_i|X_j)$>ACTIVE.

At any point, the system maintains up-to-date lists that include: (1) all the classes that have been decided, and (2) all the tentatively active classes. These lists are the focal point of the system's attention and are frequently displayed to the user.

4.6.2 Phase II - Collecting More Evidence. The active classes are associated with lower-level features which have not yet been observed and which are relevant to these classes. These features are then evaluated by weighing their potential contribution to recognizing each of the active classes against their cost of testing. As a result of this evaluation, the next features to be tested are recommended to the decision maker. This evaluation is done by the Information Request Evaluator subsystem (see Figure 4-3).

Functions for assessing the potential contributions of a feature may be derived from information measures, divergence measures, and performance measures. The following is a typical example of one of these selection rules:

Minimize the expected total weighted uncertainty measured by Shannon's entropy

$$H(X_j) = \sum_{i \in T} a_i E\,[h^i(Xj)] \qquad (2)$$

where:

$$h^i(X_j) = -P(C_i|X_j)\log P(C_i|X_j) - (1-P(C_i|X_j))\log[1-P(C_i|X_j)] \qquad (3)$$

In this equation, T stands for the set of active classes, the a_is are the costs of testing the hypothesis, and E denotes the expectation operator. Expectation is taken with respect to the mixed distribution of X_j under C_i and $\bar{C}_i$.

It is also possible to permit the decision maker to choose which active classes should be explored. For instance, the decision maker may elect to concentrate for a while on either verifying or eliminating a specific class C_i. In this case, the index class T contains only the index i. Similarly, the decision maker may elect to concentrate on a certain aspect of the battlefield. Needless to say, the decision maker has the right to override the program recommendation and select other features.

4.6.3 Mixed Initiative Aspects. The key characteristic of the situation assessment mechanism is the flexibility it offers to the user in controlling its operation. The user may specify the perspectives of the battlefield he wishes to consider, or he may let the computer choose them for him. The user may specify the features he would prefer to observe next, or

he may let the system select them for him as well. In between the extreme alternatives of full-user control and full-system control, there exists a wide variety of combinations of mixed-initiative user-system cooperation. The principle is to let the user decide on the operation strategy. The computer plays the role of a passive, intelligent, and polite advisor who serves the user requests but simultaneously makes recommendations. It also stands by to call attention whenever the user is about to commit an error in the interpretation of the data, to ignore important alternatives, or to request information that is already available explicitly or implicitly.

4.7 Detailed System Description

4.7.1 Situation Assessment Processor. Figure 4-9 is a modular breakdown of the situation assessment processor where solid arrows indicate flow of control and dashed arrows indicate flow of information. The top arm in the diagram (boxes A, B, C, F) performs Phase I and the bottom arm (boxes H, I, J) performs Phase II.

The Feature Extractor module accepts features from the user, checks them for consistency, and generate automatically the implications of these features with regard to other features.

The Tactical Category Selector associates the entered features with the relevant higher level indications and courses of actions in various aspects of the battlefield. The relevancy information (described in 4.6.2.) is part of the content of the Military Knowledge Base.

The Plausibility Evaluator performs the probability calculations and updating of all the currently relevant classes (see mechanism in 4.6.1). The updating is done by using the prior probability of each

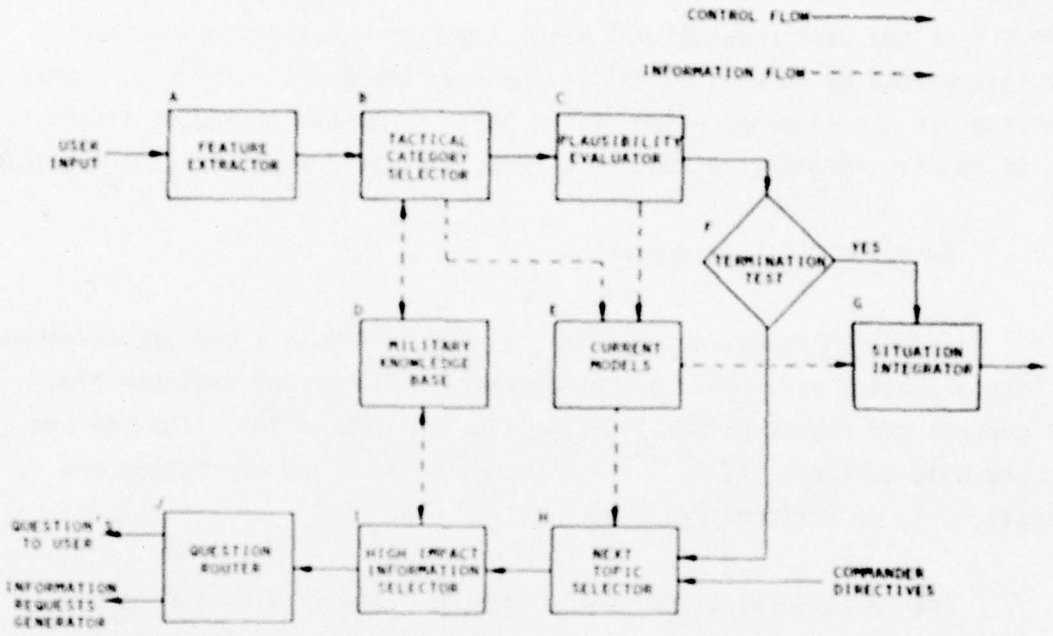


FIGURE 4-9. SITUATION ASSESSMENT PROCESSOR

category and incorporating new evidence (feature values) that came up recently. Through this updating process, the Plausibility Evaluator also manipulates the Current Model of the situation by checking tentative decisions from earlier stages, inserting new classes into the list of ACTIVE classes, and deleting others.

The Termination Test block has various criteria to decide whether the process should stop. These may be time constraints, plausibility thresholds, or sufficiency of details in the model, i.e., the situation model which had most of its key features accounted for by recognized indicators is selected to be the most plausible explanation of the situation. When the termination test is satisfied, or the user decides to terminate the process, the system is ready to provide a summary or conclusion of its deliberations. The Situation Integrator is triggered when this happens, and it puts together an integrated picture of the situation by combining in a meaningful way, all the information contained in the proven indications and courses of actions. This integrated picture is an interpretation of all the available evidence and is used as the input to the Situation Summary Generator.

If the termination test is not satisfied, Phase II is needed. The system proceeds to request additional information in order to verify or eliminate active classes, or to obtain information about battlefield aspects which have not yet been triggered. The Next Topic Selector is the algorithm that decides which of the contending classes is the most worthwhile to explore. This decision can be made, again, by several criteria, for example: (1) the class with the highest plausibility on the list, (2) the class which is easiest to disprove and then eliminate from consideration, (3) the class with the least amount of evidence for or against it, etc.) The output of this process is a list of one or more classes to be next discussed with the user.

As can be seen in Figure 4-9, the user may enter his own preference as a directive, and the system will obey and follow his directions. The High Impact Information Selector chooses, for the classes under consideration those features which, when tested in the field, will have the highest impact on the situation. The impact may be either positive -- to prove a category beyond reasonable doubt, or negative -- to disprove it. The objective of the feature selection rule may also be to distinguish between two likely contenders. The High Impact Selector determines the features with the highest information impact at the given state of affairs. The best information collection agents that will be used to obtain these features are determined by the Information Request Generator.

The Question Router will make an evaluation of the complexity of the Information Requests, whether they are simple questions that can be answered by the user on the spot, or require information gathering. The complexity of a question may be decided by checking the location of the feature in question in the knowledge base hierarchy. Low-level features can be asked directly while, for higher-level features, the cost of obtaining a result must be estimated. In the latter case, the question must go through Information Request Generation and be optimized in relation to the availability of information collecting resources and the utility of the information now requested to the overall picture of the situation. An additional consideration is not bothering the user with trivial issues or with questions whose answers can be derived from previous user answers. Once the new set of requested features is generated, a new cycle starts with the user providing features via the feature entry module.

4.7.2 Summary Generator. The Summary Generator produces a goal-oriented description of the military situation. The product is equivalent to the intelligence estimate document now produced manually by the G2.

Figure 4-10 is a block diagram of the Summary Generator. Previous systems, such as SHRDLU (Winograd, 1973) and PROSPECTOR (Duda, et al, 1977), contain similar functions and use the same pattern matching technique described below.

The Tactical Category Selector chooses from the integrated situation description a subset of indications and courses of action that afford a complete coverage of the available evidence, that is, the smallest set of recognized classes that would explain the largest part of available information in light of the mission goals. This subset would usually contain one main thrust and additional secondary efforts. (For example, the enemy would attack city x with a division level force through a central mountain corridor.) The Unique Attribute Selector will identify which attributes of the expected attack are unique and help point them out. The commander does not have to be reminded again and again what the basics of an attack are, but if the expected attack is, for example, a quick one with strong support from tactical missiles rather than the usual artillery support, this is important information to point out.

The Summary Format Selector will choose from a limited set of summary templates the one fitting the current situation using template matching technique. These templates will be derived from current military reporting practices. For example, in reporting enemy attack, the report must include the target of the attack, when it will start, what is the main thrust, weapon systems, and on which approach route. All these are contained in the internal military knowledge base but the templates will be standard formats for reporting all aspects of a recognized attack. The summary template data base contains all these templates and it may also include personal commander preferences. For example, he may like to know what is the main objective of the enemy force first, and then its tank force strength. The summary templates

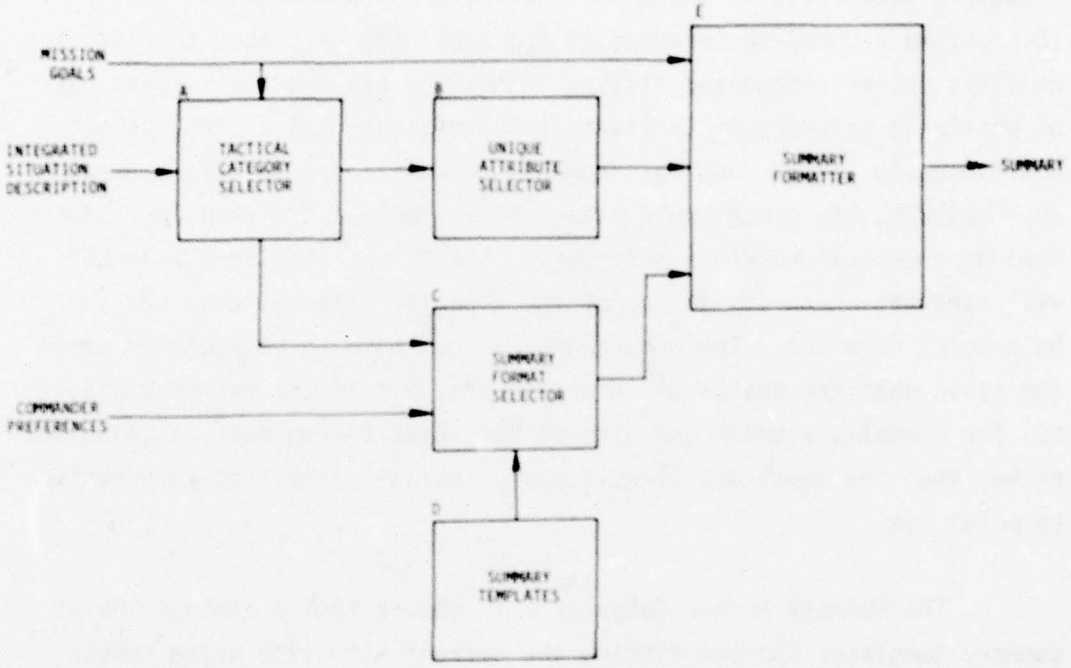


FIGURE 4-10. SUMMARY GENERATOR BLOCK DIAGRAM

would typically be different for different main enemy missions, e.g., in a defensive mission, the terrain analysis with possible avenues of approach should be given before describing enemy forces present, while the arrangement might be different for other missions.

The Summary Formatter will select the summary template most appropriate for the top level situation class recognized in Phase I. It then fills in all the empty slots in the template using the specific information about the situation obtained and verified during the recognition phase. Thus, suppose a deliberate attack was recognized as the main enemy tactical objective. In the process of recognizing this class, it was verified that the enemy is moving in columns, is using tanks as the main thrust, and is going to perform an enveloping assault. Each of these facts was picked out of several parallel classes under the same tactical perspective (e.g., "columns" is one of many possible attack deployments, [see Figure 4-1]). All these specific facts are placed in corresponding slots in the summary template for attack. The filled in template is then transferred to the man-machine dialog subsystem which generates the actual output presented to the user.

4.7.3 Information Request Generator. The Information Request (IR) Generator is an optimizing algorithm. It takes the list of features to be obtained, the prespecified coverage information (what features each information acquisition source can obtain), and the costs information, and it produces the set of minimal cost information acquisition tasks. It searches for the most cost-effective utilization of the information collection resources in light of the value of the expected information they can bring to bear upon the situation assessment process. The evaluation formulas were given in Section 4.6.2.

The input to this system (shown in Figure 4-11) is a priority list of needed information items as generated by the high impact information selector block in Figure 4-9. Together with the information items, this algorithm needs the expected utilities of each with respect to improving the picture of the situation. The algorithm uses the following additional information: (1) the cost in time, military resources and effort of each information collection resource; (2) the Coverage Information -- from which needed information items can be obtained in each mission of the collecting resource; and (3) Commander Information Request priorities -- which are standing requests placed by the commander, himself, outside the system demands. From this information, the Optimizing Coverage Algorithm produces a list of information collection missions and the corresponding Information Request for each. The Information Request Formatter transforms these missions into acceptable IR's in the usual military format. Figure 4-11 is a block diagram of the Information Request Generator.

4.7.4 Explanations Generator. The Explanation Generator (Figure 4-12) produces answers to "Why?" and "How?" questions posed by the G2 to the system. It explains the reasoning process that led to a particular conclusion and the items of information which contributed to any change in the picture of the situation.

In Figure 4-12, the inputs to this process are explanation demands which are produced by the man-machine dialog subsystem. The Topic Reference Resolver identifies which dialog topic the question references. For example, "Why?" may refer to the last conclusion presented by the system to the user. The Dialog Topic List contains the recent sequence of topics which were touched by the user or the system. Once the topic of the question is identified, the explanations are generated by filling the gaps in a standardized set of Explanation Templates.

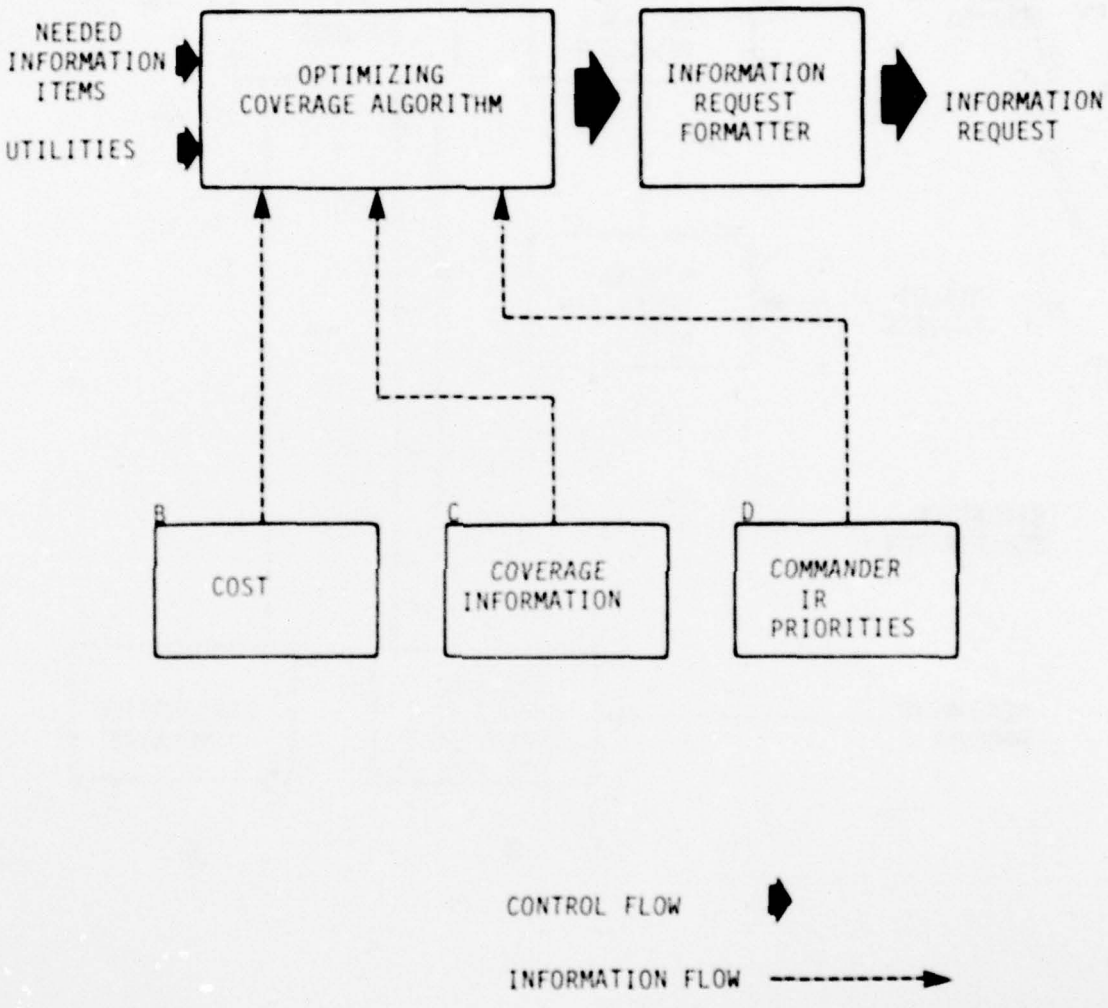


FIGURE 4-11. INFORMATION REQUEST GENERATOR BLOCK DIAGRAM

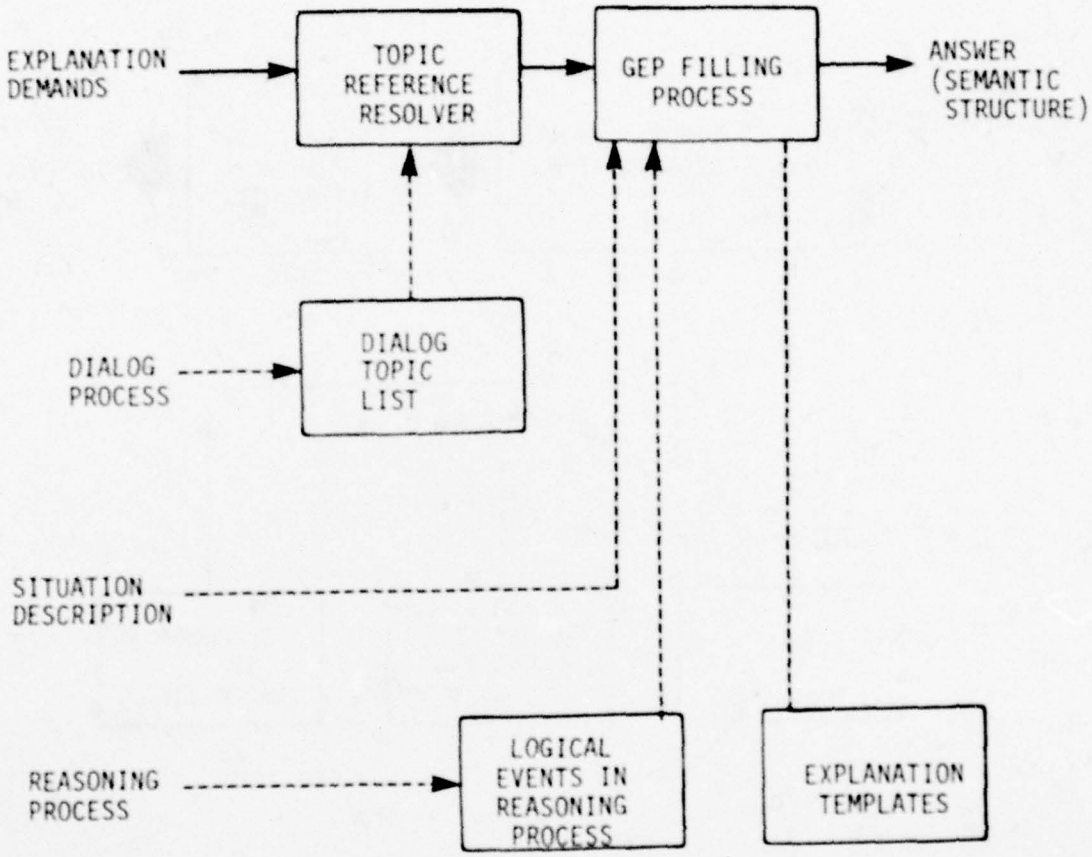


FIGURE 4-12. EXPLANATION GENERATOR BLOCK DIAGRAM

4.8 Knowledge Elicitation

An important part of the APT knowledge base construction is the elicitation of expert knowledge. This section contains the methods useful in eliciting expert knowledge for the structures described in Sections 4.2, 4.5, and 4.6. The elicitation techniques described are pattern directed. Namely, the knowledge base is composed of patterns, each of which represents the characterization of a class in the hierarchical structure by means of its significant features. Accordingly, the expert is required to provide patterns of the wide spectrum of possible situations in the battlefield. His final product goes from the situation (class) domain to the indication (feature) domain. That is, first the class is specified and then, for this particular class, the expert supplies the characteristics of this class. This direction is the complementary direction to the direction of Phase I situation assessment, where the analyst goes from the feature domain to the class domain, i.e., he first observes features and then tries to infer the meaning. The major advantage of class-to-feature direction for elicitation purposes is described by Ben-Bassat (1978c). It argues that it is simpler for an expert to specify a class and then list its features, than to start from a low-level feature and then list all the classes that can be influenced by its presence or absence.

The elicitation process of each component of the knowledge base proceeds in three main stages that may repeat themselves until a convergence to high quality patterns is reached.

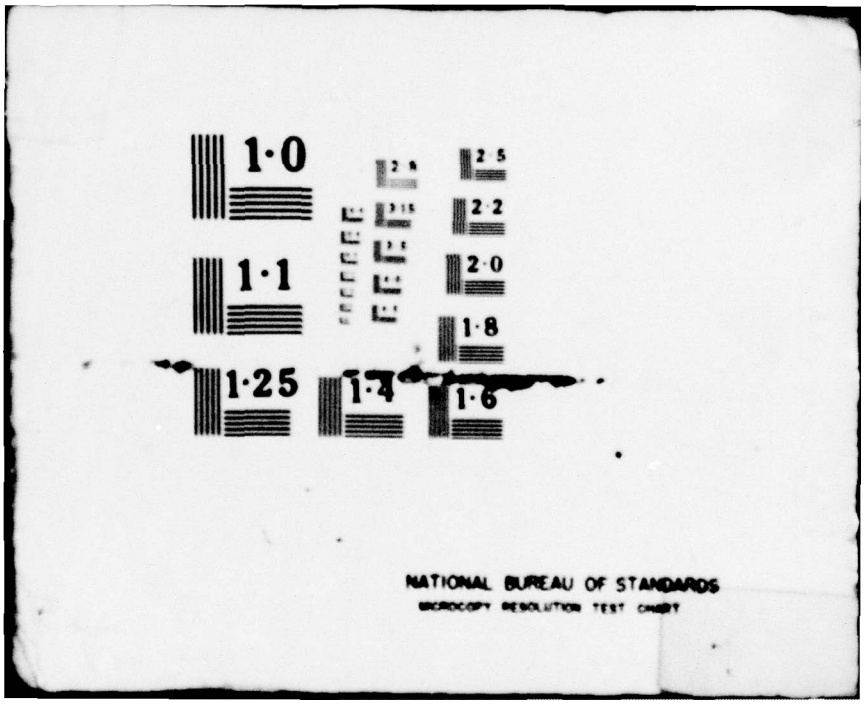
Stage 1: Class Characteristics. For a given battlefield aspect, say "type of attack", all the possible classes are first identified, for example C_1: Frontal Attack, C_2: Close Envelopment, and C_3: Deep Envelopment. With the aid of recent literature and using expert judgment,

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we list for each class those features which are significant for its recognition. Next, estimates for P_{ij} and $\bar{P}_{ij}$ are obtained to quantify the sensitivity and specificity of a feature j for recognizing class i. These estimators do not have to be point estimators. For practical purposes, interval estimators, (e.g., P_{ij} between 0.10 to 0.20) are sufficient, since correct decisions, which are based on the aggregate evidence in many observed features are not very sensitive to non-drastic changes in the P_{ij} and $\bar{P}_{ij}$ values. Of course, rigorous sensitivity analysis will have to be performed with the knowledge base that will eventually emerge. Table 4-2 shows an example of a scale that can be used for this purpose. This terminology is used also in presenting conclusions to the user.

A set of utility computer programs can be devised to provide the experts with help in developing these patterns. These programs will systematically guide the expert through all the steps in class characterization, obtain his answers, and directly generate the internal representation of classes features and probability estimates. The role of these highly interactive programs for man-machine interface is to facilitate storing, modifying, and retrieving data; to smooth the communication channels between experts; and to save everybody a lot of paperwork. The effort required for the development of these programs is marginal compared to the savings in experts' and analysts' time.

Stage 2: Class Differentiation. Having established the initial patterns for all the classes in a given battlefield aspect, the differentiability of each pair of classes is examined. The experts are requested to list the features that differentiate between each pair of classes. This may imply adding new features to each pattern or modifying the P_{ij} or $\bar{P}_{ij}$ values. At this stage, we ensure that any pair of different situations can be differentiated by means of observable features.

TABLE 4-2

INTERVAL ESTIMATES FOR
QUANTIFYING CONDITIONAL PROBABILITIES

A - Always	$P = 1$
VP - Very Probable	$0.90 \leq P < 1$
P - Probable	$0.75 \leq P < 0.9$
F - Frequent	$0.50 \leq P < 0.75$
S - Sometimes	$0.25 \leq P < 0.5$
R - Rare	$0.10 \leq P < 0.25$
VR - Very Rare	$0 < P < 0.10$
N - Never	$P = 0$

The number of pairs for each aspect of the battlefield is M(M-1)/2, where M is the number of classes in this aspect. Since M is usually not larger than five and is almost always less than ten, the number of all possible pairs is manageable. The computer may also assist at this stage by displaying pairs of patterns and computing the discrimination power of each feature in these patterns. This can be done, for instance, by Shannon's information measure.

Stage 3: Feature Characterization. In phase I and II the classes serve as the main frame of reference. Stage 3 concerns the data from the feature perspective. Using the class patterns, the feature patterns are created by a computer program. Namely, for each feature, all those classes are listed for which it was significant, together with the corresponding P_{ij} and $\bar{P}_{ij}$ values. For each feature, the list is reviewed and verified so that all the relevant classes to this feature are included. In the event that a relevant class is missing, the pattern of this class is updated to include this feature as well. The P_{ij} and $\bar{P}_{ij}$ values are also reviewed for different classes, and this may suggest modifications to obtain a more appropriate proportion for the distribution of this feature over its relevant classes. This stage of expansion and refinement would improve if a group of experts is consulted. Several techniques are available for group elicitation process. First, how to obtain the individual contribution from each of the group members, and second, how to aggregate the individual contributions into a single product. In the context of eliciting tactical intelligence indications, Johnson (1977) discusses briefly the Delphi method (see also Linstone and Turoff, 1975), and an operational gaming method (see also Shubik, 1975). Also, Perceptronics has developed an interactive group decision system (Leal, et al, 1978) which elicits and aggregates member's probabilities and values. These methods and others should be further explored.

5.1 Introduction

The system described in chapter 4 is a research and development effort aimed at producing a comprehensive demonstration of a situation assessment system. This chapter includes a discussion of the various risks that must be assessed before such a major effort can be started. The main areas of concern are: (1) technological implementability, namely whether the hardware necessary to implement such a system will be available for the militarized requirements, (2) technical feasibility, whether such a system can be built at all and can provide the level of performance claimed, and (3) knowledge base considerations, whether the appropriate knowledge base can be constructed and maintained. The relation between the SA system and future TOS systems of which it may be a part, will also be discussed, in particular, how the data base of TOS can be utilized by the knowledge base processes incorporated in the proposed situation assessment system.

There are three main conclusions of this chapter: (1) regarding technological implementability, around 1985, when the five year development program will be completed, the state of the art in computer hardware technology would provide all the computing power and memory capacity necessary to implement such a system in a compact militarized enclosure, (2) the system is judged technically feasible when comparing it to existing, successful knowledge based systems that demonstrate performance levels of experts in their respective fields of application. The transfer to the military environment and the accompanying increase in knowledge base size is not expected to cause undue performance degredation, (3) military knowledge and expertise is abundantly available. There are also several appropriate techniques for knowledge elicitation, thus, with proper attention, the knowledge base can be constructed.

Taking into account all the concerns listed above, it is estimated that the risk of an unsuccessful program product is reasonable for a major development effort, especially in light of the expected performance.

5.2 Previous Systems Analysis

The resources used by five successful APT systems and their level of performance are discussed in Appendix B, and a summary in table form is given in Table 5-1. These provide a baseline for estimating the requirements of the proposed SA system. The systems are the following: (1) MYCIN, a medical diagnosis aid, developed by Shortliffe (1976) since 1972 at Stanford, and is still in expansion. It demonstrates impressive diagnosis capability on 3 disease complexes; (2) MEDAS, a medical decision assistance system for emergency and critical care setting developed by Ben-Bassat (1977). It was built on a stand-alone minicomputer over the last three years; (3) INTERNIST, an internal medicine diagnosis aid system developed by Pople (1977) at the university of Pittsburgh since 1971. It is still under development, but several terminals are expected to provide access to the system from several hospitals in the coming year. It covers 600 diseases with over 4000 manifestations; (4) PROSPECTOR, an exploration geologist decision aid is developed by Duda (1977) at SRI. The project is in the middle of a five year program and already helped to assemble a knowledge base useful in mineral exploration. Finally, (5) SHRDLU, is a good example of natural-like language communicating system developed by Winograd (1973) at MIT.

In terms of performance quality, (i.e., "How good are the responses given by the systems?"), all these systems demonstrate expert level performance. For example, INTERNIST can diagnose a complex combination of diseases, showing the quality of analysis judged comparable to an average internist. That is far better than what a family physician can do. (Notice the judgmental evaluation which is the only method for evaluating a decision

TABLE 5-1. PREVIOUS APT SYSTEM CHARACTERISTICS

System / Characteristic	MYCIN	MEDAS	INTERNIST	PROSPECTOR	SHRDLU
Application Area	Diagnosis of blood infections, drug recommendations and explanations	Medical diagnosis and decision assistance for emergency and critical care	Internal medical diagnosis and consultation	Consultation and assessment for mineral exploration	Natural language communication
Knowledge Base Size	3 diseases 200 symptoms 500 rules	53 disorders 670 symptoms	500 diseases 4500 symptoms	118 rules 600 spaces 919 word dictionary	200 word vocabulary scene of blocks
Response Time	Response of expert quality	Instantaneous to few seconds	Internist quality <45 min per case 15-20 sec for query	~1 sec expert quality	A few seconds
Computer Used	DEC PDP-10	Data General eclipse s/20	DEC PDP-10	DEC PDP-10	DEC PDP-10
CPU Power	5-10 MIPS	1 MIPS	5-10 MIPS	5-10 MIPS	5-10 MIPS
Stand Alone?	YES	YES	NO	NO	NO
Memory used for program & data	▶1000 k bytes	112 k bytes 10 M byte Disk	~900 k bytes	▶1000 k bytes	360 k bytes
Language	INTERLISP	BASIC	INTERLISP	INTERLISP	LISP
Operating System	TENEX	ADOS	TENEX	TOPS-20	ITS
Period of Development	Since 1972, continues	2-3 years	Since 1971, continues for 5 more years	Middle of 5 years program	3 years
Man Power	2 Ph.D. + 5-10 man year per year	2-4 man years per year	3-4 man year/per year of experts, 2 man year/ year of programming	4-5 man year per year	1-2 man year per year
APT Technique	Production rules	Multi-member-chip Bayesian model	Modified production rules, semantic network	Production rules and semantic network	Procedural transition network
Developers	Shortliffe E.	Ben Bolcat M.	Pople H.E. Myers J.D.	Duda R.O. Wilcox N.J. Hart P.E. Reboh R. Slocum J. Sutherland G.L.	T. Winograd

maker's performance in medicine as well as in other complex problem domains). MEDAS, MYCIN and PROSPECTOR show comparable performance levels. SHRDLU demonstrated impressive natural language interaction capability over the limited world it knew about.

In terms of response times all the systems respond to queries in a few seconds when their operating systems are lightly loaded. In the case of MYCIN, there is sometimes instantaneous response and sometimes it extends to 2-5 seconds. Typical INTERNIST response time is a few seconds to 20 seconds. A complete session for one case takes typically 45 minutes which includes the complete dialog up until a diagnosis is provided.

In terms of knowledge base size, the different systems use different structures to represent their knowledge, the lables used vary widely, and so does the "chunk size" used (the size of a piece of knowledge considered a unit - such as a production rule). MYCIN considers 3 diseases, which include 200 symptoms and 800 rules. MEDAS includes 53 disorders and 670 symptoms, while the largest system, INTERNIST, covers more than 600 diseases and over 4000 symptoms. These numbers should not be taken as indicating the relative sizes of the systems for the reasons indicated above.

In terms of raw memory used by the systems, similar problems of incompatibility in terms arise. Most of the systems are used in a time-shared environment, and their programs and data are swapped in and out from disk. The support environment INTERLISP, which is used in most cases represents, by itself, a major memory requirement, which is mixed with the data and programs. A rough estimate would be 1-1.5 million bytes each for MYCIN, INTERNIST and PROSPECTOR.

Notice, however, that MEDAS uses only 112K bytes of memory and this decrease cannot be accounted for only by smaller problem domain

coverage. The system works on a stand-alone basis and is implemented in BASIC, which does not have all the facilities of INTERLISP, it does not incur as large of an overhead, and is more efficient in speed and memory utilization.

The computer used in most cases is the DEC PDP-10* but, again, evaluation of computer speed requirements are hard to obtain, first, because different models of the CPU are used and, second, because the computer is in a multi-user environment. Furthermore, MYCIN and INTERNIST use their computers over ARPANET and TELENET, thus degrading response time even further. All that can be said is that the PDP-10 with 5-10 MIPS used stand-alone would provide ample computing power even for a larger knowledge based system.

When the transfer to the military environment is considered, these performance measures should be taken only as very rough estimates. The following are some of the reasons for inaccuracies. First, none of the applications are in the military domain. The amount of knowledge that would be needed for a useful subtask in the military environment can be estimated to be 5-10 times larger than the medical cases. Second, all the systems were developed in a research environment. It is not clear how much effort was invested in each both directly and indirectly, also, efficiency in implementation and resource utilization was naturally of secondary importance. Third, the computers used were not dedicated; thus, response time data is not reliable. Furthermore, the languages most commonly used, LISP and INTERLISP, are notoriously inefficient. They are very useful for the development phase because of the flexible data structures and powerful control mechanisms they provide, but for an implementation system, other languages should be considered to attain reasonable response times.

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* Note: We will use, throughout the document,DEC computers as examples because they are the most commonly used computers in the AI research community. These should be taken only as examples of computing power, other computers with similar speed and appropriate software would be equally acceptable.

All told, it is estimated that an increase by a factor of 5-10 is necessary for a meaningful military SA system, expressed in terms of CPU capability and direct access memory. This fact brings up the major source of risk in the development of the military SA system. Although the previously implemented systems dealt with complex and ill-defined problem domains, it is not clear how the techniques would stand up against a 5-10 fold increase in the size of the knowledge base. The technique chosen for the proposed system (Chapter 4) tends to be relatively insensitive to knowledge base size (because of the direct pointers between features and relevant classes). Also, MYCIN was increased during the years by a factor of 3-5, without undue performance degredation. A similar experience was reported from the PROSPECTOR developers.

Another lesson that can be derived from these previous systems is an estimate of the amount of the development effort involved. The three large systems have been 5 or more years in development, and involve 3-10 man year per year of effort. This sums up to 15-50 man years of effort per system, in the medical environment.

5.3 Hardware/Software Estimates for Proposed System

5.3.1 Introduction. The resources used by the previous APT systems were discussed in Section 5.2. They provide a rough baseline for estimating the requirements of the proposed SA system. We will concentrate here on the requirements of a hypothetical stand-alone future implementation of the SA system. The intention is to show technological implementability. The computing requirements of the development effort itself, however, are similar to those used by the other APT development groups and are given in the program plan in Chapter 6. The requirements considered in this section are: (1) CPU performance, (2) direct memory, (3) operating system, and (4) language. The section concludes with a technological forecast.

5.3.2 Required CPU Performance. The processor on which the fielded situation assessment system will be implemented should have enough computing power to provide acceptable interaction response time. This time limit requirements range from 0.2 sec for trivial graphic responses, 2 sec for regular queries, and should rarely acceed 30 sec for specially complicated tasks (Shakel and Shipley, 1970). From experience with previous systems using APT, it is estimated that the required computer should be able to perform 5-10 MIPS (Million Instructions Per Second) to provide this acceptable response time. This is equivalent to one to two times the capability of the PDP-10 computer. This range of performance will be well within the expected available technology by 1984-1986 as will be discussed in Section 5.3.6.

For the first year's concept demonstration a much lower performance is needed. This is due to the limited scope of the algorithm and reduced complexity of the situation dealt with. It is estimated that a minicomputer such as a PDP 11/45 would be sufficient. The PDP 11/45 provides 0.5-1 MIPS performance.

For the balance of the 5-year development plan a larger minicomputer is needed, with 1-5 MIPS. This may be a PDP 11/70, VAX 11/780 or a PDP-10 with the appropriate development environment.

5.3.3 Memory Requirements. The fielded computer aided situation assessment system is estimated to require between 2-4 Megabytes of primary memory. This includes space for all the major system blocks described in Chapter 4 and a substantial part of the knowledge base to be resident in primary memory. A breakdown of the estimates of the various blcok memory requirements are given in Table 5-1. These estimates represent a 5 to 10 fold increase in the memory requirement of the system when compared to the existing APT systems described above. It is due to the more complex and dynamic nature of the military knowledge base that the system will have to contain and manipulate.

Table 5-2

Memory Requirement Estimate

Principle Function	Memory Needed (Bytes)
Situation Assessment Processor	300 K - 600 K
Summary Generator	75 K - 150 K
Explanation Generator	100 K - 200 K
Information Requests Generator	150 K - 300 K
Man-Machine Dialog Subsystem	250 K - 500 K
Additional Processing	125 K - 250 K
Knowledge Base	1000 K - 2000 K
TOTAL	2000 K - 4000 K Bytes

In terms of secondary memory such as disks, drums, and tapes, the proposed system may have its own 10-50 MByte secondary storage or it may share secondary storage with the rest of the TOS system of which it will be a part.

Together with computer speed, other limiting parameters, such as complexity, size, power requirements and price, are expected to be well within the available technology of the mid 80's. 1 million bit chips for primary memory and 4 million bit bubble memory chips for solid state secondary memory are expected to be available at that time.

For the first year concept demonstration a memory capacity of 250K Bytes of memory would suffice -- again, due to the limited scope of the first year's effort.

5.3.4 Operating System Requirements. The operating system necessary for the development and support of the implementation of the situation assessment system needs to be able to support real time, multi-task and interactive processing. It should provide for flexible file structures and all the facilities needed for communication with the rest of the C3 computer network. These capabilities are necessary because of its modular, incremental nature, and the continuous updates the knowledge base system would require even during normal use. For the software development phase, the system should support, in addition to the above, an appropriate language (as discussed below), an interactive text editor, a linker, a loader, and additional system utilities. These software development tools would not be needed on the run time fielded system.

As for the first year concept demonstration system, an operating system such as UNIX can provide all the necessary facilities. UNIX is a general purpose, multi-user, multi-processing, interactive operating system. It provides all the utilities and file structure support needed

for an efficient software development task and supports a number of programming languages such as C and LISP.

5.3.5 Language Requirements. The language needed for the development and implementation of the situation assessment system should be a "high-level" language appropriate for real time list processing applications. It should provide primitives for dynamic structure modifications and advanced control structures and be compatible with recent structured programming conventions. All these requirements would facilitate the development, documentation, and maintenance of the complex software package that a situation assessment system will become.

The first year inhouse demonstration can be implemented using any one of a number of possible languages available on minicomputers. The UNIX operating system for example, can support C, LISP, or Fortran among other possible languages. C meets all the requirements listed, is very efficient, and is generally well known. LISP is a list processing language used in many Artificial Intelligence type of applications where non-numeric data processing are made. Another possible language for implementing this proposed system would be INTERLISP, which is an advanced adaptation of LISP and runs on a PDP-10 under the TENEX operating system. It is a modern language, has all the necessary control facilities, and is increasingly popular for its structured programming compatibility. The same languages would equally apply for the implementation of the fieldable situation assessment system when the time comes.

5.2.6 Technology Forecast. The hardware requirements in terms of computing power and memory capacity given above, may raise the objection that such capabilities will not be implementable in a compact enough militarized enclosure appropriate for the field. Such objections are unwarranted in light of past and expected future progress in microelectronic digital technology. In the last 20 years, the state-of-the-art in integrated

circuitry has demonstrated a steady progress by doubling the complexity of the circuits available on a single integrated circuit about every year. This amounts to more than five orders of magnitudes of complexity increase in the last 18 years. From one gate per chip in 1960, to 100,000 gates last year. A vivid demonstration of this progress is shown in Figure 5-1 adapted from Shepherd (1977). It shows the dates of the first introduction of advanced integrated circuits versus the number of active element groups they contain.

The current state-of-the-art includes 64,000 bit memory integrated circuits, 250,000 bit bubble memory devices and advanced 16 bit microcomputers with the capacity of about 1 MIPS.

In the mid 80's time frame, conservative estimates peg these numbers for the state-of-the-art at:

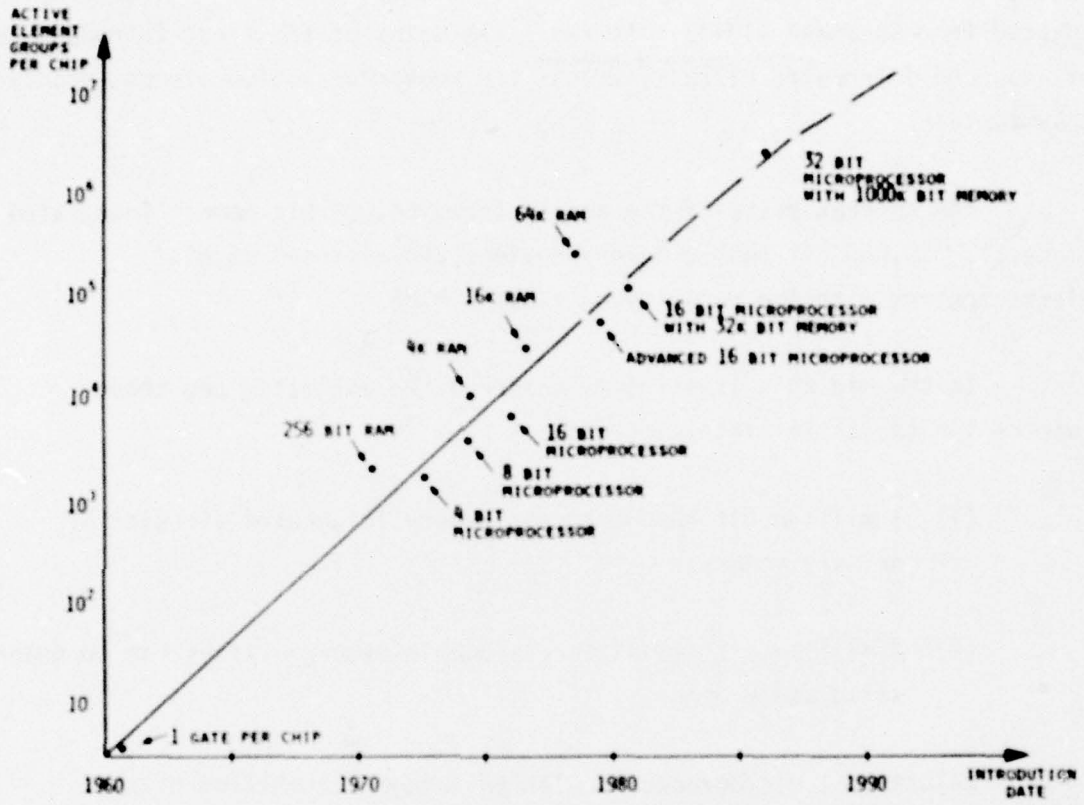
(1) 1 million bit random access memory integrated circuit for primary memory.

(2) 4 million bit serial access bubble memory devices for secondary solid state memory.

(3) 32 bit microprocessor with an integral 1 million bits of internal memory and 5-10 MIPS speed.

These predictions make it safe to assume that all required computer and memory capacity will be available in the mid 80's in an enclosure smaller than 1 cubic foot.

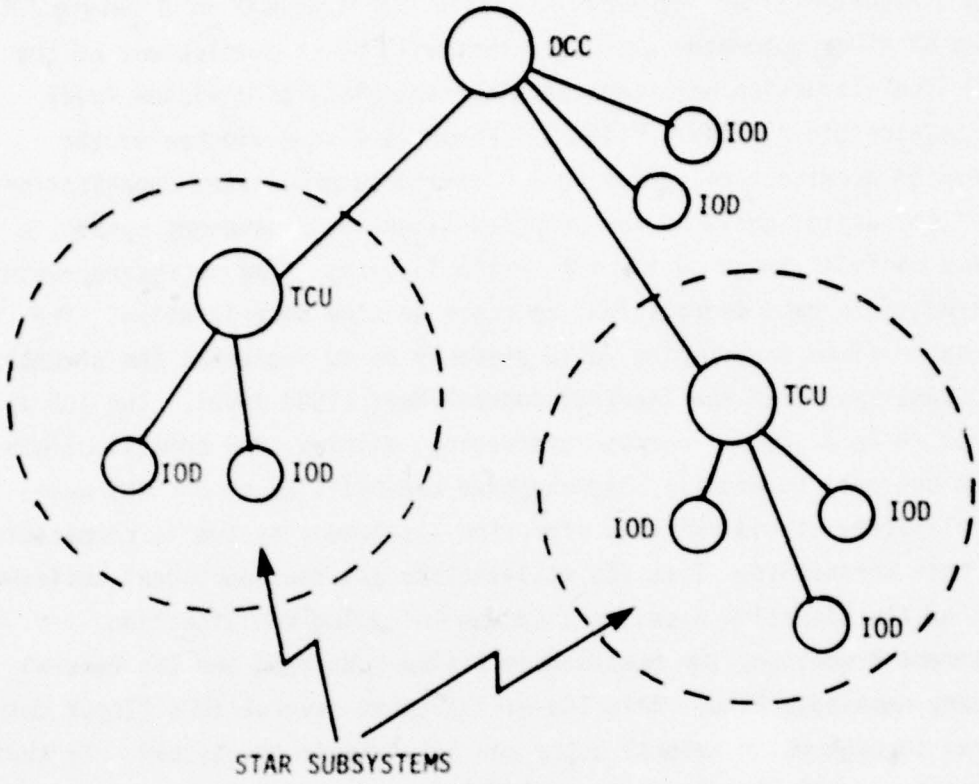
TABLE 5-1. MICROELECTRONIC CIRCUITS DATES OF FIRST INTRODUCTION VERSUS COMPLEXITY



5.4 Interfacing with TOS

5.4.1 System Organization. The situation assessment system discussed in this report will be implemented within the framework of a future TOS system or other automated C3 system that will be in development at the time. The discussion here addresses current plans of division level TOS as described by AURBACH (1978). Figure 5-2 is a diagram of the TOS system architecture depicting a distributed processing organization. One of the design goals of the proposed situation assessment system is to have minimal impact on the TOS system in terms of major restructuring required, data base degradation, or response time deterioration. The most appropriate structuring would probably be to implement the situation assessment system at the Terminal Control Unit (TCU) level. The TCU is defined to be a general purpose processing, display, and communications system designed to procide comprehensive capabilities to the TOS user. The relatively closed-function situation assessment system is compatible with this definition. This TCU will include all the functional building block of the situation assessment system including the Situation Assessment Processor, the Man/machine Dialog Subsystem and the General Military Knowledge Base. This TCU will support several IODs (Input Output Device) through which several users can interrogate the system. To obtain information available in the general TOS data base, residing in the DCC, (Division Computer Center) the system would communicate its requests using the regular network protocol. The TCU may be physically located in the division CP, but logically it is a relatively independent processing unit.

5.4.2 Data Base Utilization. An important implementation issue for the situation assessment system is the communication with and utilization of TOS data bases. What is the relation between the knowledge base maintained by the SA system and the various data bases that will exist in TOS? The distinction can be made by contrasting general structured knowledge with specific current facts, i.e., "How?" versus "What?". The SA knowledge base contains general information about typical enemy units, their typical structures, movements, missions and other activities. It does not include



DDC: DIVISION COMPUTER CENTER (CENTRAL DATA BASES/NETWORK CONTROL/USER LANGUAGE)

TCU: TERMINAL CONTROL UNIT (CENTRAL DATA BASE/CONCURRENT LOCAL DATA BASE/SUBNETWORK CONTROL/USER LANGUAGE

IOD: INPUT-OUTPUT DEVICE (USER LANGUAGE/PROMPTING)

FIGURE 5-2. TOS SYSTEM ARCHITECTURE

specific facts about the current situation. These are contained and are accumulated in the TOS multiple data bases. The SA will know what type of information is available in the different data bases and will address specific queries when it needs specific answers. For example, "What is the current location of a particular enemy tank battalion?" This query will be addressed to the appropriate data base and the response translated into the knowledge base structure and used to develop the situation picture. From time to time, the SA system has to update its assumptions, i.e., the facts that led to the current global picture, so that the most recent facts available in TOS will be used. At the same time, the SA conducts continuous interactions with its users via the IODS and obtains additional information directly.

Figure 5-3 shows the series of translations that take place when the SA system requests a fact from one of the data bases in TOS. The SA system generates an Information Request knowing what is available in the particular data base. This information request is translated by a Querry Translator into a Data Base Query compatible with that particular data base addressed. Such automatic query generators are available today but some development effort is required to produce one for the particular data bases that will be part of TOS. The rest of the translations shown in the figure are common translations that take place in most DB systems. When a response is found, an inverted sequence of translations produces a response that the SA system can use.

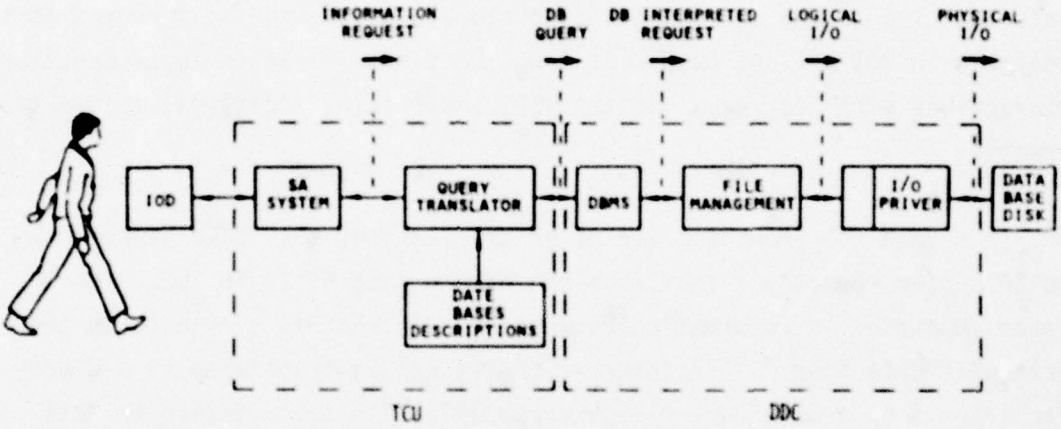


FIGURE 5-3. DATA BASE UTILIZATION

6. PROGRAM PLAN

6.1 Overview

This chapter describes a five-year plan to design, develop, and implement a portable demonstration decision aid for a division level G2 performing the situation assessment task. The major tasks that have to be completed to accomplish this objective are the following:

(1) Analyze, select, and develop the most applicable APT techniques to the situation assessment task.

(2) Elicit and develop a complete APT model of the military knowledge involved in division tactical engagements.

(3) Develop detailed mechanisms for automatic inference, recognition, information request evaluation and summary generation.

(4) Implement a demonstration prototype system.

The final product of the five-year program would be a complete, working, stand-alone and well documented demonstration system which can be demonstrated at ARI. At that stage, the system will be ready for field prototype development. The detailed, documented knowledge base and algorithms would be transferable to the hardware available at that time. Current conservative estimates of the state-of-the-art of computer technology around 1985, assures the availability of the required computing power in a small, militarized, portable package. The estimated computing power that will be required is up to 10 MIPS (million instructions per second) and a direct memory of up to 4M byte (million bytes).

The program is divided into three phases. Phase I, extending over the first year, develops a small scale concept demonstration system. It will show what kind of capabilities can be accomplished with APT. Phase II, extending over the second and third years, develops the knowledge base, modules and mechanisms for a well bound sub-domain of the tactical situation encountered by a G2 officer. Phase III, forming the last two years, expands the scope of the system military knowledge to the complete spectrum of the G2 SA task. It expands the capabilities of the system to the full roster described in Chapter 4, and it develops the mechanisms for integrating the system with other existing C3 and data base systems. The major yearly objectives are as follows:

Phase I - Concept Demonstration

Year 1 - Basic mechanism transfer and implementation

Phase II - Algorithm Transfer

Year 2 - Situation assessment mechanisms transfer
Year 3 - Knowledge base construction and system implementation

Phase III - Expanded knowledge base SA system construction

Year 4 - Scope and capability expansion and interfacing with TOS
Year 5 - Integrated, expanded demonstration system implementation

The five-year plan is oriented toward modularity, demonstrability, and usefulness. Each year's product will be a useful document or program that can be utilized in other military application areas as indicated in the appendix. The products will be modular so that systems with various capabilities can be constructed from these modules, and will provide yearly demonstration of progress and expanded capabilities. The rest of this

chapter will give the yearly plans in detail.

6.2 Phase I - Concept Demonstration (first year)

Task: Concept demonstration and implementation. The first year's goal is to show the value of the APT approach by developing only what is necessary to allow the central algorithm to operate. It will include a preliminary version of the following specific tasks:

(1) Select and analyze a specific military domain
(2) Preliminary development of a single scenario military knowledge base
(3) Selection and adaptation of APT techniques
(4) Implementation of basic situation assessment algorithm
(5) Development of software for a fixed sample scenario
(6) Demonstrate the system in a dynamic scenario.

Product: The product of the first year would be an inhouse concept demonstration system. The system will interact with an expert performing continuous situation assessment during a scenario of a division level tank battle. The system will accept low level indicators observed in the field and will generate a skeleton situation summary. The situation summary will include estimates of enemy forces, their target and main thrust, their overall plan and the expected timetable of imminent actions.

System Requirements: The demonstration can be performed on a minicomputer such as a PDP-11/45 with 250k bytes of memory, or on a large PDP-10 computer at one of the artificial intelligence research centers (Stanford or MIT). This could be done from anywhere in the U.S. over the ARPA network. The advantage of the stand-alone minicomputer is its availability, while the large research computers have more advanced languages and a wider spectrum of helpful utilities.

Languages and Operating System: On the small minicomputer, the development can be done in LISP, or C under the UNIX operating system. On the PDP-10, the most appropriate language would be INTERLISP which is the most advanced language for these applications, provides the most "friendly" development environment and runs under the TENEX operating system.

Manpower: The manpower requirement for the first year is estimated to be 2-4 man-years, plus an additional 3 man-month of a military expert.

Management Considerations: The first year tasks should be assigned to one team of experts in APT. The military aspects are secondary at this phase and the size of the effort does not justify breaking it into subparts. An alternative course, which would increase the chance of success, would be to assign the whole task, in parallel to more than one group, in different places, and select the more successful approach produced by the end of the year, for further development.

6.3 Phase II - Algorithm Transfer (years 2 and 3)

6.3.1 General Tasks: Phase II of the program will extend over the second and third years. Its main objectives are:

(1) To develop the military knowledge representation and mechanisms for a situation assessment decision aid.

(2) To implement an interactive stand-alone decision aid for a division level G2 officer performing situation assessment against a constrained set of enemy missions.

The specific tasks that have to be accomplished to achieve these objectives are the following:

(1) Analysis of the Situation Assessment Process. This will include detailed system analysis, development of system structures, and detailed specification of functional requirements for each module and algorithm.

(2) Selection and Adaptation of APT Techniques. Led by the functional requirements, the available APT techniques will be evaluated and those most appropriate will be adapted to the military knowledge base representation formalism (developed under task 4 below).

(3) Elicitation of Military Knowledge. This task will be done by extensive literature analysis and detailed expert interviews. It will provide an explicit knowledge base about general military concepts, mechanisms, and tactical and strategic principles. It will not include any information about specific weapons, engagements, or scenarios.

(4) Analysis of Military Knowledge Structure. This task will be done to isolate the set of mechanisms necessary to represent the general military knowledge base on a computer. This will include formalisms, data structures, procedures and control structures.

(5) Development of Mechanisms. This will be performed for situation assessment, inference mechanisms, summary generation, explanation generation, and man/machine communication mechanisms.

(6) Development of Software Tools. Software tools will be adapted to the knowledge base elicitation environment using a stand-alone minicomputer.

(7) Design of Software. The software will be designed for the implementation of the Phase II system on a specific scenario and a simulated division level engagement.

(8) Computer Implementation of Phase II. Complete software coding of stand-alone Phase II will be performed.

(9) Experimentation and Tuning of Phase II System. The system will be tested on several simulated scenarios. The system's response will be compared to military experts responses and modifications made to the internal knowledge base, until the responses are acceptable for the experts.

(10) Evaluation and Demonstration of Phase II.. The system will be demonstrated and evaluated on an inhouse computer.

Most of these tasks will span more than one year and will be carried out largely in parallel in task groups which interact closely. The task will also be broken down into stages so that some complete capabilities can be demonstrated each year.

6.3.2 Second Year

Task: The main task of the second year is APT mechanisms development and knowledge base elicitation and construction. The APT techniques must be adapted and refined for the military application and a formalism developed for the military knowledge base. This formalism must then be used to implement the elicited military knowledge. These mechanisms and formalisms will be the base upon which the situation assessment system will be built. The specific tasks for the second year are to:

(1) Elicit military knowledge from experts and available literature, pertaining to division tactical situation assessment.

(2) Analyze military knowledge structures and mechanisms. Identify the important issues, their interrelatedness and how they are used by experts to assess a military situation.

(3) Develop formalisms for computer implementation of military knowledge base.

(4) Develop detailed situation assessment mechanisms using the selected APT technique.

(5) Develop algorithms for summary generation.

(6) Develop algorithms for explanation generation.

(7) Develop mechanisms for man/machine dialogs.

(8) Evaluation by outside experts.

Product: The product of the second year program is a document providing a detailed design of data structures, content and algorithms for a situation assessment system. The situation covered is that of the division level tank battle. It will be expanded, however, to include the activity of various offensive forces, support forces such as artillery and tactical missiles and also logistics and supply operations. Fully developed data structures will be used to encode the specific military knowledge elicited from the experts. The mechanisms will include the recognition, assessment, information request evaluation, summary generation and man/machine interaction. This document will be evaluated by military experts outside the development group to provide judgment of the completeness, balance and compatibility with enemy doctrine of the representation.

System Requirements: The expanded knowledge base and algorithms developed in the second year would require more computer resources. It is estimated that a PDP-11/70 with 500k byte of memory would be sufficient. Alternatively, a PDP-10 computer, at Stanford or MIT, can be accessed over the ARPA network.

Language and Operating System: On the minicomputer, the development can be done in either LISP, or C under the UNIX operating system. On the PDP-10 computer, the most appropriate language would be INTERLISP or QLISP running under the TENEX operating system.

Manpower Requirements: The manpower requirements for the second year are estimated to be 3-5 man-years, including computer science and software personnel. Additionally, 6-10 man-months of a military expert would be required.

Management Considerations: At this stage, the knowledge elicitation is used to help define the detailed characteristics of the knowledge base and the mechanisms that manipulate it. Thus, the two functions must be accomplished with close interactions, preferably by the same group. Beyond the second year, the two functions can be separated.

6.3.3 Third Year

Task: The third year's goal is to develop a well rounded knowledge base appropriate for a detailed scenario and to complete the design and implementation of the full Phase II stand-alone system. The specific tasks to be performed are:

(1) Complete algorithms for summary generation
(2) Complete algorithms for explanation generation
(3) Develop algorithms for man/machine dialog

(4) Elicit and construct a rounded knowledge base

(5) Design software

(6) Implement software

(7) Tune the knowledge base structures and mechanisms

(8) Demonstrate system - Phase II

(9) Evaluate performance

Product: The final product of the third year's program will be a complete, documented, stand-alone system with a software package capable of performing the situation assessment task interactively with an expert G2 who knows the system. The system will be able to accept facts about previously unknown situations and be informed about new events as they unfold in the scenario. It will interact with the expert to obtain necessary additional information, and generate a supportable situation assessment. The system will then be able to explain and justify its reasoning and conclusions. The system will be demonstrable inhouse or at an ARI facility.

System Requirements: Same as for the second year.

Language and Operating System: Same as for the second year.

Manpower Requirements: The manpower requirement for the third year is estimated to be 3-5 man-years, with more emphasis on software personnel for coding and testing. Additionally, 6-10 man-months of a military expert would be required for refining, tuning and testing the military aspects.

Management Considerations: In the third year the knowledge elicitation will be a substantial task that can be separated from the refinement and implementation of the APT techniques. A group with easy access to several military experts would construct the scenario knowledge

both software and hardware efficiencies of the implementation. The task will include close interaction with military experts.

(2) Expand Military Scope of System. The scope of the system will be expanded through analysis, representation refinement and mechanisms' improvements. The expanded capabilities would be on the following dimensions:

(a) Range of mission types covered
(b) Range of scenario types covered
(c) Type of units and mix of unit types involved in mission
(d) Size mix of units
(e) Range of terrain features covered
(f) Unusual weather conditions
(g) Unusual relief and vegetation effects
(h) Type and mix of weapon systems

(3) Interfacing with Existing Data Bases. Analyze military data bases, to which future SA systems may be interfaced, then develop knowledge representation techniques, inference algorithms, and query generation and interpretation techniques to interface with these data bases.

(4) Refine Situation Assessment Algorithms. The situation assessment mechanisms will be extended to be able to utilize the specific data available in other military data bases.

(5) Expand Capabilities of Dialog Subsystem. The man/machine interface, which is the dialog subsystem, will be improved to allow the following capabilities.

(a) Interactive hierarchical expansion of the situation summary

(b) Capability to explain reasons for events in the preceding dialog

(c) Capability to infer user's reasons for questions asked and to produce proper answers

(d) Capability to explain tactical doctrine independent of a specific situation.

(6) Software Design. The software for implementing the expanded system level will be designed.

(7) Develop a Battery of Test Scenarios. A flexible set of test scenarios will be developed to provide a complete demonstration testing and evaluation of the system.

(8) Computer Implementation of Phase III System. Implementation of the complete level III system including both expanded knowledge base and refined mechanisms.

(9) Test, Demonstrate, Evaluate and Transfer Level III System. The final version of the system will be a transportable software package that can be demonstrated on the PDP-11/70 computer with the appropriate resources.

Product: A complete, stand-alone, documented situation assessment demonstration system. The system will be introduced to a new situation by accepting general objectives and terrain description. The system will be able to accept low-level facts about current activities, ask for additional necessary information, giving specific recommendations on how to get it. It will then provide a situation summary in a format similar to the intelligence report currently produced manually. This final system will

base, using software tools developed in the second year. The evaluation of the completed system should also be done with military experts.

6.4 Phase III - Integrated Expanded Demonstration System

The second phase of the program will extend over the last two years and will expand and build upon the achievements of Phase II. The specific objectives of the phase are:

(1) To expand the military scope of the system concepts and mechanisms in terms of: (1) type of missions, (2) type of units, (3) size mix of units, (4) weather, terrain, and vegetation, etc.

(2) To refine the SA algorithms and knowledge base representation formalisms in light of the evaluation of the complete Phase III system.

(3) To develop techniques for interfacing the system with other existing military data bases (the query translator).

(4) To implement an expanded, conversational, integrated Phase III demonstration system.

Tasks:

The specific tasks that have to be completed to achieve these objectives are the following:

(1) Evaluate Phase II System. The evaluation of the Phase II system is aimed at identifying the limitation of the representation techniques and APT mechanisms, and improving

be able to handle information coming from higher echelons, parallel friendly units, and from subordinate units in the field. It will also accept a full spectrum of division level subunits, weapons and mission mixes. The system will also be portable and demonstrable at ARI.

System Requirements: The expanded knowledge base and more complex algorithms would require a more powerful computer than necessary in Phase II. A PDP-11/70 with 1-2M byte of memory would be a minimal requirement, but it would not be able to perform in real time. It is estimated that a single task PDP-10, with 2-4M byte of memory would be a more appropriate system to use if real time response is mandatory.

Language and Operating System: The choices for language and operating system are similar to those mentioned before. On the minicomputer, the languages that can be used are LISP, C or PASCAL running under the operating system UNIX. On the PDP-10 the latest version of INTERLISP would be most appropriate, running under TENEX.

Manpower Requirements: The level of effort for Phase III should be stepped up because of the increased scope of the system's capabilities. It is estimated that 5-7 man-years per year will be necessary, with 1-2 man-years for a military expert.

Management Considerations: The Phase III effort can be broken down into four sub-efforts that can be assigned to separate groups. Close cooperation and tight communication, however, are still very important. One group will do the algorithm and knowledge base refinement to comply with the analysis of the second phase system and the expanded military scope. The second group will elicit the military knowledge base for the expanded scenario. This group should have regular access to several experienced G2's. The third group can work separately on the dialog and explanation capabilities. The fourth and last group will work on the interface with other C3's that will be most appropriate at the time.

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APPENDIX A

MODEL AND SYSTEM GENERALIZABILITY

A.1 Overview

The APT functions and techniques to be adopted under this program to the military environment appears to have a wide and immediate applicability to many other functions and tasks supported by automated military decision aiding and training systems. The possible usefulness of the various modules of the situation assessment system to five other military application areas is discussed in this appendix. Such immediate technology transfer increases the value of the R&D effort expanded on the situation assessment system. The following five application areas were considered the most important areas for computer aiding in decision making and training.

In decision aiding and performance enhancement:

(1) Detection of unusual events.

(2) Resource allocation.

(3) Battlefield simulation.

and in training systems:

(4) Scenario generation.

(5) Trainee monitoring.

A.2 Detection of Unusual Events

Important functions of the commander encompass the detection and recognition of significant changes and opportunities in the battlefield situation. This includes, for example, sudden changes in the enemy morale during a defense operation, which could change an orderly attack operation into a retreat. The recognition of low probability/high risk events, which may cause drastic changes in the battlefield situation. Finally, the ability to identify unique tactical opportunities and enemy vulnerabilities (or even vulnerabilities in friendly forces) can be very valuable. Early recognition of such events can give the commander an important edge. He can modify his plans in time to take advantage of the opportunities.

As an example, suppose that enemy activity were detected near a key bridge in the rear of the friendly forces. The friendly forces are outnumbered in that area. When such a situation occurs, a goal-oriented inference system could draw the following sequence of inferences:

(1) The enemy has potential power to capture and destroy the bridge.

(2) This would reduce the number of retreat and supply routes for our forces.

(3) Our forces are threatened to be cut off from the main body, cutting off supply and reinforcement.

(4) The original observation is critical and should be addressed immediately.

Thus, by being goal oriented and the inference capability of a system can make it very useful as an alerting mechanism. The APT techniques have

demonstrated the capability to perform complex inferences. This basic capability stems from their knowledge representation capability, their goal-oriented, control process, and their ability to communicate at the conceptual level of the expert. The APT system will address exactly the same issues that are important to the military expert (the commander) and for the same reasons they are important to him: the military threats or opportunities they represent.

The situation assessment system algorithm is almost identical to the one needed for the detection of unusual events. The difference is only in the length of the inference chains allowed and in the focus of attention. In the situation assessment system, the goal is to find the interpretation that accounts for most of the evidence available. Thus, the recognition process tries to incorporate as many observed features as possible without "climbing" high in the tactical categories hierarchy. In an unusual event detection system, however, there would usually be very little evidence and the system would try to find the worst consequences that can be inferred from the meager evidence available. The algorithm would have different termination parameters and different thresholds for abandoning a hypothesis.

A system for the detection of unusual events can work in the background of another tactical decision aiding system and produce an alarm only when an important objective of the commander is endangered. An additional advantage of such an automated aid is that it can include the accumulated experience of many commanders, so that the commander using the system would be alerted to some rare event that may not be in the realm of his own personal experience.

A.3 Resource Allocation

Resource allocation is a very general problem that applies wherever a scarce resource has to be divided among several competing demands in such a way that would maximize some measure of effectiveness.

In the situation assessment system, the algorithm which evaluates the importance of an information item, and chooses which information collection agent should be assigned to obtain this information is, essentially, a powerful resource allocation algorithm. The APT approach to this problem is unique in that it is goal-oriented and the allocation algorithm can adapt to changing environments without explicit analytic expressions of such complex relationships.

Figure A-1 shows an example of the relational structure for a resource allocation system dealing with the problem of equipping a platoon for a mission. The example shows the adaptability of the approach. The platoon must be equipped with food, weapons, ammunition, shelter, etc. These basic requirements are contained in the military knowledge base. The choice of the type of shelter needed is influenced by the weather, terrain, and mission of the platoon which the evaluation mechanism can take into account. These are constraints imposed on the allocation procedure. The amount of the shelter required will be influenced by other demands on this resource, etc. The resource allocation process thus adapts to the dynamics of the situation and is not a rigid analytical structure that was designed for some ideal situation. Such adaptive capabilities are natural in APT systems.

A.4 Scenario Generation

As part of the contingency planning process, the decision maker

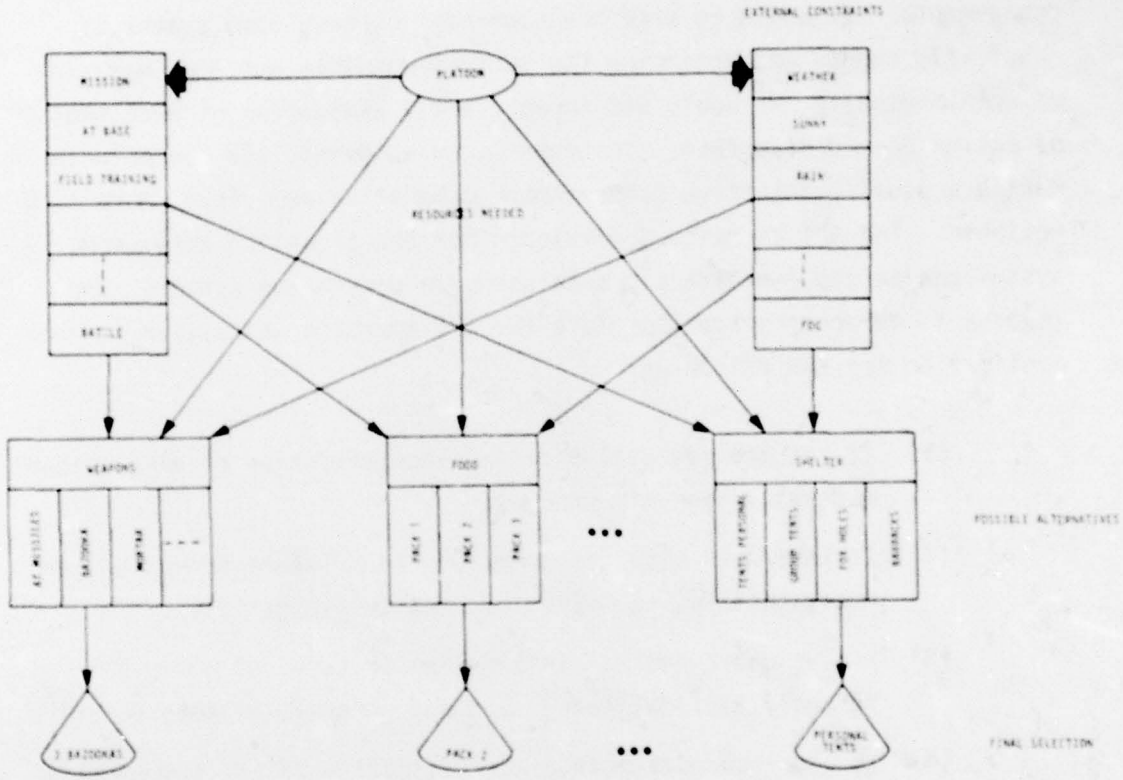


FIGURE A-1. RESOURCE ALLOCATION PROCESS MODEL

can benefit from a hypothetical exploration of probable consequences of alternative courses of action. This exercise will help him choose the best alternative with minimal expenditure of time and resources. A decision aid for scenario generation would cooperate interactively with the decision maker, point to potential threats or available resources, suggest possible approach routes, or assess probable outcomes of active engagements. It would go with the commander through long chains of "What if?" events and determine the various possible outcomes and side effects. Finally, it would aid in an overall evaluation of each course of action deemed plausible. In general, an automatic aid can help in making a usually intuitive process more exhaustive and, thus, more reliable. The APT techniques developed for the situation assessment system can be applied directly to a scenario generation system. The important characteristics that make the APT approach attractive in this application are the following:

(1) It can provide goal-directed identification of alternatives and evaluation of outcomes.

(2) It interacts with the commander in military terms such as enemy threats, capabilities, and vulnerabilities.

(3) It evaluates factual information in terms of enemy or friendly tactical techniques and general military doctrine.

(4) It can incorporate into the evaluation of the commander's mission, his directives, and his personal preferences for tactical methods.

Altogether, a scenario generation system can be a very useful advisor and aid to a commander in the task of tactical contingency planning.

A.5 Battlefield Simulation

This training application area includes systems that provide realistic simulated battle scenarios to a trainee command group. Such a system interacts with the training command group through the regular communication channels typical to the trained unit. It simulates the activities of subordinate units as they carry out the assignments given to them in face of the enemy and given environment. It also simulates parallel, friendly forces acting in the unit's neighborhood using commands and information descended from higher echelons. The main part, however, is a realistic simulation of enemy forces. These forces should react realistically to the command group actions, utilize opportunities in the environment, and pursue "single-mindedly" some predetermined military mission. In addition, the simulation process should be flexible and easy to set up in new scenarios, with no more initial preparation necessary than that needed to introduce a commander to a new battle arena. Such a system affords extensive, directed training without spending the time, resources, support personnel, and even possible loss of lives, as in live maneuvers.

The algorithms developed for the military knowledge based in the situation assessment system are applicable for realistic simulation of military unit behavior. They provide goal-directed mechanisms that can take into account tactical opportunities in the environment (terrain, relief, weather, and obstacles) and in the tactical disposition of the interacting forces. The simulated forces would use warfare doctrine that is predefined (e.g., Soviet) but would be able to adapt to the details of the specific situation. The concept orientedness of the algorithms can make the initialization of a scenario very easy. The training director would specify, for example, "aggressive tank division," and the system would be able to translate this request into typical tactical

units, with all the proper behavior traits. Using currently available programming techniques, these capabilities are very complex to program. APT can provide the tools for making them possible.

A.6 Trainee Monitoring Aids

This application area deals with improved monitoring of trainee behavior and the evaluation of his performance. Automating at least parts of the monitoring function of the trainer can produce more detailed data, consistent measurements of performance, and validated determination of trainee shortcomings. Such training aiding can provide substantial improvements in training effectiveness. Four sequential levels can be discerned in the scope of automation in trainee monitoring systems: (1) event history logging, (2) behavior tracking, (3) performance assessment, and (4) instructional strategies adaptation.

A6.1 Event Histories Logging - At this low level, the system is used as a recorder and counter of discrete events. It follows the activities happening during a training session, identifies significant events, and logs various statistics about them. The statistics may be the number of decisions made of a given type, how long it took to make them, what were the information sources relied upon, etc. An increased amoung of explicit data can improve training by providing specific material for detailed debriefing and for evaluation of specific trainee performance parameters.

A6.2 Behavior Tracking - This level of monitoring systems includes adaptive aids that contain adaptive models of the trainee and can adapt the parameters of these models to track the trainee's overt behavior while he is performing actual tasks. Such training aids can provide direct, parametrized, behavioral data obtained by direct observation of task performance rather than through a separate testing phase. It can

direct the training toward improvement of specific behavioral parameters. Behavior tracking training systems have been developed and tested for specific training tasks such as electronic troubleshooting and also for the ASW task (Leal 1978). There is a need, however, before such an approach can be adapted to decision making aids, to develop parametrized models of the decision making process compatible with the structure of the adaptive trainable systems.

A6.3 Performance Assessment - At this level, the automatic training system assesses the trainee's intentions and hypothesizes his internal values in terms of the training goals. Such training systems aid the evaluator in the interpretation of trainee behavior and allows him to identify conceptual errors and lack of specific skills on part of the trainee.

A6.4 Instructional Strategies Adaptation - This is automation at the meta-training level. Rather than assessing trainee performance the automatic system adapts the training material (scenarios, etc.) and training approach to the individual cognitive characteristics of the individual trainee and to the observed weaknesses in his performance, based on previous observations and conclusions about the trainee's weaknesses.

A6.5 Conclusions - The four levels of trainee monitoring systems described above are hierarchical, in the sense that, each requires the achievement of the previous one as a precondition for its development. Systems of the first two types exist today for various training tasks. However, substantial progress can be made in attaining the latter two types through carry-over from situation assessment systems. Such a carry-over can be made through the following analogy between the structural concepts and processes in the situation assessment task and training assessment task:

Situation Assessment	Training Assessment
1. Observed facts in the field.	1. Overt trainee actions.
2. Enemy and friendly goals and intentions.	2. Trainee goals and intentions in task performance.
3. Military tactics, goals and doctrine.	3. Training methods, goals, and theories.
4. The situation assessment process.	4. Assessment of training progress and performance of training systems.

Additional benefits that can be derived in training methodology from progress in situation assessment systems are, the development of methods to represent military goals and tactics which can be used for representation of training methods. Such computer based explicit models can provide a testable vehicle for direct comparison and evaluation of different training methods.

The situation assessment system itself can be an invaluable training device through the method of apprenticeship. The trainee encounters a graded sequence of scenarios and is called upon to give his evaluation. He then obtains the evaluation produced by the Situation Assessment system and, in case of conflict, can ask for explanations and justifications and thus draw incrementally on the expert knowledge base stored in the system. Such apprentice or "quiet advisor" relationship can be carried through even to the command group environment, provide a means for equalization of performance between analysts of differing capabilities, and elevate the average command group decision performance.

APPENDIX B PREVIOUS SUCCESSFUL KNOWLEDGE-BASED SYSTEMS

This Appendix provides a short summary of several successful APT systems. They cover medical applications, mineral exploration and natural language man-machine communication. The characteristics of these systems are used in the estimation of technical and technological feasibility assessment of Chapter 5.

MYCIN. MYCIN (Shortliffe, 1976) is the forerunner of the production rules based systems that were constructed recently. It is a system developed by E. Shortliffe at the Stanford Medical School. Its task is the diagnosis of blood infections, meningitis infections and the recommendation of drug treatment. MYCIN conducts a consultation (in English) with a physician-user about a patient case, constructing lines of reasoning leading to the diagnosis and treatment plan. Currently, it can diagnose three different diseases with 200 different symptoms. The knowledge elicitation is accomplished using a set of "IF (situation) THEN (action)" rules. The knowledge base contains, now, more than 800 rules. The system can explain its line of reasoning, if requested, and can be modified and updated continuously during regular use.

The system is implemented on a DEC PDP-10 computer with a TENEX interactive time-sharing operating system. It communicates remotely over the TELENET. It is under continuous development since 1971, with an effort level of 5-10 man years per year. Since MYCIN does not run stand-alone, the response time is dependent on the system load. During a typical question and answer session, when the system is lightly loaded, the response time is about 10 seconds. During consultation, the response time is generally instantaneous. MYCIN is programmed in INTERLISP using approximately 200K words (900K bytes) of memory, including the INTERLISP interpreter.

MEDAS. MEDAS (Ben-Bassat, 1977) is a computer-aided medical decision and assistance system used for improving the effectiveness of medical care in emergency and critical care settings. The system was developed at the University of Southern California by Ben Bassat.

Its current capabilities include life support, diagnosis, treatment recommendation, record management, and a consultant library. Presently the system can handle 53 major medical disorders which are identified by 670 specific symptoms.

The computer system consists of a Data General Eclipse S/200 CPU using Memory Mapping and Protection. The system uses 56K words (112K bytes) of memory, and a 10M byte moving head disc. MEDAS design followed top-down design practices using independent modules which are controlled by an executive. The system is written in BASIC under the RDOS operating system. User requests are menu-driven.

INTERNIST. INTERNIST (Pople, 1977) is another computer-based consultative system for medical diagnosis developed by Dr. Jack D. Myers and Dr. Harry E. Pople, Jr. This system has even larger capabilities than the previous two, handling 600 different diseases (not all major ones,) with over 4000 manifestations. The knowledge base for the system is stored as an inverted list so that each disease has an associated list of manifestations, and each manifestation is associated with a list of diseases along with a measure of the strength of association. The system is implemented on the same interactive DEC PDP-10 system as MYCIN. It uses approximately the same amount of memory as MYCIN, about 200K words (900K bytes). It is also written in INTERLISP. INTERNIST is under development since 1971 with a yearly effort of 3-4 man years. By next year the system will, experimentally, provide consultation services through remote terminals at several research hospitals. A final deliverable system is expected to be completed in five years. The diagnostic quality of INTERNIST outputs for complex medical cases is judged by expert physicians to be comparable to that of an average internist, i.e. much better than a family physician.

As can be seen from the last three medical systems, a comparison between the apparent capabilities of a system and the resources used to implement the system is a difficult task. On comparing MYCIN with INTERNIST, it is found that INTERNIST has apparently greater capabilities as far as the number of diseases it can diagnose is concerned, yet the two systems use approximately identical resources. This can be attributed to factors not taken into consideration, e.g., the fidelity of the model or the amount of processing the system does to disburden the user.

PROSPECTOR. PROSPECTOR (Duda et. al., 1977) is a computer-based consultation system used to aid exploration geologists in their search for ore deposits. It is currently being developed at the Stanford Research Institute as part of a 5 year development effort. It uses a knowledge base containing encoded models of a variety of ore deposits. Like MYCIN, PROSPECTOR uses a set of inference rules in performing its inference and knowledge representation. Currently the system contains 118 rules and 600 spaces which make up the semantic network encoding of the models, and more than 900 words and synonyms are in the system's dictionary. The effort level is about 4-5 man years/per year, half of which is done by expert mineralogists.

The PROSPECTOR system is implemented in the INTERLISP language on a DEC PDP-10 computer running under the TOPS-20 operating system. It uses more than 1000K bytes of memory for programs data and the interpreter. Processing time for a typical question is approximately 1 CPU second. A consultation session on the time-shared computer costs no more than a few dollars in computer time.

SHRDLU. SHRDLU (Winograd, 1972) is a system developed by Terry Winograd at MIT for understanding English in an interactive question and answer session. Knowledge in the system is represented in the form of procedures, rather than tables of rules or lists of patterns. The software

is written in a modular fashion with communication performed directly between modules. The system was implemented on the DEC PDP-10, ITS time-sharing system and was written in LISP. When operating with a 200-word vocabulary and a fairly complex scene, the system occupies approximately 80K words (360K bytes) of memory. This includes the LISP interpreter, all the program, dictionary entries, and data. Each sentence takes from 5 to 20 seconds to analyze and respond to. The system took 3 years to develop, ending in 1972, with a yearly effort of 1-2 man years.

The analysis and comparisons of these five systems, and the conclusions relevant to the development effort of a military situation assessment system is presented in section 5.2.