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COGNITIVE ENGINEERING OF ADVANCED INFORMATION TECHNOLOGY FOR AIR FORCE SYSTEMS DESIGN & DEPLOYMENT:

Prototype for Air Defense Intelligence & Operations

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Leonard Adelman

INTERNATIONAL INFORMATION SYSTEMS
MARSHALL, VA 22115

OCTOBER 1989

FINAL REPORT FOR PERIOD MARCH 1989 - OCTOBER 1989

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TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-89-038

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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19 ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This Phase I SBIR project was undertaken given the working premise that empirically verifiable findings from the cognitive sciences have not been effectively applied in systems design, and that recent advances in information technology have also been under exploited. This report documents the findings from an analysis in the domain of strategic air defense, and assessments of the broad fields of cognitive science and advanced information technology. A set of interactive "storyboard" prototypes were designed and developed to demonstrate how cognitive science and information technology can be married to design systems compatible with the ways humans structure and solve problems.

The prototypes suggest clearly that the working premise is valid and that it is feasible to marry information technology and cognitive science in systems that will enhance air defense intelligence, operations and the intelligence/operations interface. This project has demonstrated that "cognitive systems engineering" of advanced information technology is possible.

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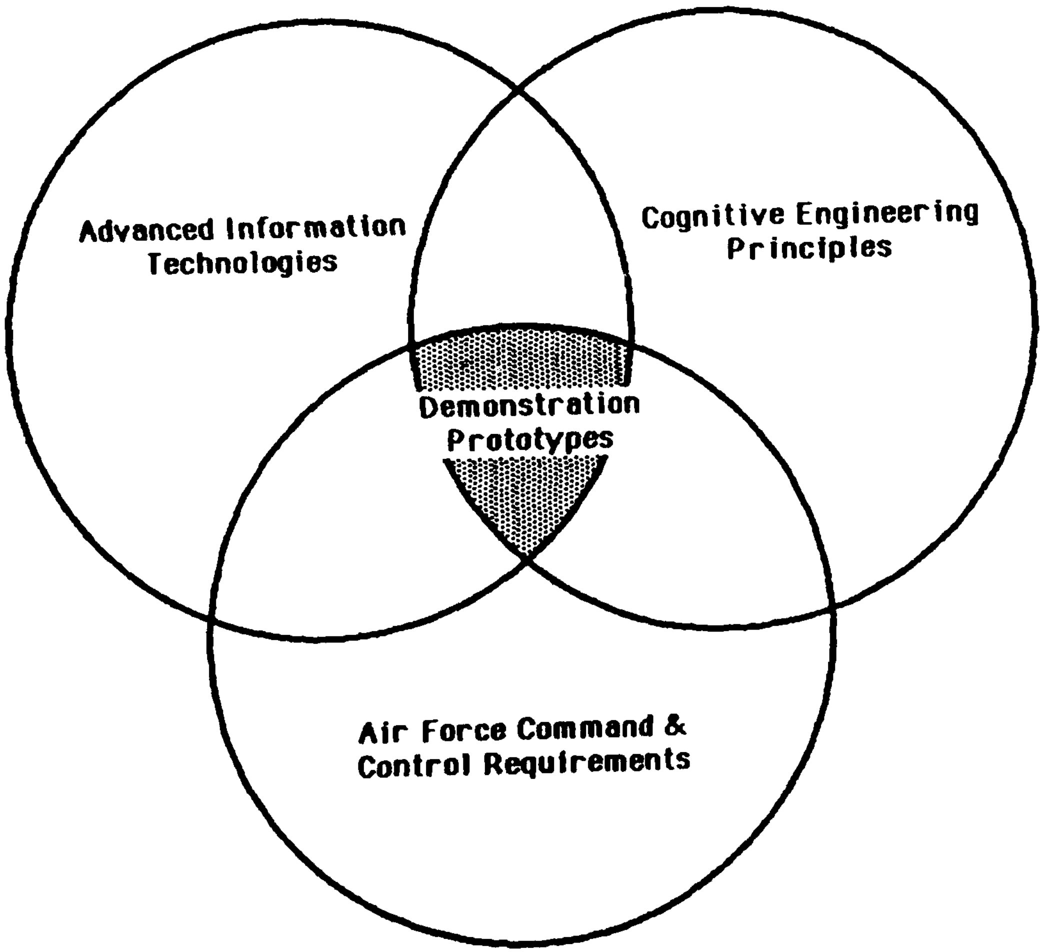
EXECUTIVE SUMMARY

This project covered a lot of ground. The working premise was -- and remains -- that empirically verifiable findings from the cognitive sciences have not been effectively applied in systems design, and that recent advances in information technology have also been underexploited. The project -- a Phase I Small Business Innovation Research (SBIR) undertaking -- demonstrates how information technology, cognitive science and a specific Air Force domain -- strategic air defense -- can be merged to yield some novel system concepts. Several prototypes were designed and developed that demonstrate how strategic air defense intelligence, operations, and integrated intelligence/operations processes can be supported with interactive computer-based systems. The overall structure of the project appears in the following figure.

An assessment of the target domain was undertaken. Strategic air defense intelligence analysis and production is located within the larger and more generic intelligence analysis and production process. A set of tasks and sub-tasks are identified and organized. Strategic air defense operations are examined in the context of decision-making and planning. The domain analysis also suggested a range of possibilities for treating the intelligence/operations process as a continuum. In spite of doctrinal precedent to the contrary, there are times when the intelligence and operations processes should be intertwined.

Project Structure



Intelligence analysts should have access to operational plans, and vice versa.

The domain analysis was followed by an assessment of the broad field of cognitive science. A variety of findings were identified, findings extremely relevant to the design of user-computer interaction routines as well as other system processes. Findings were identified that describe how humans make inferences and decisions, and communicate their analytical processes and priorities. We noted, for example, that humans make inferences via causal schema and analogies, and decisions based upon multiple criteria. We also learned that a variety of biases and cognitive predispositions influence the inference- and decision-making processes.

An assessment of advanced information technology was also undertaken. This assessment concentrated on hypertext, multimedia, interactive graphics, low-level knowledge-based systems, animation, simulation and adaptive user-computer interface technology. The assessment concluded that these technologies are ready for implementation, cost-effective, and naturally synergistic with empirical findings from cognitive science.

A set of interactive "storyboard" prototypes developed to demonstrate how cognitive science and information technology can be married to design systems compatible with the way humans structure and solve problems. These prototypes run interactively on Apple Macintosh computers and suggest how air defense intelligence, operations, and intelligence/operations can be enhanced via the use of interactive computer-based support systems. Output from the prototypes appears below.

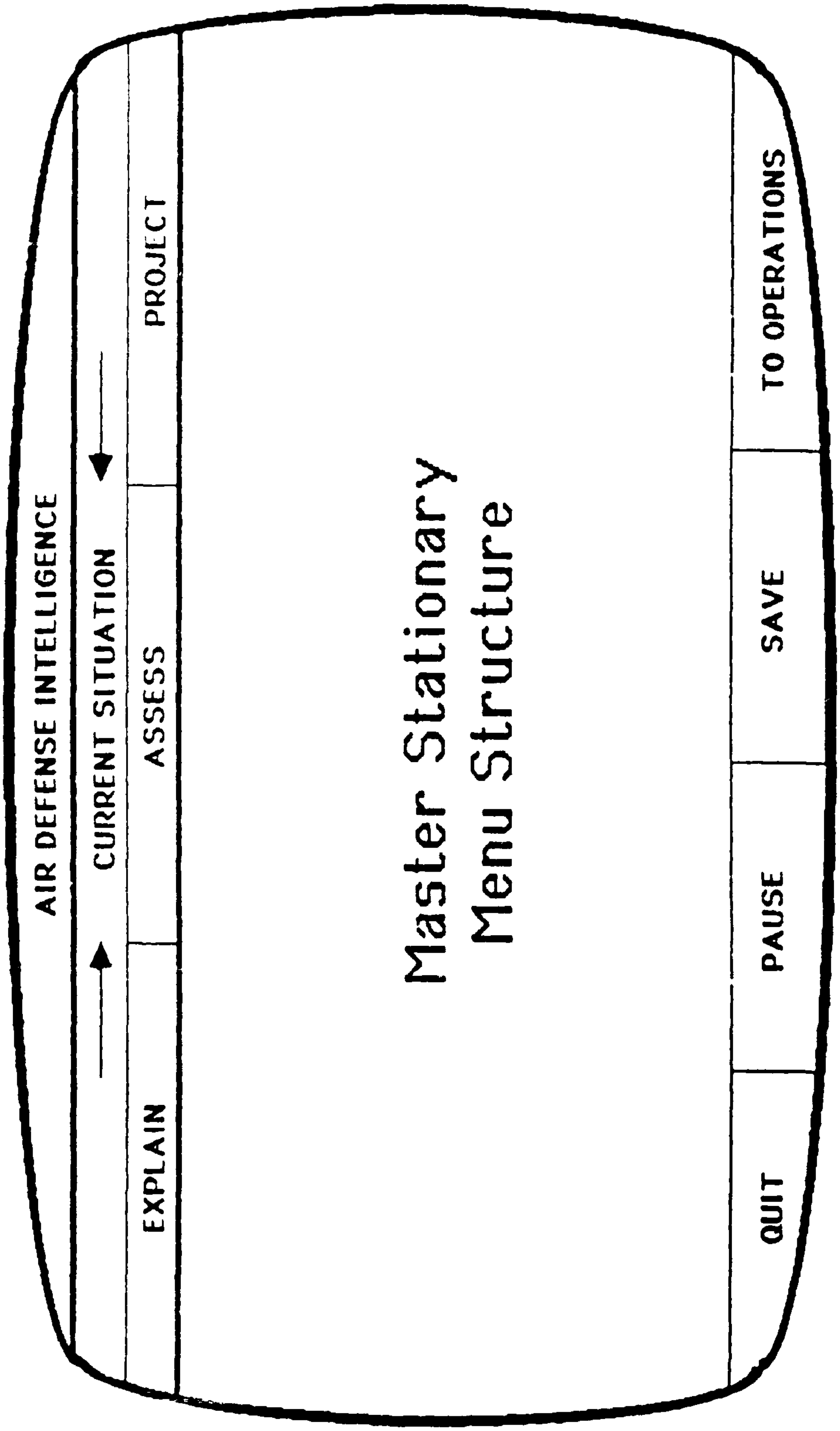
The prototypes suggest clearly that the working premise is valid and that it is feasible to marry information technology and cognitive science in systems that will -- at least hypothetically -- enhance air defense intelligence, operations and the intelligence/operations interface.

We also demonstrated how intelligence and operations can be intertwined to yield analyses greater than the sum of their individual parts. The prototypes suggest that the conceptual and functional gaps between intelligence and operations are minimal, and that the organizational and doctrinal gaps should be closed.

This Phase I SBIR project has demonstrated that "cognitive systems engineering" of advanced information technology is possible. It also demonstrated the power of multidisciplinary research and development.

Storyboard Prototypes For Strategic Air Defense Intelligence, Operations & The Intelligence/Operations Interface

Air Defense Intelligence
Prototype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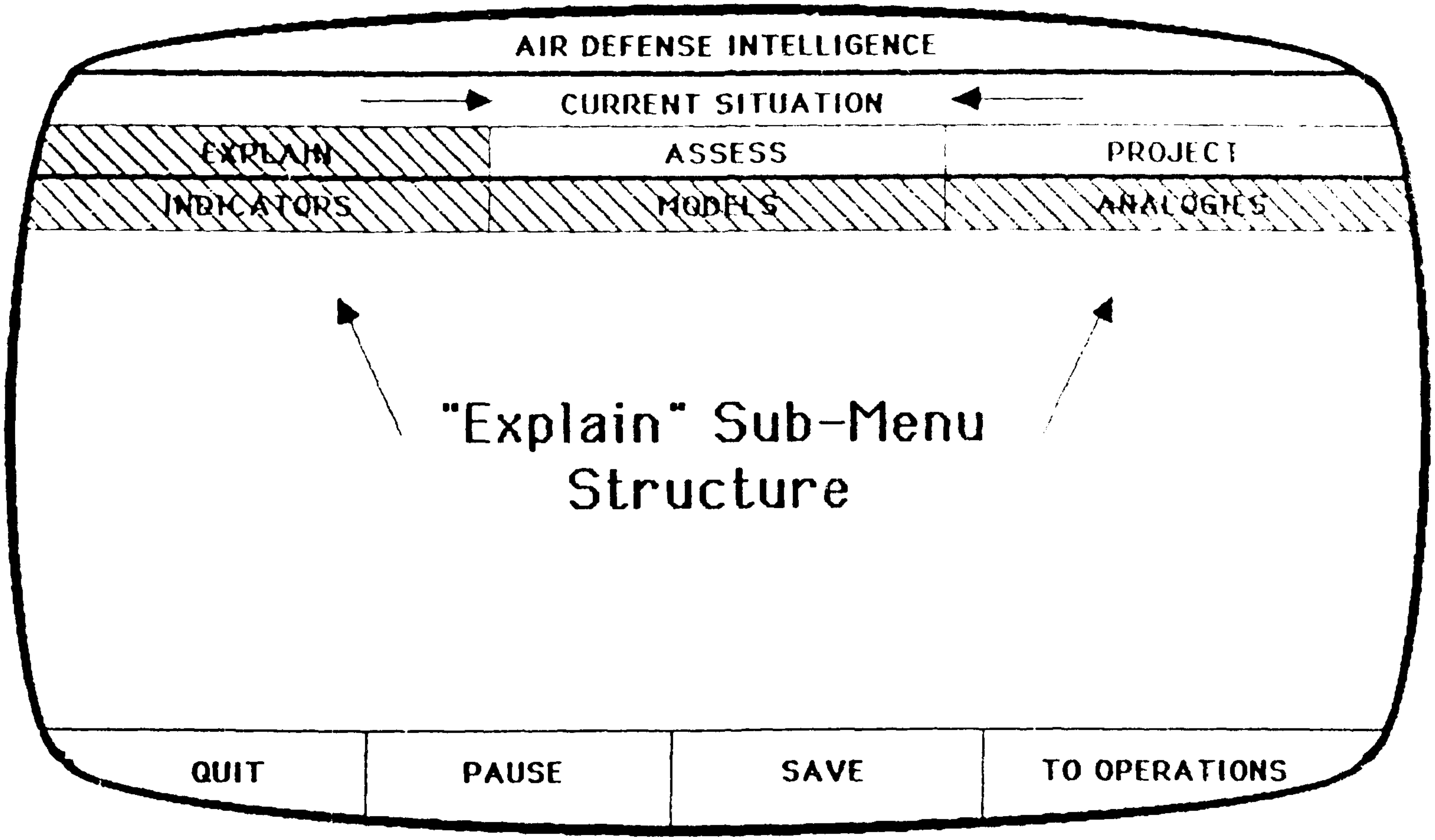
EXPLAIN
ASSESS
PROJECT
Master Stationary
Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS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CURRENT SITUATION
EXPLAIN
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PROJECT
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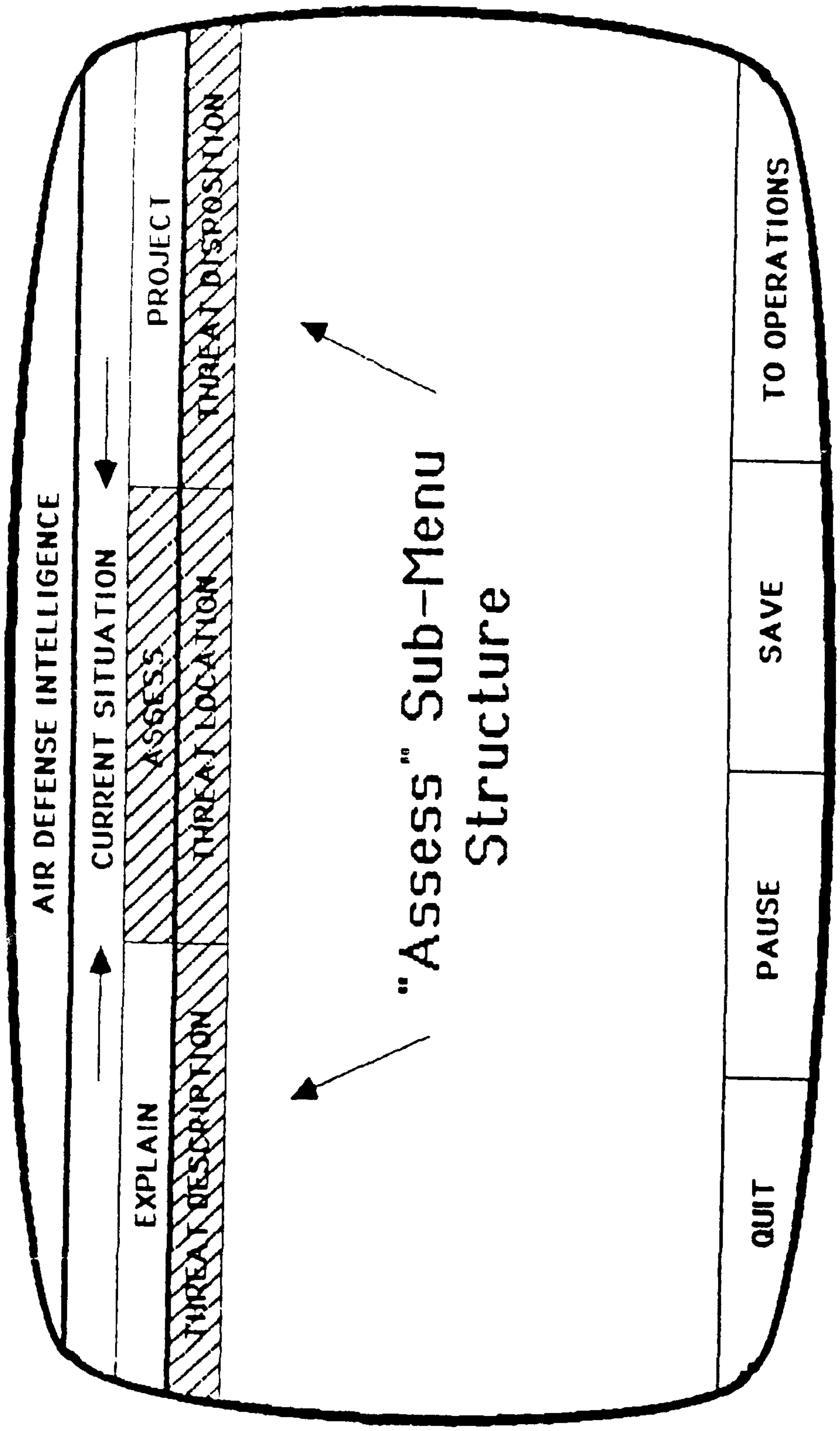
MODELS
ANALOGIES
"Explain" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS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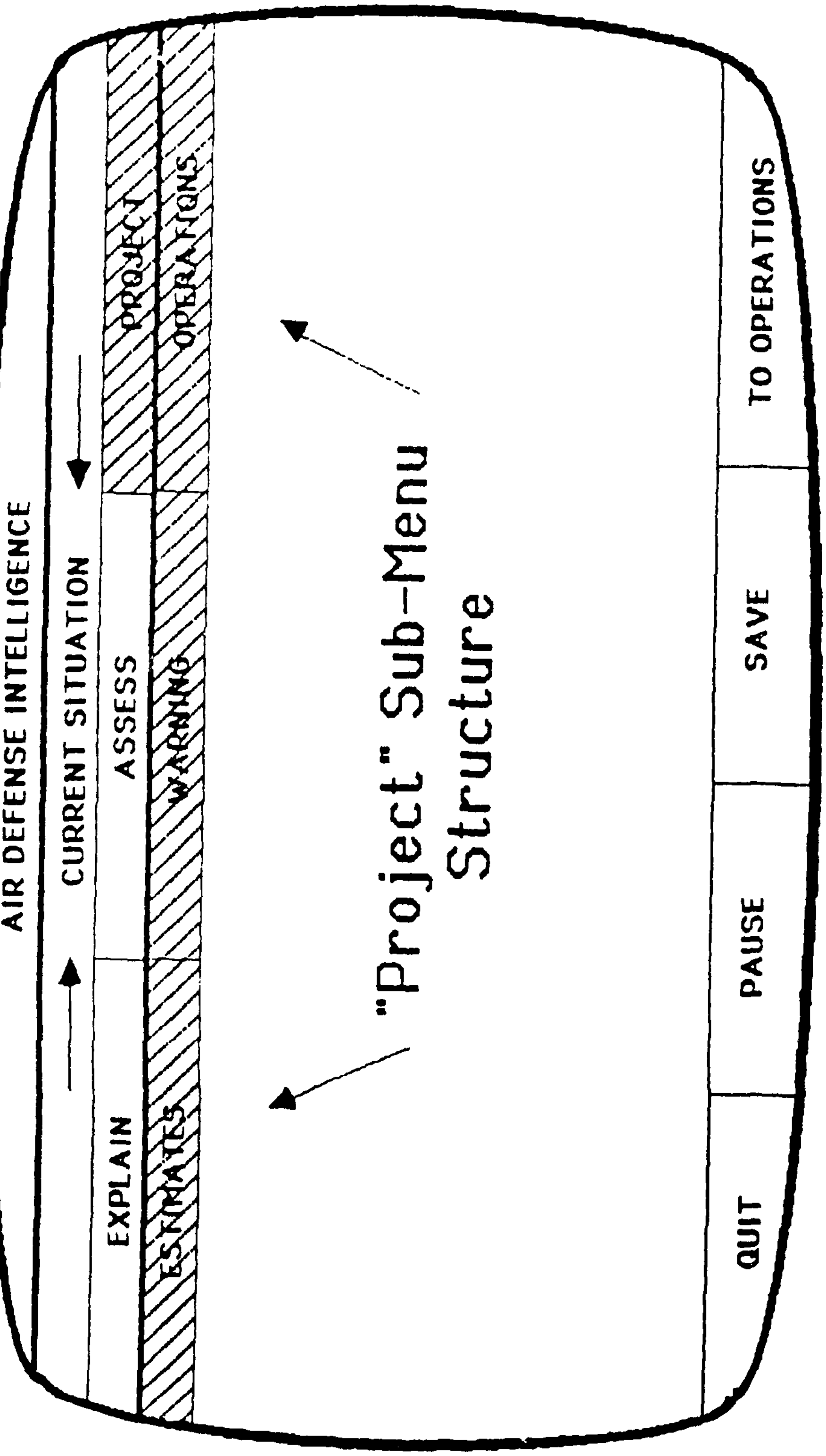
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
THREAT DESCRIPTION
THREAT LOCATION
THREAT DISPOSITION
"Assess" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
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PROJECT
ESTIMATES
WARNING
OPERATIONS
"Project" Sub-Menu Structure
QUIT
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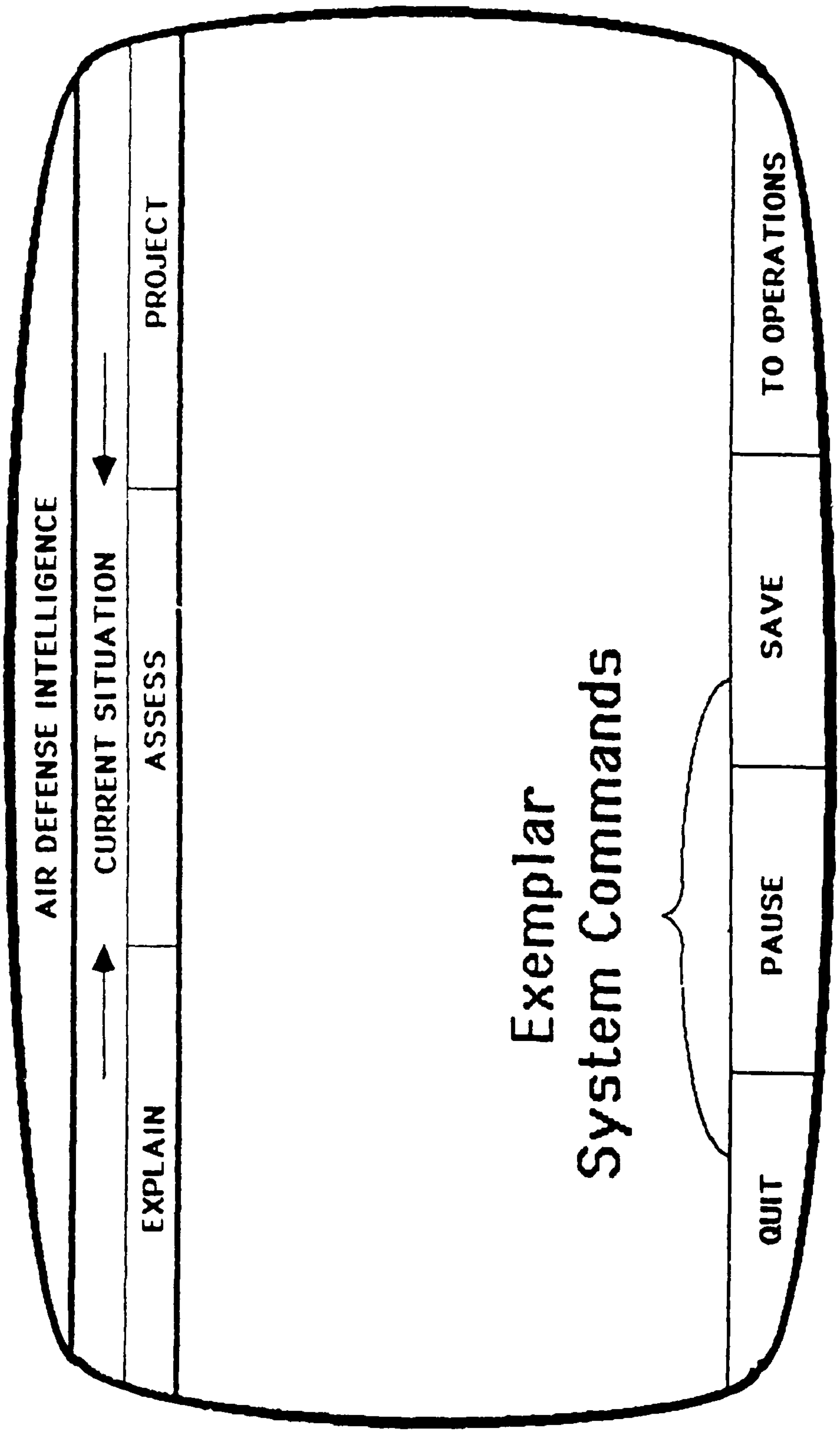
SAVE
TO OPERATIONS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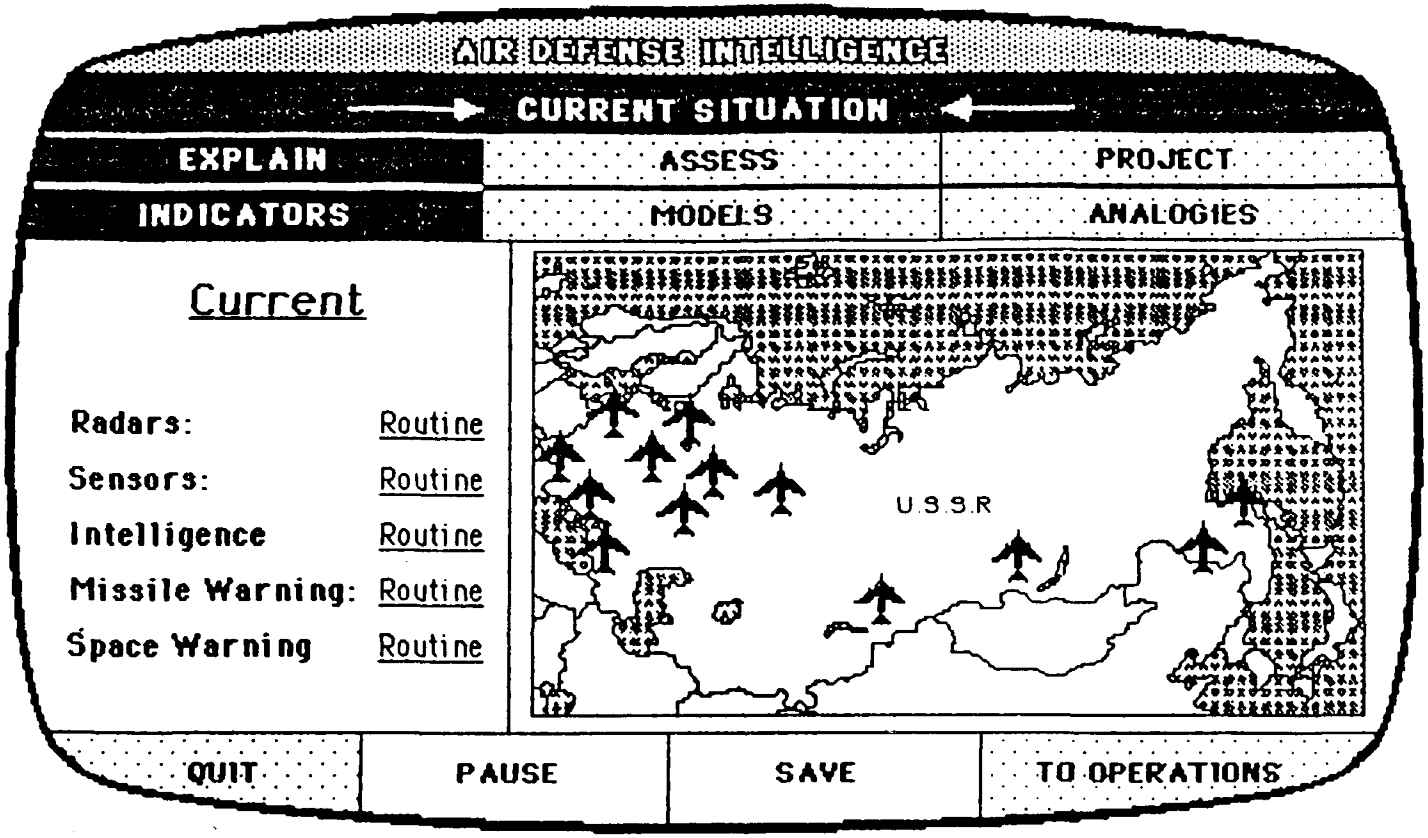
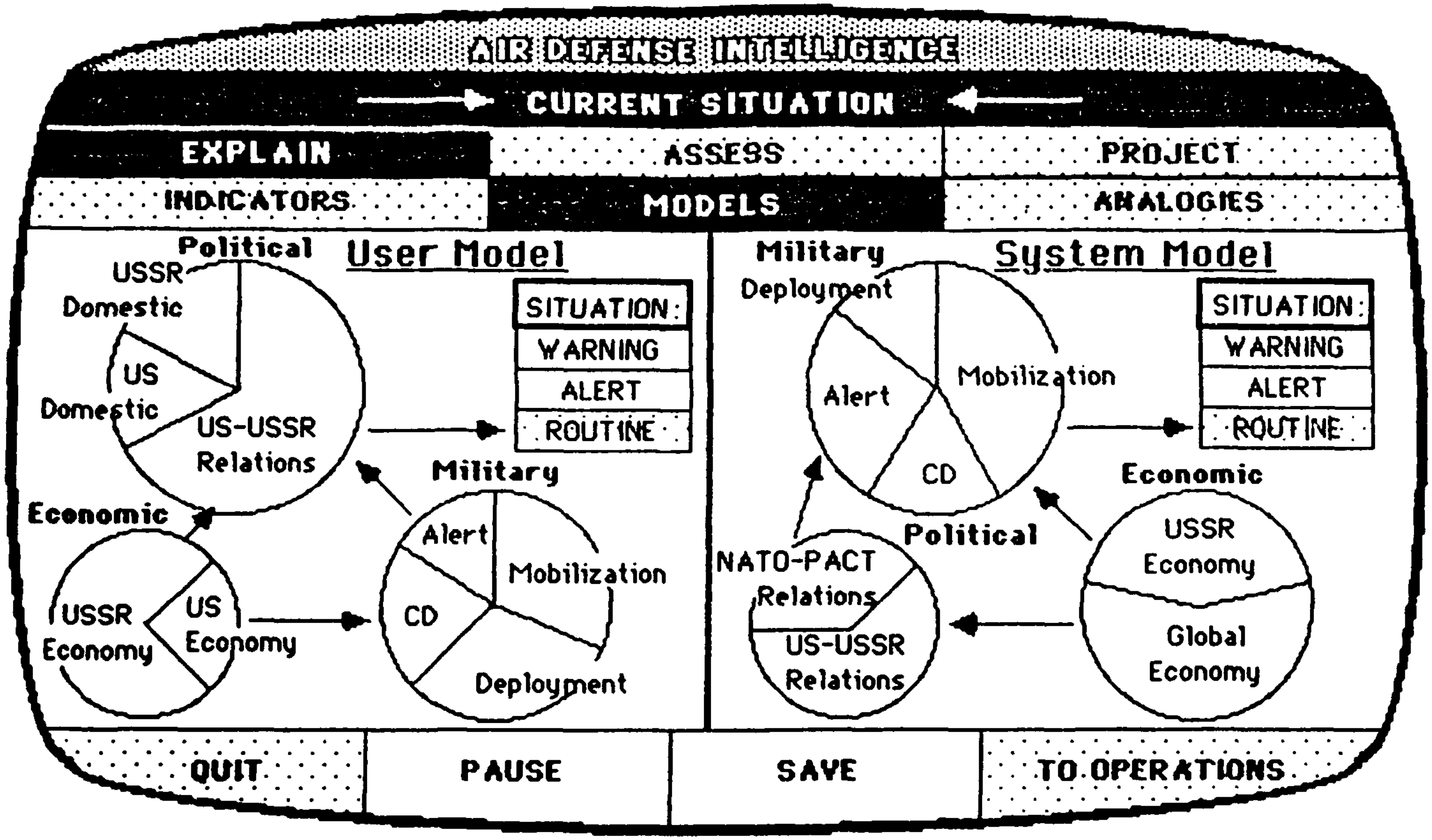
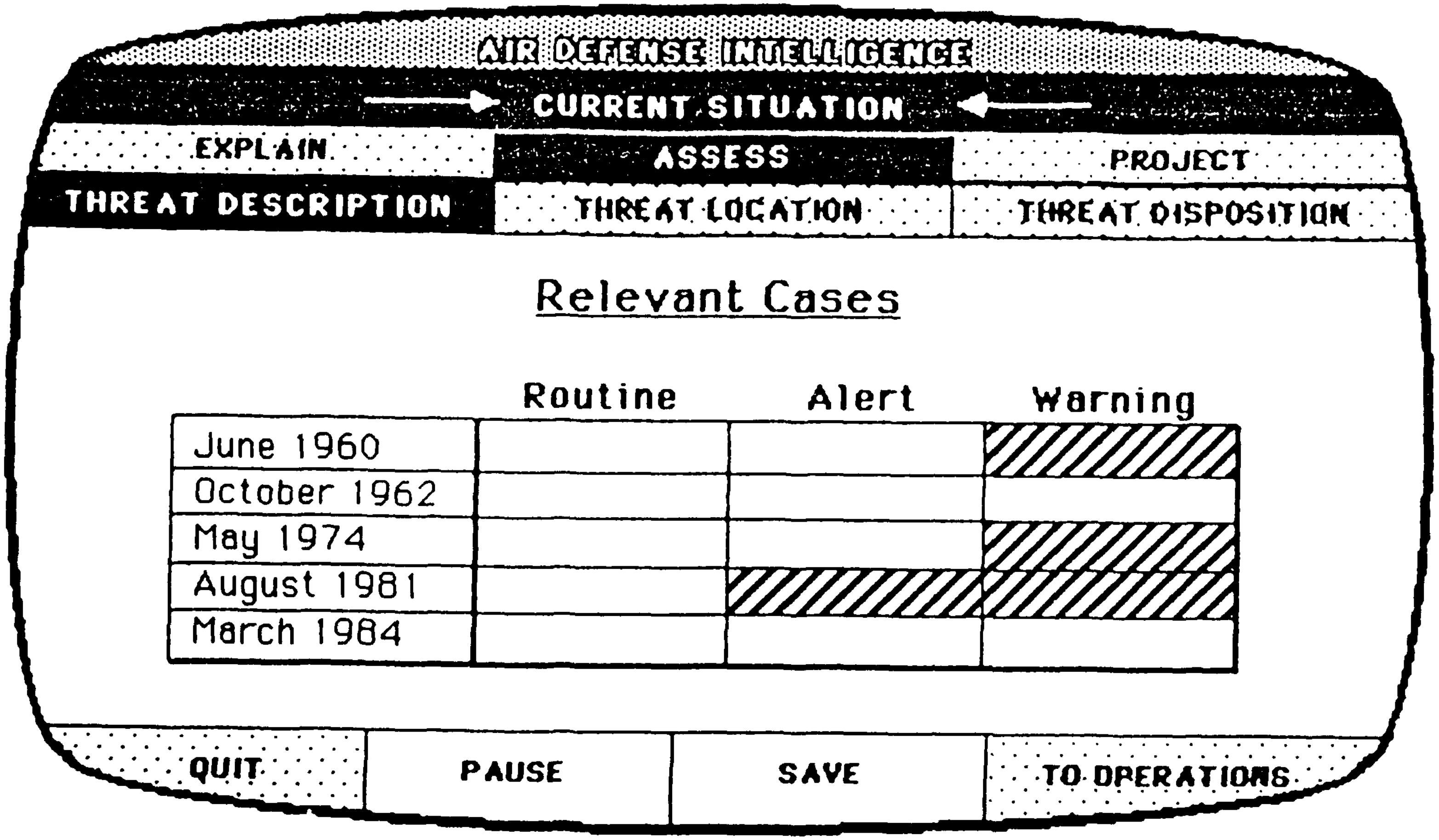
PROJECT
Exemplar
System Commands
QUIT
PAUSE
SAVE
TO OPERATIONS



This display presents a map of the Soviet Union that locates its long range aviation (bomber) capabilities. The system also presents data on the missile and space threat. The user -- having received an overview of the current situation -- decides more information is necessary. He selects the **Explain Indicators** option (with two clicks). Hierarchical data, information and knowledge organization and storage is by design: human information processors store information hierarchically (from general-to-specific and specific-to-general). The system is structured to be compatible with human data, information and knowledge organization and storage.

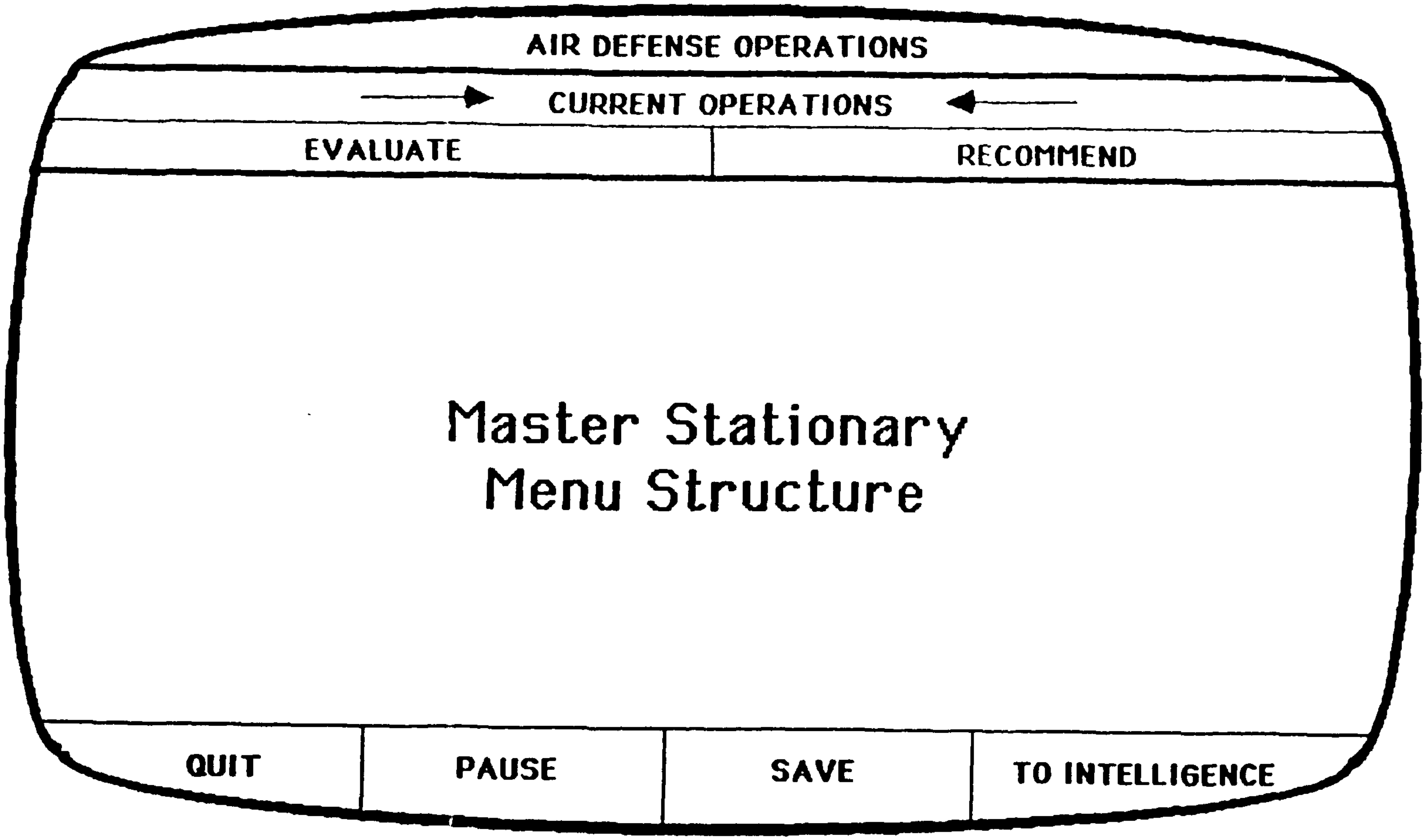


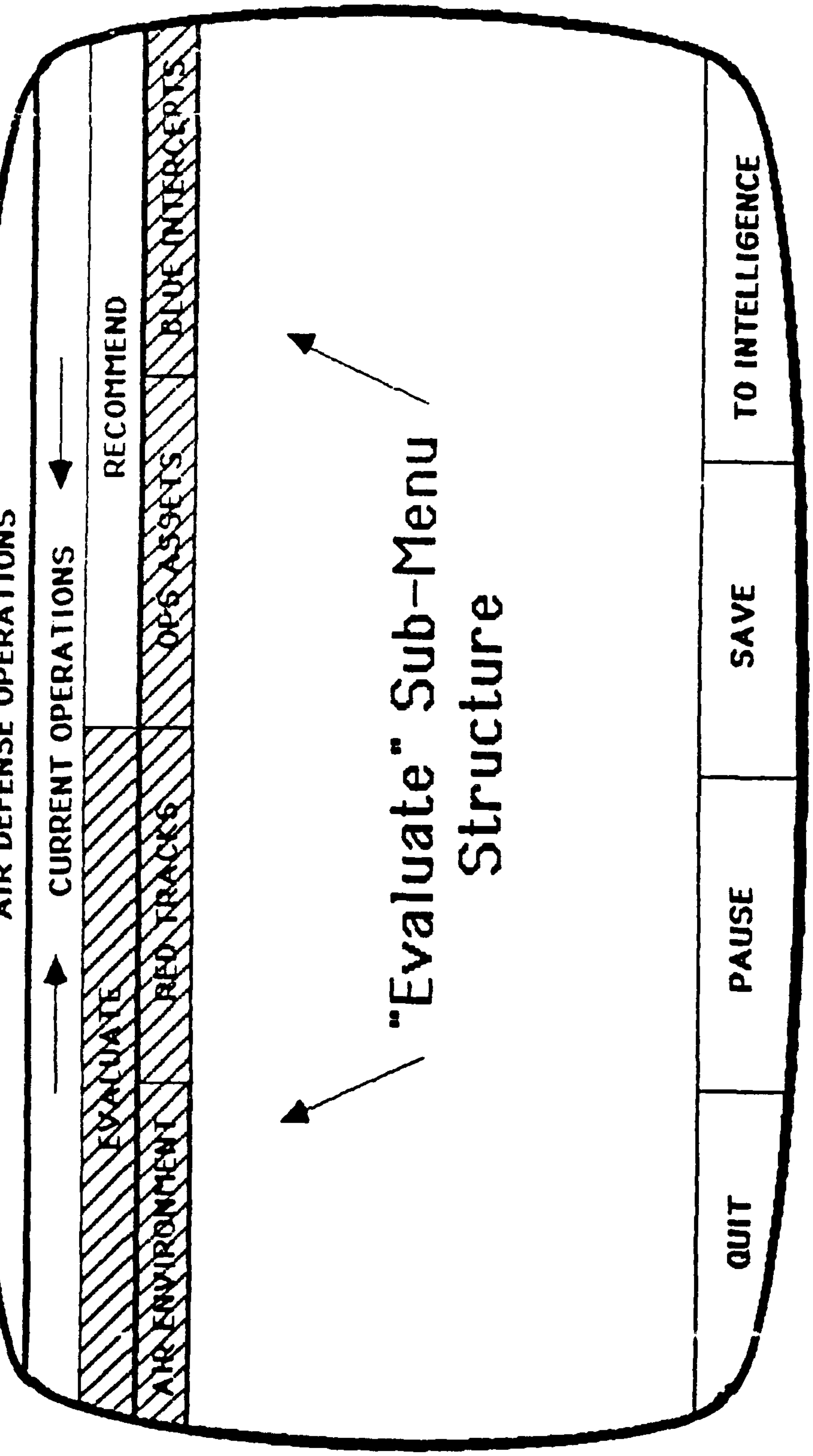
The system displays two models to the user -- that differ in some important ways. The "user model" was constructed by the system from previous user-system interaction and from the queries and responses by the user during the session at hand. The system is providing feedback to the user on his cognitive modeling of the current situation. The "system model" was developed from the system's embedded models. They are presented side-by-side to call attention to the differences and stimulate additional user analysis. The models are presented as "causal"/"influence" diagrams of the situation assessment process, since analysts tend to diagnose problems causally. The user then selects **Analogies**.



The system identifies the "cases" that are relevant to the current situation. It identifies -- via a simple pattern recognition process -- a set of dates and situations for inspection by the analyst. While the story-board does not illustrate the process, the analyst would be capable of calling up "causal/influence" diagrams of the past and overlaying them onto the current situation for comparison. The user then clicks on **Assess Threat** for additional information.

Air Defense Operations
Prototype


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Master Stationary
Menu Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
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RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
"Evaluate" Sub-Menu Structure
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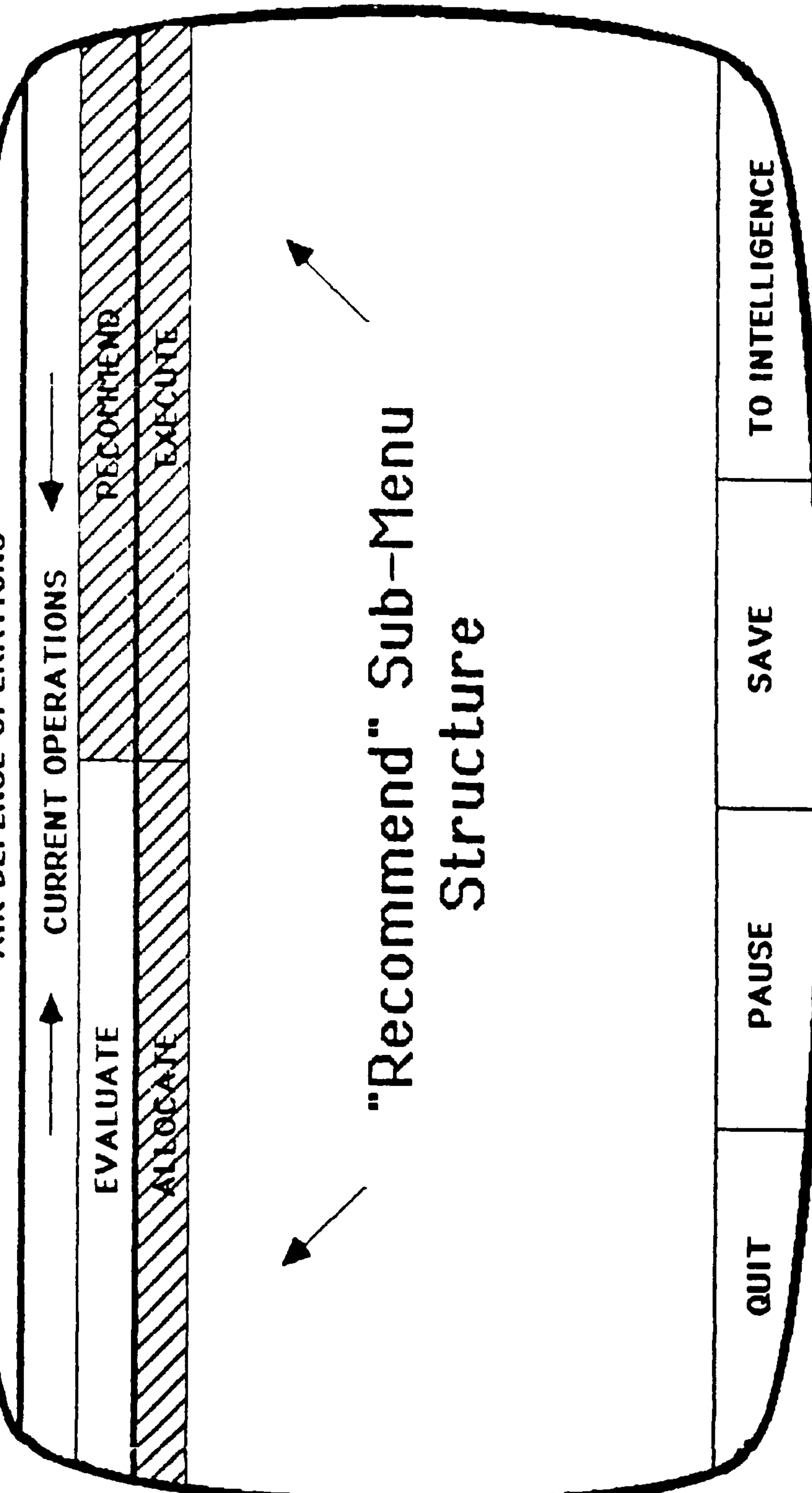
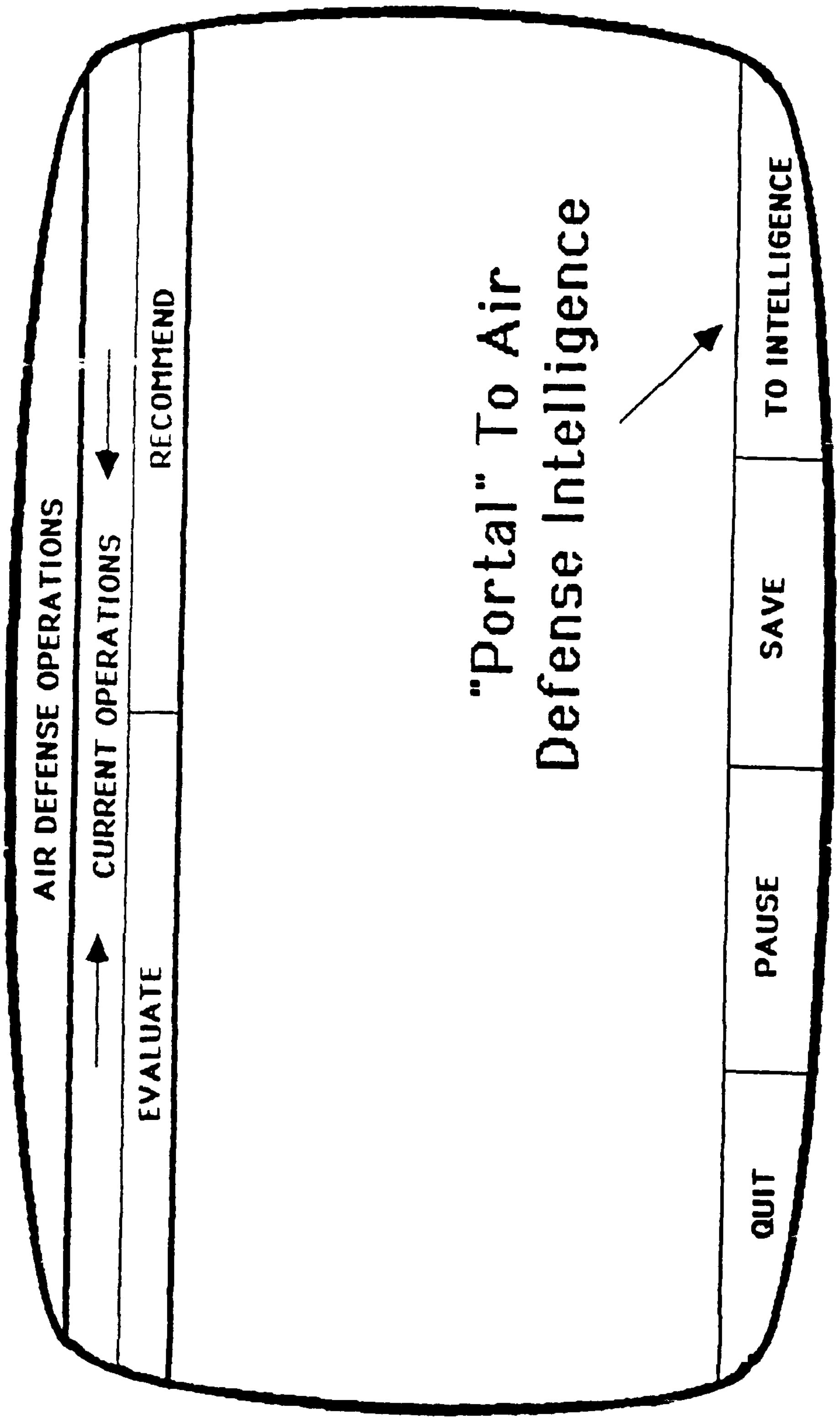
PAUSE
SAVE
TO INTELLIGENCE



AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
"Recommend" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
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"Portal" To Air Defense Intelligence
QUIT
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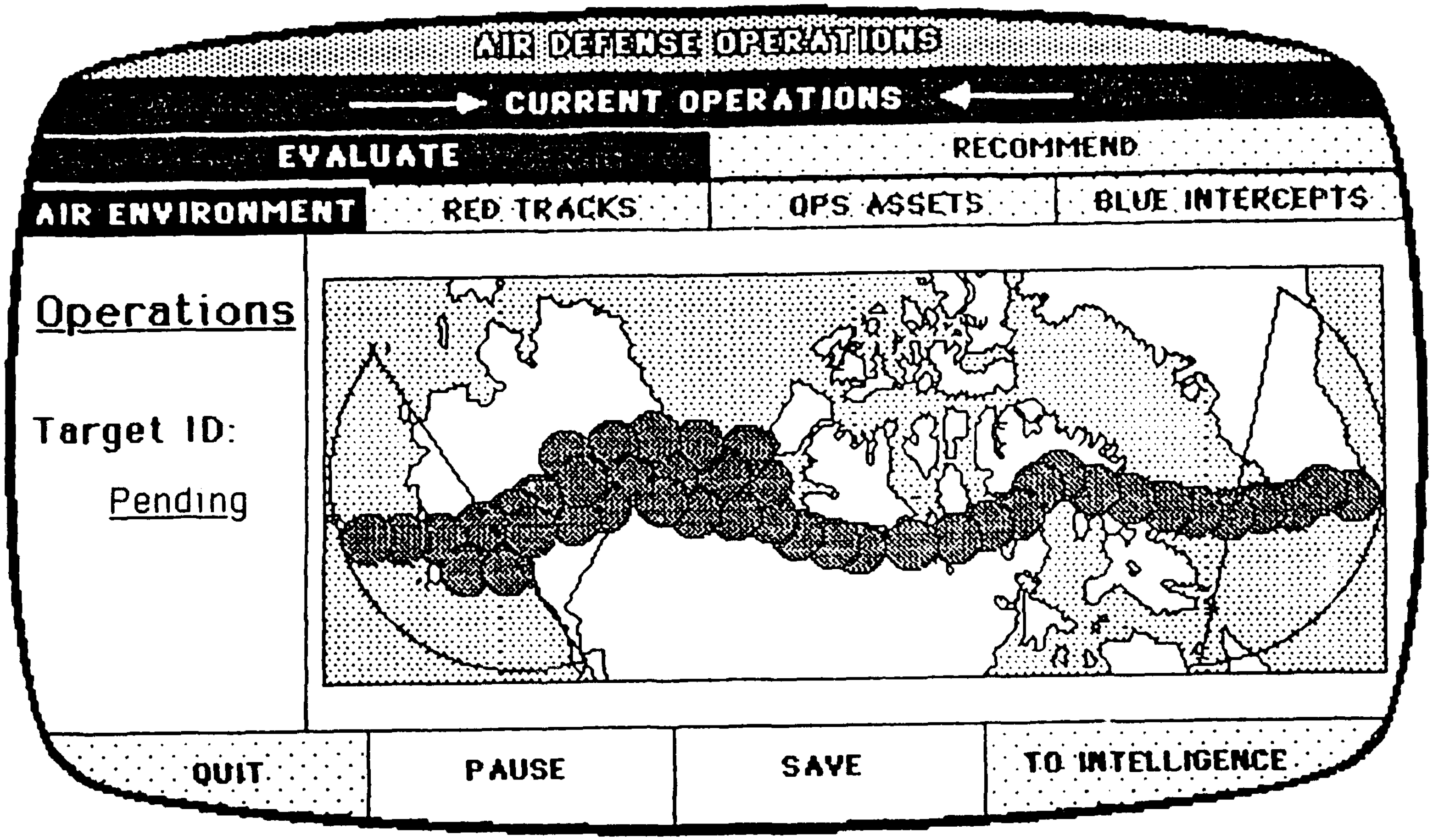
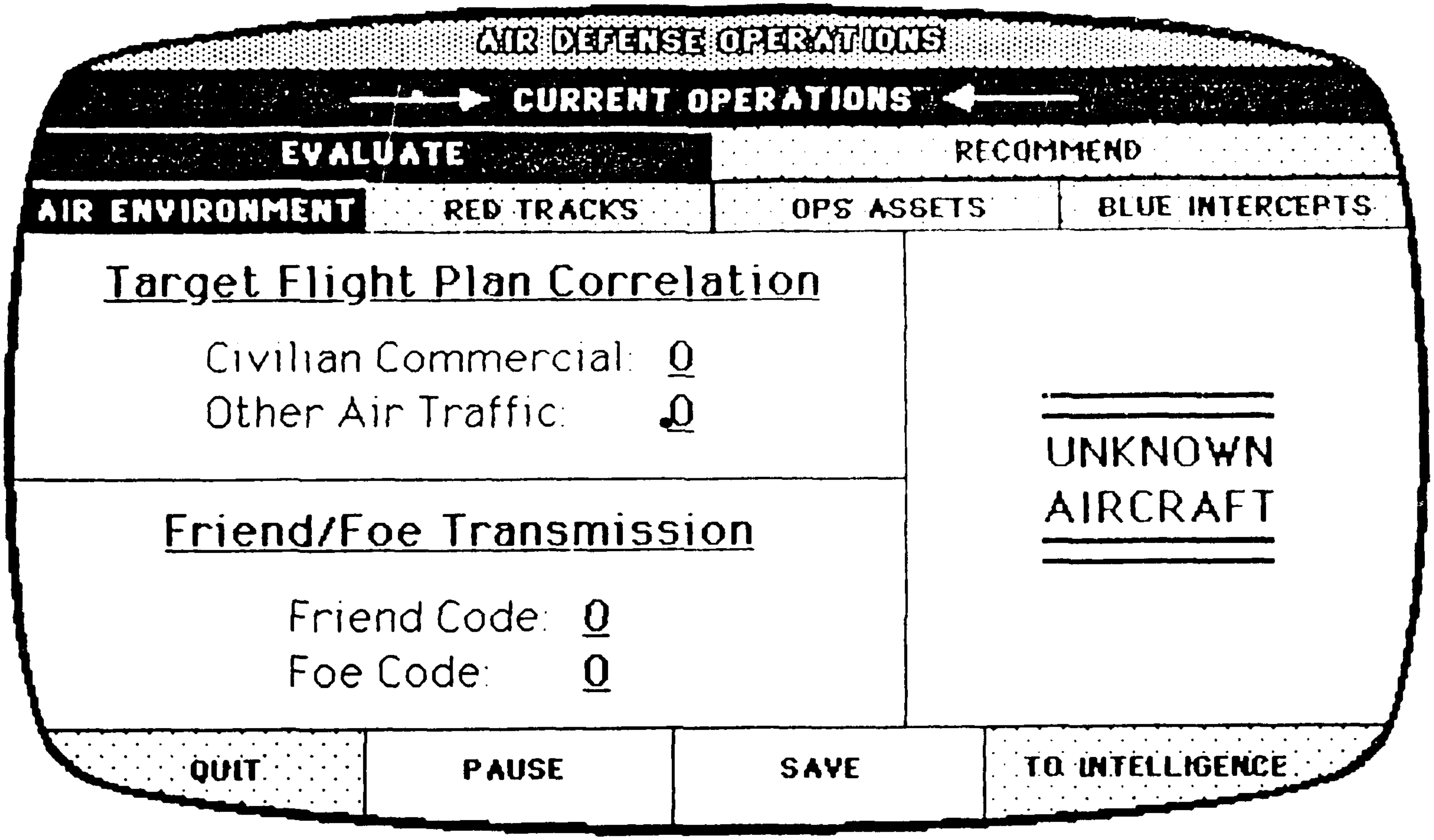
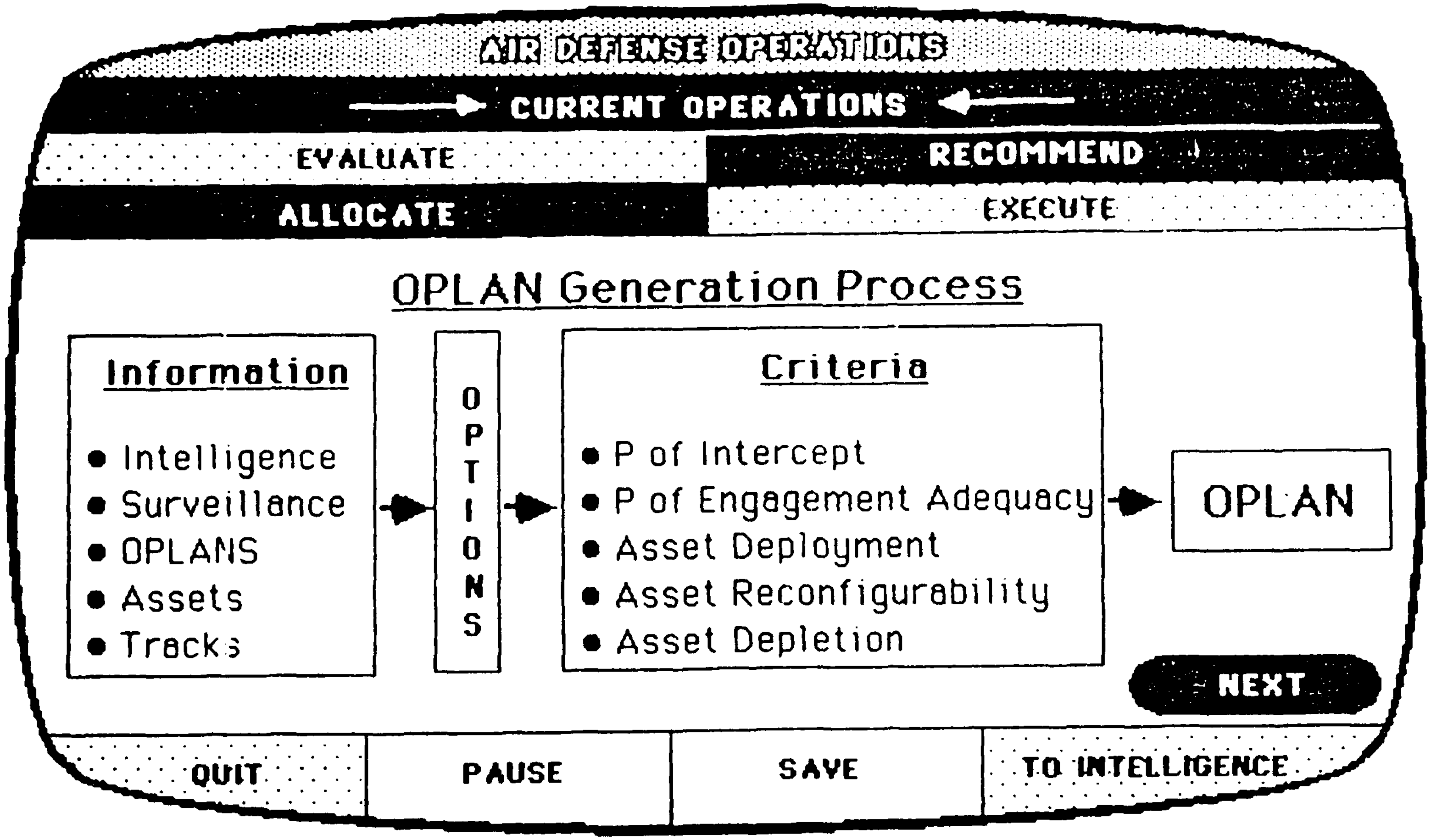
SAVE
TO INTELLIGENCE



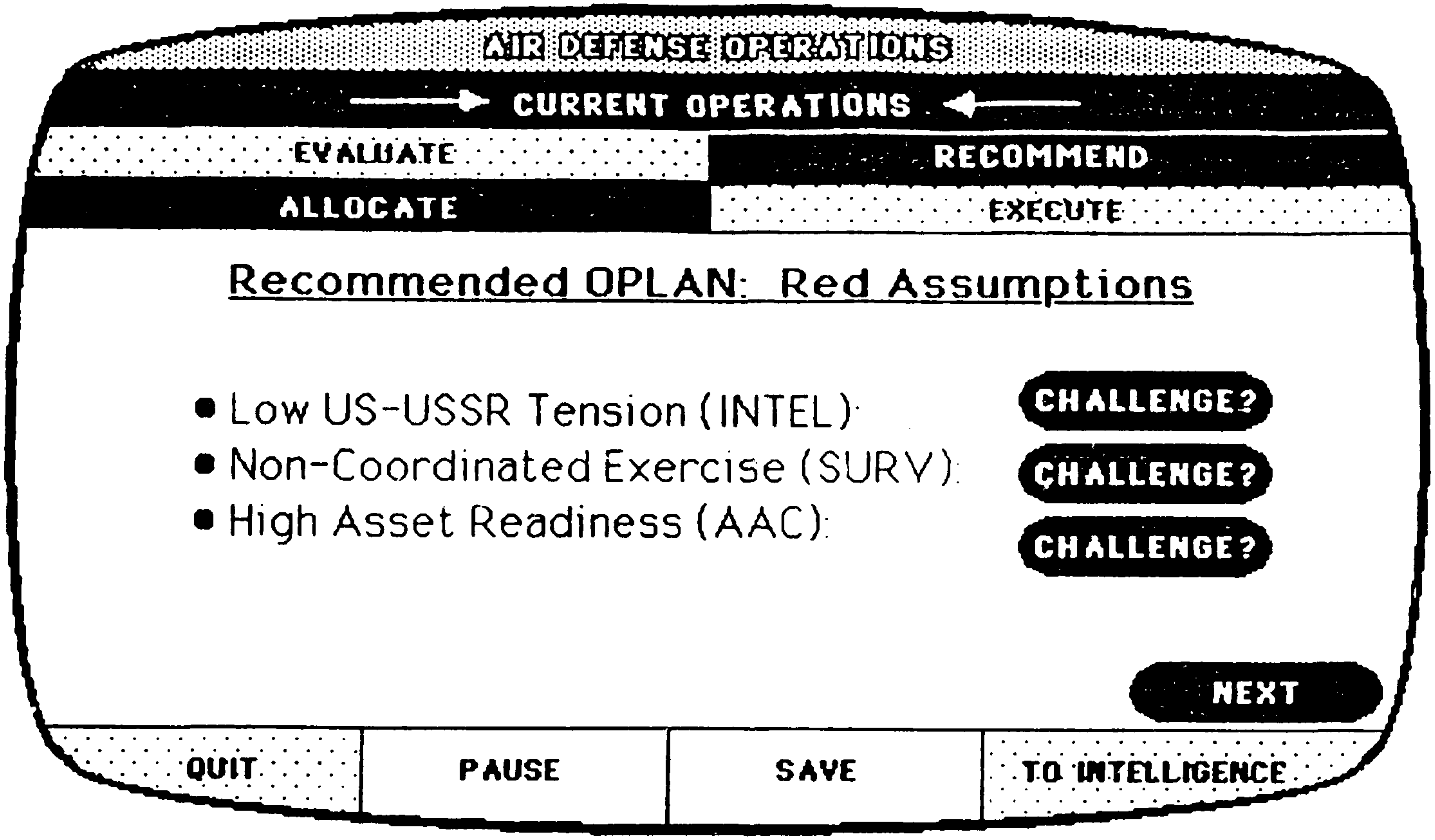
This display presents the current situation at the "Top ROCC," NORAD's Region Operations Control Center at Elmendorf AFB near Anchorage, Alaska. Surveillance has detected several aircraft in the zones of coverage that surround North America. The target ID is designated as "pending," consistent with ROCC operations. The user clicks on **Evaluate Air Environment** to get more information about the situation.



Normal procedure calls for aircraft identification via checks against commercial flights and other civilian aircraft expected to be in the area. The system determines that it is not likely that it is commerical or civilian, and that no IFF transmission has been received. It concludes that the aircraft is unknown. The user then clicks on **Red Tracks**.

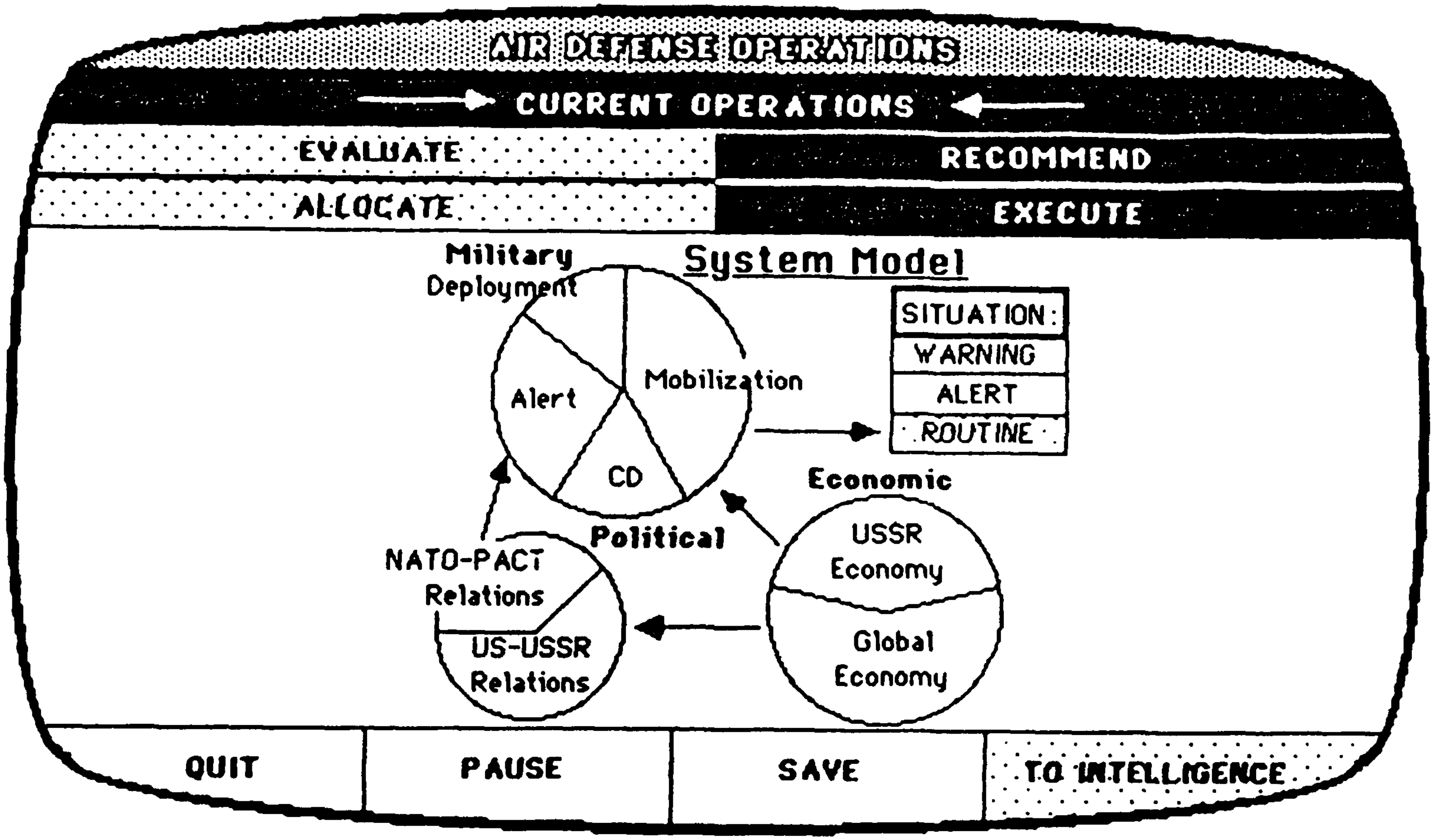


After the user challenges the system, the system presents its "internal (decision-making)logic" to the user. Here the system is actually displaying its option generation/selection process to the user. Users are better able to understand system output if they understand the model from which it came. The system suggests that it processes information, then looks to a set of correlated candidate OPLANS, and then scrutinizes them vis-a-vis a set of normative criteria. The user clicks on **Next**.

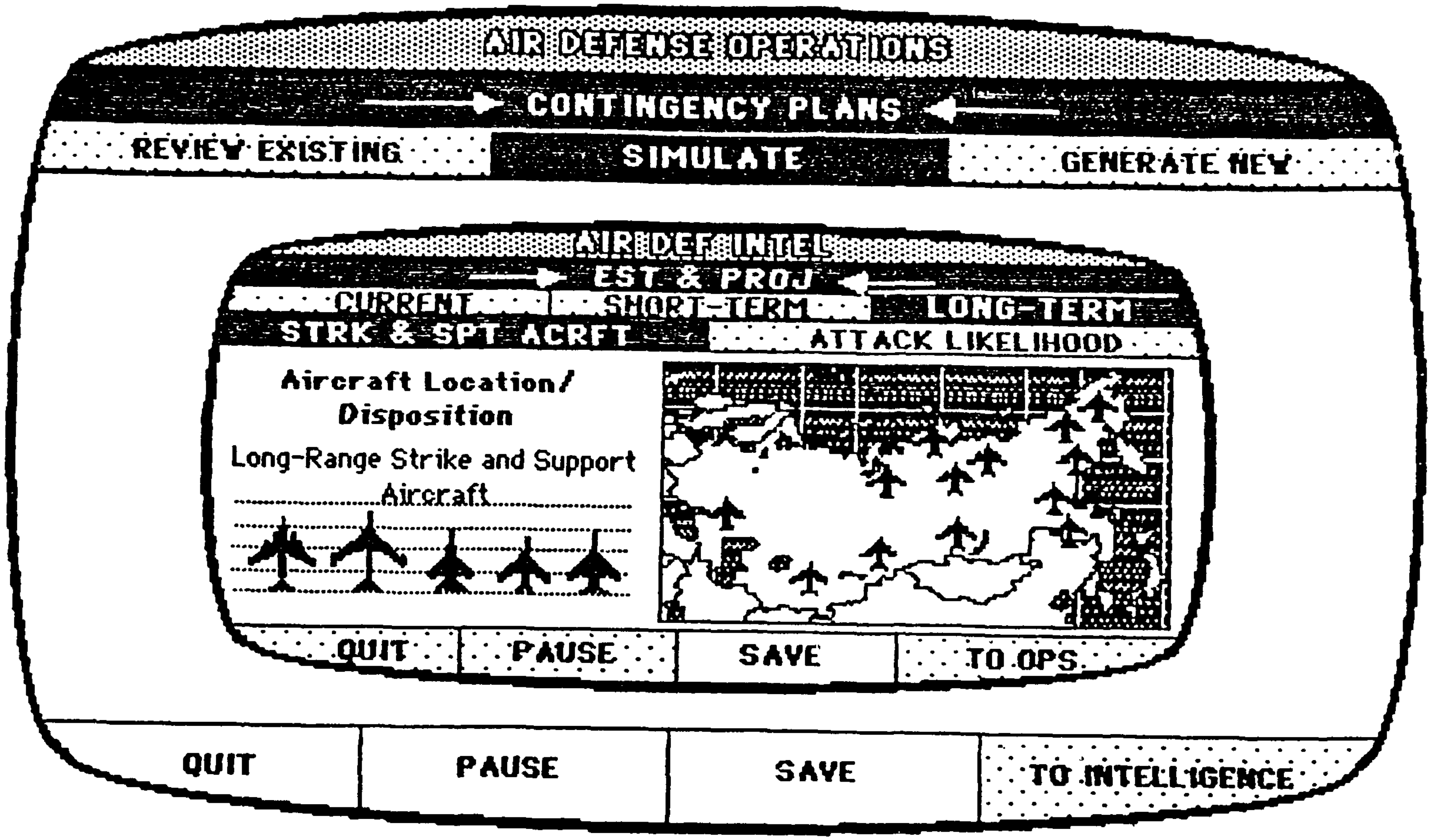


The system then displays the key assumptions it made during the OPLAN calculation. The user can override the system's assumptions by **Challenging** them. In effect, this capability permits users to alter the facts (conditions; stimuli) that trigger the system's knowledge base about optimal OPLANS given certain (pre-specified) sets of conditions. This additional insight into the system's decision-making process provides users with a deep understanding of the option generation/selection process and, therefore, into their own decision-making processes (via their agreement or disagreement with the system). He clicks on **Next**.

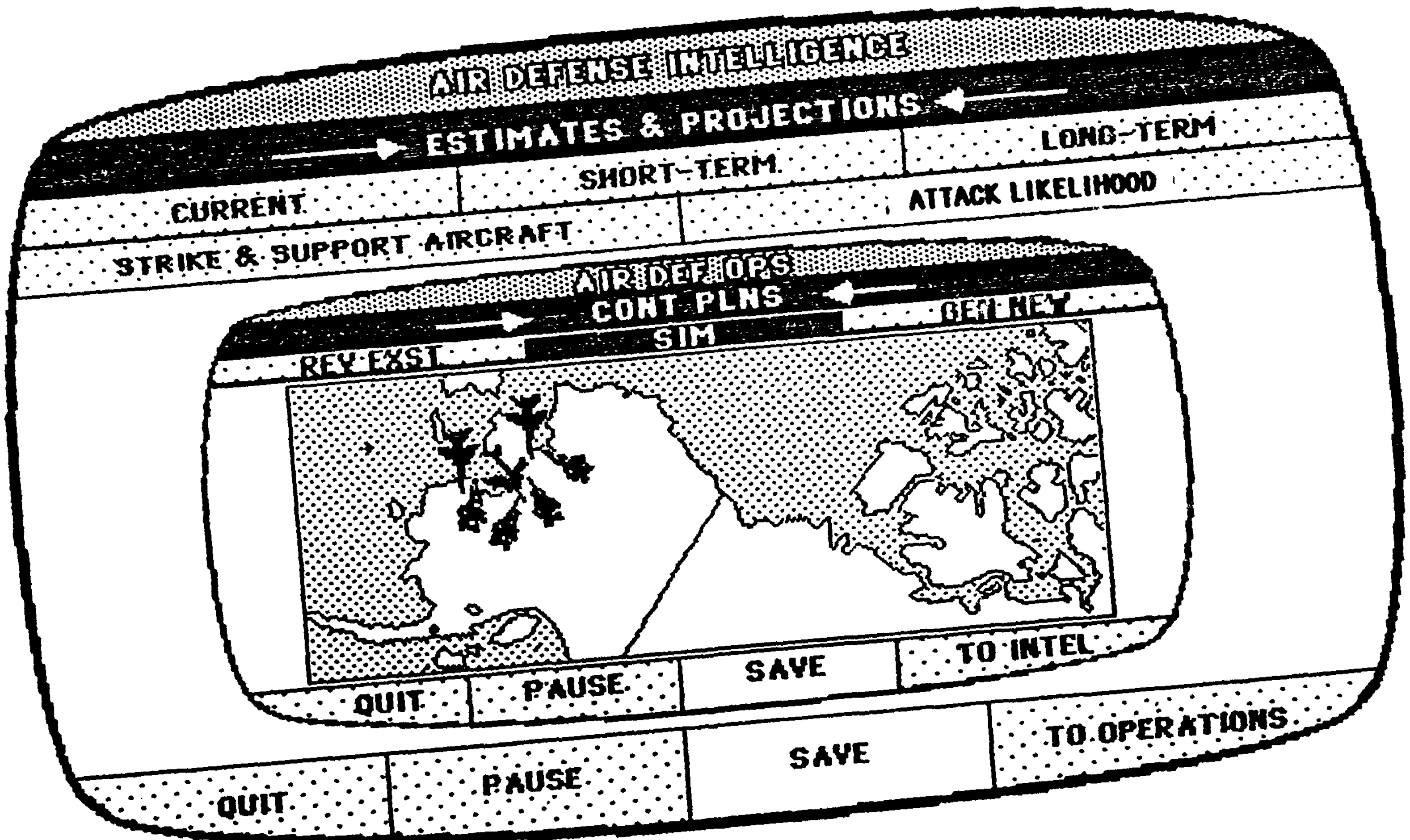
Air Defense Intelligence/
Operations Interface
Prototype



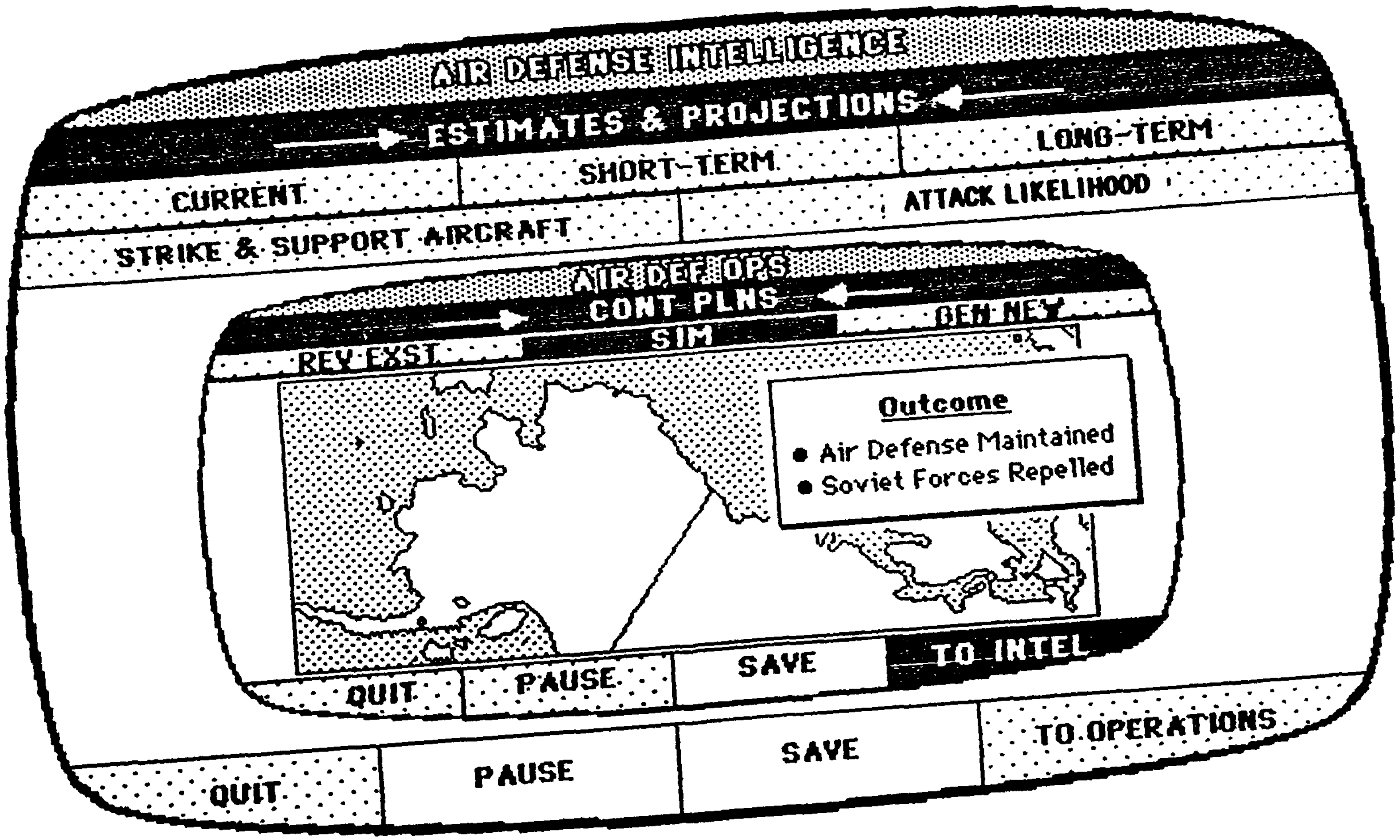
The system presents its inference model to the planner. Note that the planner is seeking information about the likelihood of increased tension between the superpowers to determine if he should favor reconfigurability over timeliness. The operations planning system provided direct access to the intelligence analysis and production system, as well as the capability to browse through the inference models embedded in the system. Specific queries can be made quickly and resolved much faster than if OPS tasked INTEL to conduct additional analyses.



The system displays a window into the intelligence system. The menu structure and interaction process is identical to "his" system. He clicks on **Long-Term Strike & Support Aircraft** to look at what intelligence believes is likely. The system presents him with its best estimate. He then clicks on **Short-Term Strike & Support Aircraft**. A variety of "what-if" activities would be possible via such interaction.



The analyst then enters the Air Defense Operations system via **To Operations**. Here the intelligence analyst decides to simulate some plans based on "his" intelligence estimates.



The system suggests that the plans are adequate, given current intelligence estimates. Had the plans been inadequate the intelligence analyst would inform Operations of potential problems.

PREFACE

We would like to acknowledge the contributions of Gary Klein of Klein Associates, Inc. and Jane Ware Hall of International Information Systems, Inc. Gary provided insight into the process by which we attempted to marry cognitive science and information technology, while Jane produced the offspring storyboard prototypes. We would also like to thank Major Michael McFarren for his support, guidance and ideas.

This research was conducted under Contract #F33615-88-C-0547, a Phase I Small Business Innovation Research (SBIR) Program effort. The research was performed for the Armstrong Aerospace Medical Research Laboratory (AAMRL)/Human Engineering Division (HED), Wright-Patterson AFB, OH.

CONTENTS

1.0 INTRODUCTION

1.1 Evolving Information Processing Challenges

Regardless of whether the task is to detect incoming bombers or determine what the late burning lights in the Kremlin really mean, today's defense analyst is buried in information collected from a variety of sources. The strategic intelligence analyst has too much data and too little time to make too many judgments. Planners must contend with uncertainty, intelligent adversaries, and the fog of war all seen through sensors that struggle to correlate strategic and tactical phenomena.

Over the past twenty-five years we have placed more emphasis upon the collection of data than upon its correlation and analysis. Recently, however, decisions have been made to optimize the use of sensed data and information. The operative question is fast becoming: "how will the information be used?" Systems designers have discovered the under-utilization of very, very expensive data, and have begun to conceive systems that distill information into highly useful content and form.

Command, control, communications and intelligence (C3I) systems must address a broad range of problems. Commanders must rely upon intelligence estimates developed from incomplete and uncertain data <u>and</u> estimates based upon less-than-perfect sampling from the avalanche of data to which analysts have access. Operations analysts must interpret the intelligence estimates and select from a set of sanctioned responses. This template-like approach works fine until completely unanticipated events occur or until the intelligence estimate becomes ambiguous or uninterpretable. Operations personnel earn their pay when they have to induct or abduct; deduction is relatively painless.

Too much information, very little processing time, uncertainty, and ambiguity represent but a few of the problems that organic and silicon information processors face every day. These problems are exacerbated by the need for security, survivability and reconstitutability, among other requirements unique to C3I systems design, development and deployment.

Attention is also now turning toward the organizations that process information, and the humans that staff them. We now know that human information processors suffer from a variety of shortcomings, including biasing and anchoring. We know that humans find it difficult to make inferences from ambiguous information or generate comprehensive sets of options. We know that they sometimes reason analogically, though the process by which pertinent analogies are selected remains largely confusing. We know that analysts bring mental models to the problem-solving process, that such models influence the decision-making process enormously, though somewhat unpredictably.

Finally, we know that the processes by which human information processors communicate is far from optimal. Groups are notoriously inefficient and members find it difficult to share their analytical procedures. This latter problem is especially vexing when procedures assume cooperation and understanding, as when intelligence sends estimates to operations.

This report describes research that addresses a subset of these information processing challenges. The focus here is on human information processing and the models, tools and techniques that can enhance inference-making, option generation, and analyst communication.

1.2 The Information Technology Response

If we were to assemble a room full of computer scientists and ask them to respond to the above challenges, their responses would be predictable. The problem of too much information, they would argue, is only a "throughput" problem: all we need are faster machines. The problem of uncertainty can be managed, they would insist, via the application of fuzzy sets, Bayes' Theorem, Cohen's model of endorsement, or Dempster-Shafer formulae. In spite of occasional breaches, computer security is well within reach, the group would suggest, as is our redundancy technology.

While few share all of the above optimism, progress in information technology has in fact been dramatic over the past decade. We do have faster machines. Aspects of uncertainty and ambiguity can be addressed, and -- perhaps most importantly --

user computer interface (UCI) technology has evolved to the point where we can begin to blur the distinction between the user of the system and the system itself. Such progress results in new system concepts that recognize human users as integral parts of the total system, and, therefore, new system design strategies.

Progress has also been made in the modeling of complex behavioral and analytical phenomena, modeling that can be displayed and communicated to users before, during and after the computer-based problem-solving process.

There is a vast inventory of information technology at our disposal, but selecting the right tool from the inventory can be difficult. Information technology represents a range of solutions that can only be successfully applied when the "match" is right. When should hypertext be used? When should displays be animated? How should abstract concepts like risk, opportunity, and vulnerability be communicated graphically? These and other questions can only be answered in context. Andriole (1989a) describes a methodology for system concept design that calls for the identification of tasks, profiles of the system users, and organizational requirements <u>prior</u> to the selection of any information technology. The argument calls for design prudence and pragmatism.

The procedures for matching requirements with information technology are far from precise. At the same time, there is a growing body of empirical evidence that informs the matching process. The use of specific interface technology (like icons, mice, windows and high resolution graphics) can now be justified given user experience and the nature of the tasks to be performed on the system. Smith and Mosier (1984) have compiled a handbook of sorts to help with the design of effective UCIs.

This project recognizes the generic power of current and emerging information technology, but suggests that the real leverage lies in the matching of specific information technology to user and system requirements. An additional inventory of hypotheses and findings is leveraged here. Our research suggests that the power of information technology can be multiplied when combined with findings from cognitive science and emerging principles of cognitive systems engineering.

1.3 The Emerging Importance of Cognitive Systems Engineering

Cognitive systems engineering owes its origins to "low level" human factors research. The industrial and systems engineering communities, with a great deal of encouragement from psychologists, began to treat human factors seriously several decades ago. Early research was oriented to ergonomic concerns, but as the years passed "high level" human factors foci emerged. High level human factors research inspires the design and development of systems compatible with the way humans store and display data and information, structure problems, and generate options. High level human factors speak directly to the synergism between cognitive information processing and system capabilities. Cognitive systems engineering provides guidelines for the conversion of findings in the cognitive sciences into system concepts compatible with their human components.

The principles of cognitive systems engineering have become important over the past few years because of the growing number of inexplicable system failures. In fact, the "failure literature" has been unable to pinpoint recurring problems or attribute failures to specific flaws in the conventional design process (Ligon, 1989). It is clear, however, that systems designed without reference to human information processing and problem-solving are likely to alienate their users. We know from past painful experience that if users have to re-learn a familiar problem-solving process to accommodate a system's quirks then the system will go under-utilized or be ignored altogether (Ramsey and Atwood, 1979). Designers now respect the need for "cognitive compatibility." It is now even considered cost-effective to cognitively engineer simple and complex systems.

This project endorses the importance of cognitive systems engineering -- especially when coupled with current and emerging advanced information technology. The project assumes that complex information processing problems can be addressed via the cognitive engineering of advanced information technology.

1.4 Project Overview

The working premise of the project described here was -- and remains -- that:

> Recent advances in cognitive science, systems engineering and advanced information technology have provided new opportunities for C3I systems designers, opportunities that have, by and large, gone unnoticed by the major C3I systems houses. It is now possible to dramatically enhance human performance via the merger of the principles of cognitive systems engineering and the tools and techniques of advanced information technology. Cognitive systems engineering is a relatively new field of inquiry that calls for the design and development of computer-based systems consistent with the way humans store, retrieve, "display," and process information. The advanced information technologies available to us now include hypertext, multimedia, simulation, animation, cost-effective color, interactive graphics and deductive knowledge-based inference models, among others. The principles of cognitive systems engineering and the power of advanced information technology can be synthesized to yield interactive systems that can greatly enhance human performance in C3I.

1.4.1 Project Tasks

1.4.1 Project Tasks - The research described here was organized around five tasks:

- Task 1: The identification and analysis of a suitable Air Force domain to demonstrate the cognitive engineering of advanced information technology;
- Task 2: An assessment of the major progress and findings in cognitive science and cognitive systems engineering, especially as they pertained to the target Air Force domain;
- Task 3: A description and assessment of the major new thrusts in applied information technology, especially as they pertained to the designated domain and provided opportunities for application of validated principles of cognitive engineering;

- Task 4: The design and development of several Apple Macintosh-based working "storyboard" prototypes that demonstrate the cognitive engineering of advanced information technology; and

- Task 5: The documentation of the project in a final technical report and a set of working demonstration prototypes.

1.4.1.1 The Target Domain: Air Defense - Air defense intelligence and operations provides a fertile ground for analysis. On the inference-making (intelligence) side are the classic monitoring, warning and estimation tasks that define so much of the intelligence process. On the operations side we find tasks connected with situation assessment (informed by intelligence), option generation, evaluation and selection. We began with a set of tasks that were refined in an air defense requirements analysis. Some of these tasks included:

INTELLIGENCE TASKS

- Assessment of events and conditions;
- Inferences about likely outcomes;
- Identification of high probability crisis situations;
- Mechanisms and procedures for discriminating between "signals" and "noise";
- Qualitative and quantitative indicator development and synthesis;
- Procedures for mapping relationships among events; and
- Extending warning lead time via backchaining "causal" data, indicators, and activities, among others.

OPERATIONS TASKS

- Option generation;
- Assessment of operational constraints;
- Cost/benefit options analysis;
- Search for historical precedents;
- Sensitivity ("what - if") analysis;
- Option outcome assessment; and
- Option rank-ordering, among others.

These tasks were interpreted specifically with reference to air defense intelligence and operations (see Section 2.0 of this report). In addition to the requirements analysis of air defense -- as it is conventionally understood and practiced -- we injected yet another project task: <u>analysis of the interface between intelligence and operations</u>.

This added dimension of the project required us to first analyze the processes by which intelligence estimates and operational responses were formulated, independent of one another (as is often the case) and then as a continuum, where intelligence becomes the front-end to a process that iterates upon options (and refined intelligence estimates) until an appropriate response is identified. Conceptually, the continuum metaphor is accurate, but in practice the intelligence/operations process is much more stochastic and, at times, even totally disconnected. <u>Intelligence is often treated by operations personnel as static; proposed here is treatment of the variable as dynamic</u>. More to the point, intelligence and operations analyses should be shared by all parties, since insight into the production or consumption of information and knowledge will widen the analytical horizons of both sides. Subsequent project research was thus conducted around discrete and continuous assumptions about the Air Defense intelligence and operations processes.

1.4.1.2 Cognitive Science and Systems Engineering - Recently a number of psychologists, information scientists, and systems engineers have joined forces to create a new field of inquiry currently known as cognitive systems engineering. The key word in the phrase is "engineering," because it reflects an intention to apply what we know about human information processing to larger systems engineering efforts. Had "cognitive engineers" been around (in name, at least) in the 1970s, they would have invented windows, the mouse, navigational aids, spatial data base management, direct manipulation interfaces, and interactive graphics.

During the course of the research described here, we attempted to take what is "known" about cognitive information processing and overlay it onto air defense intelligence and operations requirements. An assessment was undertaken to distill key findings from the cognitive science literature, findings that could be leveraged against our domain requirements (see Section 3.0). The assessment permitted us to isolate a set of hypotheses, tools and models that could -- when coupled with advanced information technology -- be used to enhance air defense intelligence, operations, and the intelligence/operations interface.

1.4.1.3 Advanced Information Technology - Substantive requirements in air defense and findings in cognitive science about inference-making and option selection beg the technology question. How can advanced information technology be leveraged against requirements and what we know about cognitive information processing? Can information technology be cognitively engineered? The prototypes described in Section 5.0 suggest that it can, though a series of experiments designed to measure their contribution to human performance should now be conducted.

For the purposes of this project information technology was defined very broadly. It includes all of the tools, techniques, models and methods used to represent complex phenomena with a high data, information or knowledge content. Obviously, the revolution in affordable distributed computing has played a part in the evolution of information technology; today it is impossible to address the field independent of hardware and software correlates.

The emphasis here is on advanced information technology, technology that is new yet cost-effective enough to be considered viable for real applications. The technology solutions that fall into this category today (that, incidentally, would not have been admitted just five years ago) include:

- Hypertext;
- Multimedia;
- Animation;
- Real-time simulation;
- Interactive color graphics;
- Deductive inferential knowledge bases; and
- Adaptive and direct manipulation interfaces, among others.

Our research suggests that (a) enormous leverage can be gained via the cognitive engineering of these technologies and (b) by and large the technologies have been grossly under-exploited by modern systems engineers (see Section 4.0).

1.4.1.4 Demonstration Prototypes - Section 5.0 describes the prototypes that we developed to demonstrate how advanced information technology can be cognitively engineered to enhance air defense intelligence, operations and the intelligence/operations interface. These prototypes run interactively on Apple Macintosh (Plus, SE and II) series computers. They are designed to illustrate how systems compatible with human information processing can be designed by exploiting findings in cognitive science and recent progress in information technology. Figure 1.1 locates the prototypes within the larger project organization.

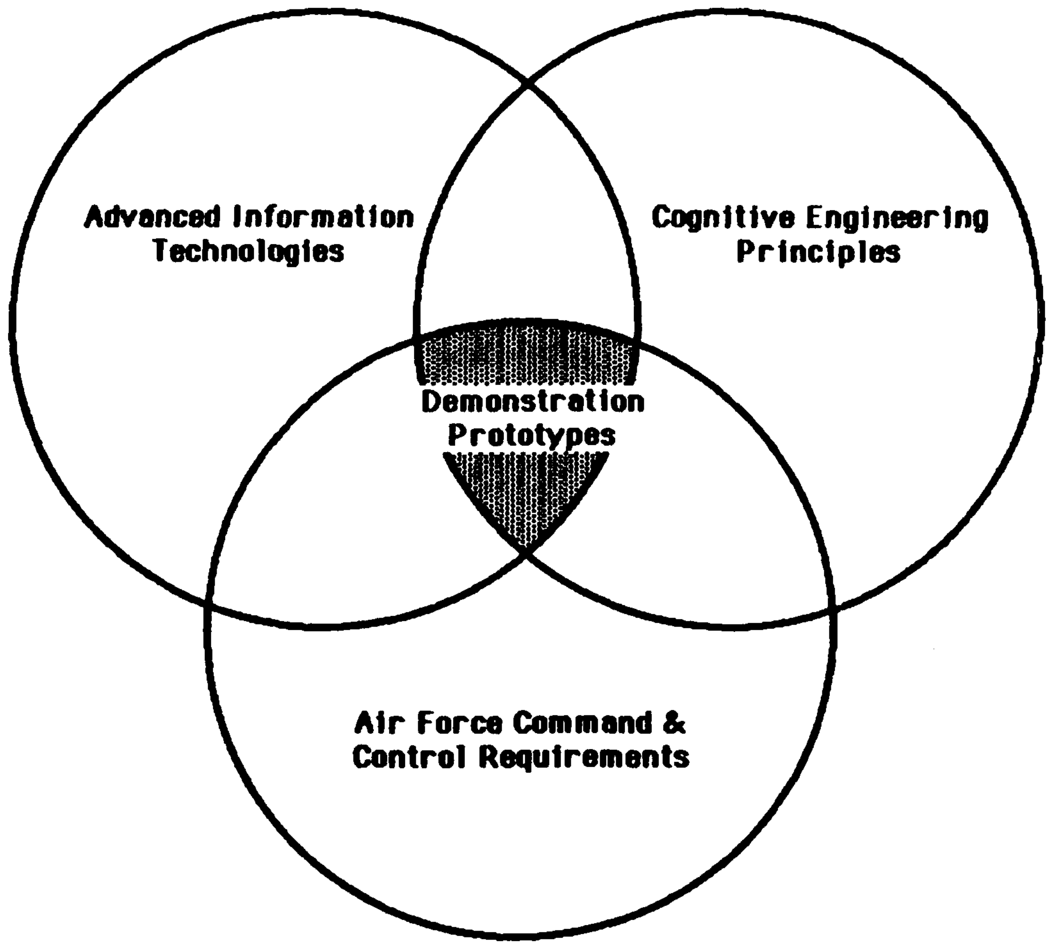


Figure 1: Project Organization

1.4.1.5 Project Documentation - This report represents only part of the project's documentation. In addition to tne final technical report, we produced a set of working prototypes; we delivered these prototypes along with supporting files, run time versions, and necessary applications software.

1.4.2 Project Summary - The project is chronicled in this report and the prototypes; the Executive Summary above and Section 7.0 distill our findings into a few pages. At the very least, we have demonstrated that leverage can be gained from the marriage of cognitive science and advanced information technology. The evidence has yet to be empirically verified, but the means for testing the efficacy of the marriage are well within reach. The prototypes demonstrate what is technically feasible and analytically justifiable today; they also suggest a new research emphasis for the future.

The call for experimentation is not mere lip-service to the process by which hypotheses are tested and confirmed, rejected, or modified. Too many of our advanced systems concepts -- while intuitively exciting -- have never been empirically tested. While our prototypes may or may not represent exciting, intuitively appealing system concepts, before they can be applied to real air defense intelligence or operations problems, they should be tested to determine if, where, and how they enhance human performance. This Phase I Small Business Innovation Research (SBIR) project may well have succeeded in advancing some proof-of-novel-concept-demonstrations, but serious questions remain about how the demonstration prototypes might evolve into working systems.

2.0 THE TARGET DOMAIN: AIR DEFENSE

2.1 The Air Defense Intelligence and Operations Continuum

It is important at the outset to recognize the integrated nature of our strategic intelligence, warning and operations processes. According to Latham (1988), "it's a mistake to think of air defense, space defense, and ballistic missile defense as separate missions . . . they fit together naturally as parts of a single package." Similarly, it is important to recognize the integrated nature of the intelligence and operations processes. Intelligence is an input to operations and operations feed back to intelligence. While there are often bureaucratic obstacles to their integration, they are conceptually and functionally integrated.

Our research assumes both realities. We assume that air defense is a component of a larger strategic mission and that air defense intelligence and operations are inextricably linked.

2.2 Air Defense Intelligence

General Robert T. Herres has suggested that we

> " . . . must be capable of providing timely, reliable and unambiguous warning and high confidence assessments for posturing U.S. and Canadian forces for survivability and for force execution. This requires an integrated attack warning and assessment system with the capability to detect and assimilate the overt and covert indicators of a coordinated Soviet attack -- even when the attack is orchestrated to create confusion. Put another way, if an all-out attack

were launched against North America, it would most likely be an integrated attack. The Soviets would not rely solely on ballistic missiles, but would probably use offensive air forces, cruise missiles, anti-satellite weapons and other resources at their disposal. [NORAD] must accurately detect, warn, assess, engage and respond to such an integrated attack."

These insights suggest clearly the essence of strategic intelligence and warning; the air defense intelligence process can be located in Herres's challenge, though it by no means should be seen as independent of the other dimensions of strategic intelligence.

2.2.1 Generic Intelligence Collection, Analysis and Production - Intelligence is the "poor relation" of command, control, and communications. Yet without intelligence commanders cannot generate or evaluate options. There is a gap between the intelligence and operations communities; there are alternative intelligence missions across the national intelligence agencies and the Services.

Figure 2.1 suggests what the intelligence process assumes (DIA, 1984). Collection, production and dissemination constitute the primary phases of the process, while eight steps support the three phases.

Figure 2.2 presents the forms and components of strategic intelligence (Andriole, 1984). Note the variety of potential intelligence products and the range of the intelligence mission. Analysts are responsible for a variety of intelligence products

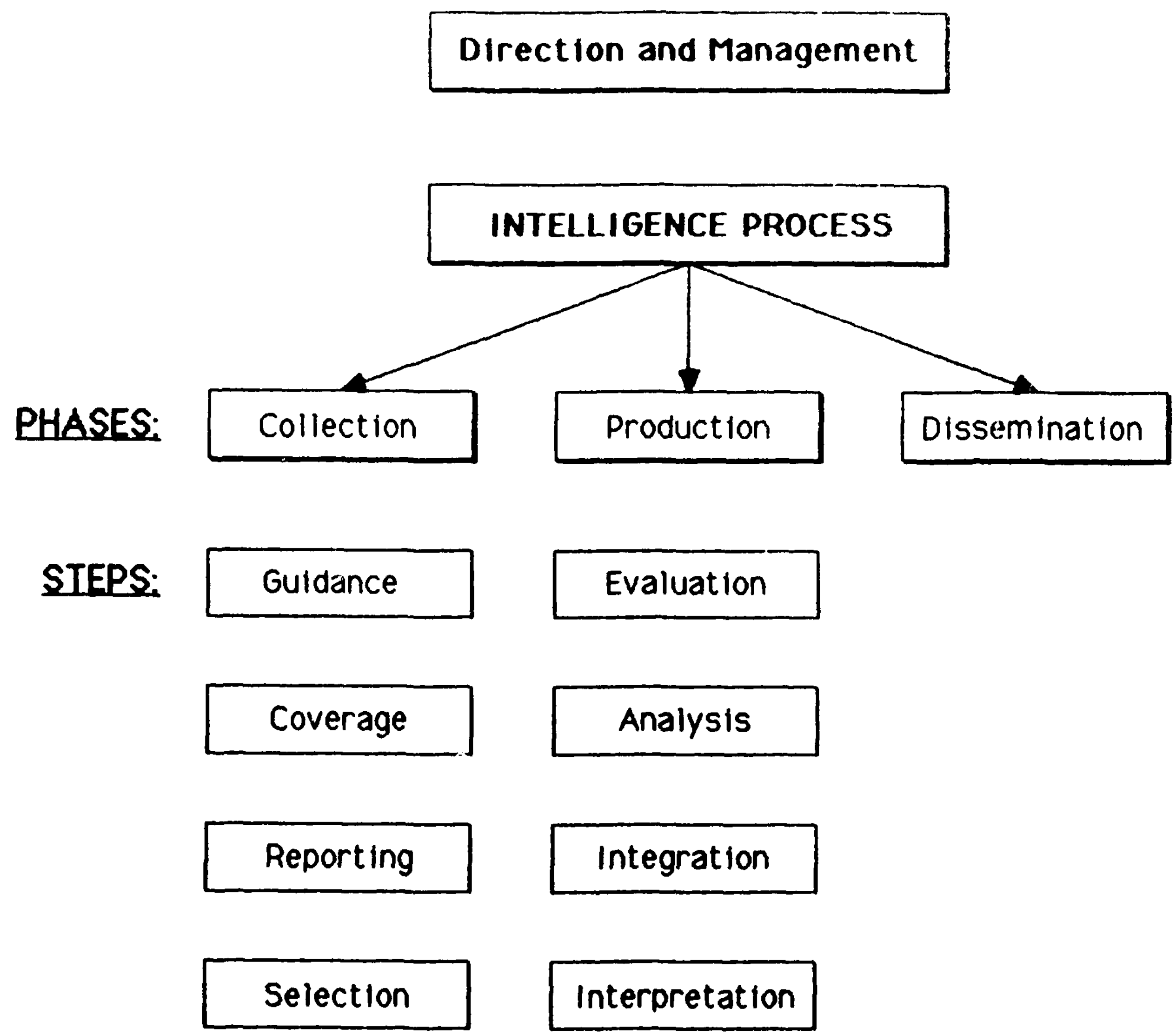


Figure 2.1: The Strategic Intelligence Process

Forms / Components	PAST ← 6 Months			PRESENT	6 Months →		FUTURE		
	Basic			Current			Estimative		
	E**	DESCRIPTIVE*	EV**	D**	EXPLANATORY*	P**	E**	PREDICTIVE*	EV**
Armed Forces, or Military									
Biographic									
Economic									
Geographic									
Political									
Scientific & Technical (S&T)									
Sociological									
Transportation & Telecommunications									

* Primary Focus
** Secondary Focus

D = Descriptive
E = Explanatory
P = Predictive
EV = Evaluative

Figure 2.2: The Forms and Components of Strategic Intelligence

of various natures.

Clarkson (1981) describes the strategic intelligence process in a series of stages (see Figure 2.3) and steps, as suggested in Tables 2.1, 2.2, and 2.3. Figure 2.3 presents the "major functional stages in strategic analysis." Tables 2.1, 2.2, and 2.3 describe the steps that comprise the analysis process. These steps suggest the analytical and cognitive processes implemented during the intelligence process. They also suggest how the air defense intelligence process is implemented.

The repeated reference to indicators and correlations is significant. Intelligence essentially reduces to pattern recognition, where diverse data is filtered into hypotheses about likely situations and behavior. Put another way, intelligence analysis is often deductive, where evidence is sought to confirm or disconfirm hypotheses.

Deductive inference frequently dominates the intelligence process. Analysts look to data, indicators, and groups of indicators and data -- activities -- to infer likely situations and event likelihoods. Environments are monitored to determine (a) what is happening, (b) how serious it is and (c) when the critical event will occur.

Figure 2.4 from Barclay, et al. (1977) presents a generic "hierarchical inference structure" that represents the relationship among data, indicators and activities, while Figure

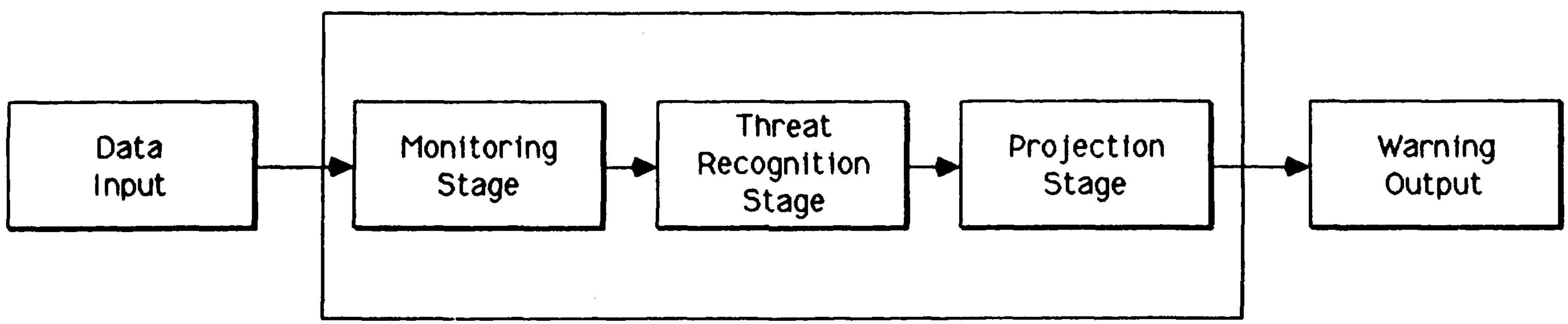


Figure 2.3: Clarkson's Functional Steps in Strategic Analysis

Step 1: Review incoming data

Step 2: Sort incoming data

- **Procedure 1:** Geographic
- **Procedure 2:** Military
- **Procedure 3:** Political
- **Procedure 4:** Economic
- **Procedure 5:** Cultural
- **Procedure 6:** Other

Step 3: Match sorted data against predetermined indicators

Step 4: Identify correlations

Step 5: Display correlations

Step 6: Make preliminary evaluation of indicators

- **Procedure 1:** Assess relative levels of activity
- **Procedure 2:** Assign significance to activities

Step 7: Route results to next analysis stage

Step 8: Review residual data

Step 9: Move appropriate residual data forward for further analytic review

Table 2.1: Strategic Monitoring Steps

Step 1: Match indicators from Monitoring stage against predetermined threat models

Procedure 1: Call up preestablished threat models
Procedure 2: Match indicators against models

a. Call out critical events/stages (or nodes) of threat models
b. Search for correlations to indicators
c. Identify correlations
d. Review correlations against other critical events whose occurrence has been previously detected within developing situational context
e. Assign confidence values to results of c and d
f. Identify key events and activities whose occurrences have not been detected
g. Identify further information needs
h. Compare all preestablished threat models to which the data has correlated, establish:
   (1) Duplications
   (2) Similarities
   (3) Differences
i. Explore for possible alternative explanations/ hypotheses for data

Step 1: Move pertinent threat models to projection stage of analysis

Step 2: Conduct novel threat analysis

Procedure 1: Formulate new threat hypotheses
Procedure 2: Display threat hypotheses
Procedure 3: Compare residual data against hypotheses

Step 4: Move appropriate novel threat models to projection stage of analysis

Table 2.2: Strategic Threat Recognition Steps

Step 1: Compare candidate threats in unimpeded, predictive domain

Procedure 1: Translate individual threats into predictive format based on information categories

- a. **Who** (or what)
- b. (Could do) **what**
- c. (To) **whom** (or what)
- d. **Where**
- e. **How**
- f. **When**
- g. **Why** (or because X conditions apply)

Procedure 2: Compare specificities of individual threat predictions

Procedure 3: Elucidate rationale behind specificities

- a. Estimate conditions that would support various threat enactments, and their relative importance and interdependence
  - (1) Political situation
  - (2) Military capabilities
  - (3) Economic conditions
  - (4) Social/cultural conditions and forces
  - (5) Decision-maker/leadership perceptions and predispositions
  - (6) Other
- b. If conditions now hold, estimate earliest possible **occurrence** in *future* of threat enactment
- c. Identify any missing conditions
- d. *For missing* conditions, estimate earliest **occurrence** in future
- e. Estimate earliest point in future pertinent threats that could occur after missing conditions occur

Procedure 4: Indicate sources (e.g., outside expertise)

Procedure 5: Indicate/summarize assumptions

Procedure 6: Indicate/summarize uncertainities and data requirements

Procedure 7: Across predictions, and added to previous comparisons, isolate and identify by information category the following:

- a. Duplications
- b. Similarities
- c. Differences

Procedure 8: Compare predictions in terms of probability against selected timelines

Step 2: Compare candidate threats in influenced predictive domain

Procedure 1: Consider potential U.S. and friendly decision maker influences on development of situations

- a. Identify friendly influence options

Procedure 2: Translate influenced threat models into predictive format (as in Step 1 above)

Procedure 3: Repeat rest of procedures in Step 1

Procedure 4: Make grand comparison of unimpeded and influenced predictions

Step 3: Perform similar procedures for unimpeded and influenced forecasts

Table 2.3: Strategic Projection Steps

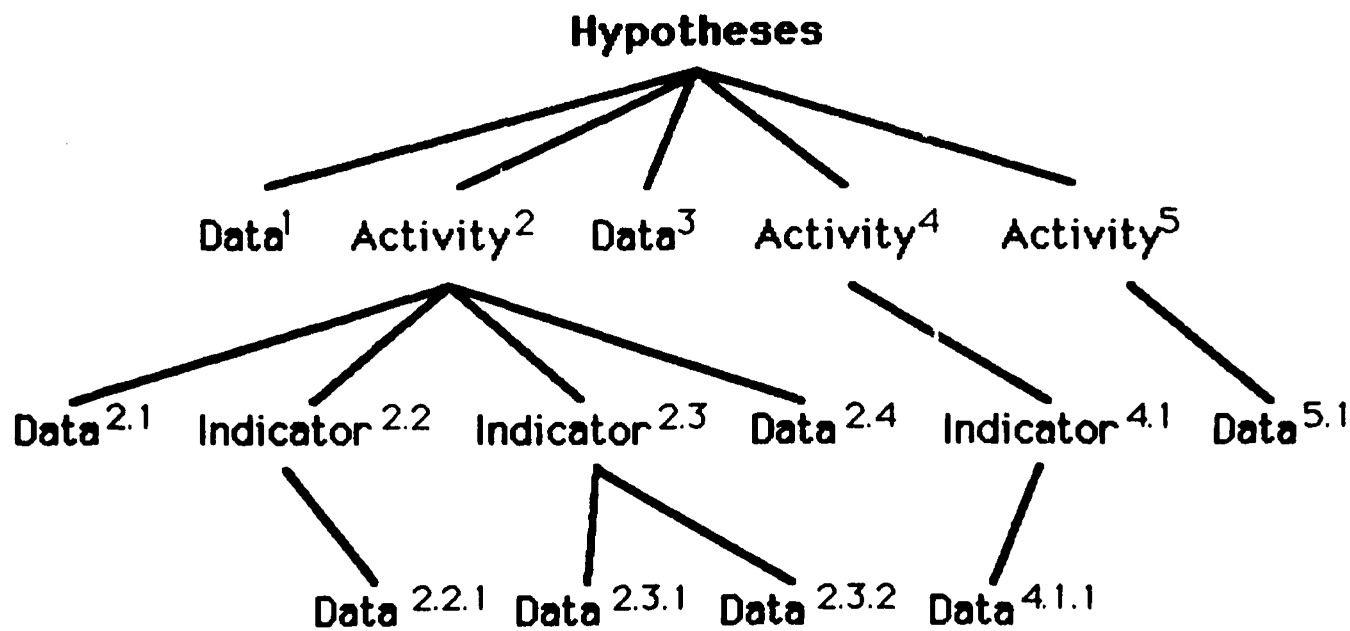


Figure 2.4: Generic Hierarchical Inference Structure

2.5 (also from Barclay, et al., 1977) illustrates how the hierarchical inference structuring technique can be used to model, monitor and project North Korean behavior toward South Korea. The military posture model is comprised of a variety of indicators and activities that when combined in alternative ways will determine the likelihood of each of the four hypotheses that sit on top of the hierarchical inference model.

A simpler inference model is the influence diagram that recognizes the interrelationships among events and conditions. Influence diagrams are conceptually "causal," though no attempt is made to verify the causality statistically or mathematically. Rather, the focus is placed upon how events "chain-react" to increase (or decrease) the likelihood of a specific event or condition. Figure 2.6 illustrates the influence diagramming process, while Figure 2.7 presents an influence diagram of the likelihood of having to evacuate American nationals from Lebanon (Andriole, 1984).

Finally, probability trees can be used to describe the intelligence process. Figure 2.8 presents a model of the likelihood of a Soviet invasion of China given the death of the Chinese Premier.

All of these models suggest that the intelligence process is procedural and directed. They also suggest how we might describe and understand the air defense intelligence process.

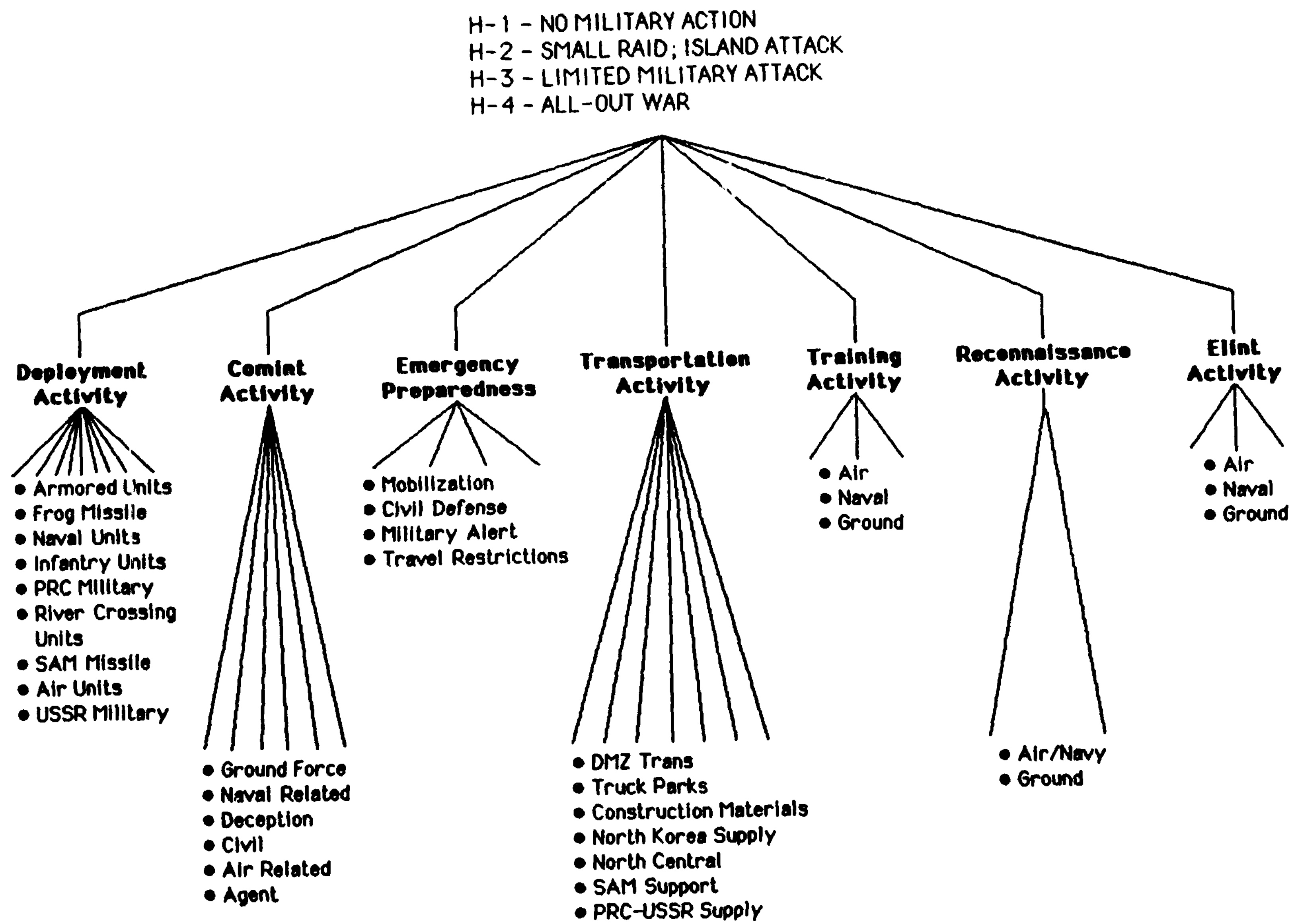
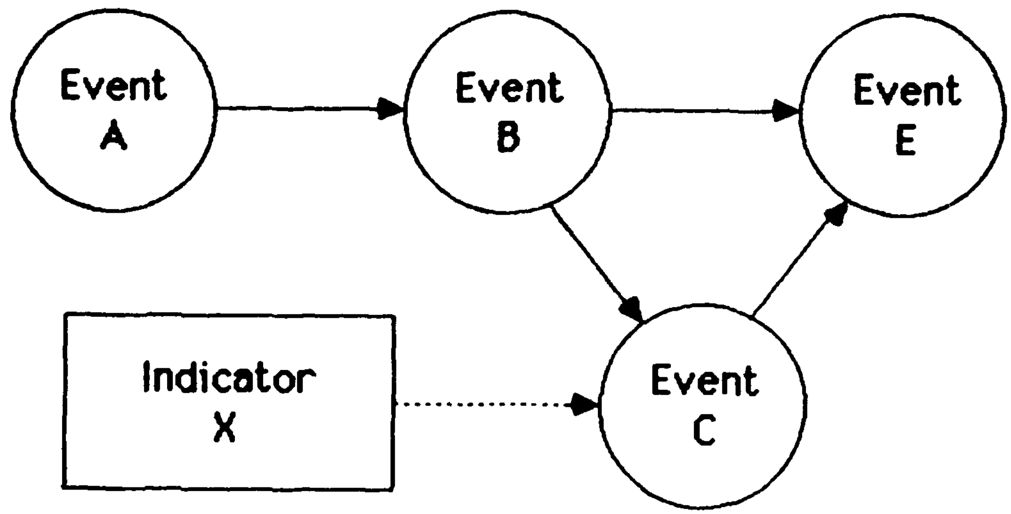


Figure 2.5: Korean Hierarchical Inference Structure



Event	Conditioning Events		Event Type
E	B	C	Terminal
B	A	-	Intermediate
A	-	-	Unconditioned
C	B	-	Intermediate

Figure 2.6: Influence Diagramming Process

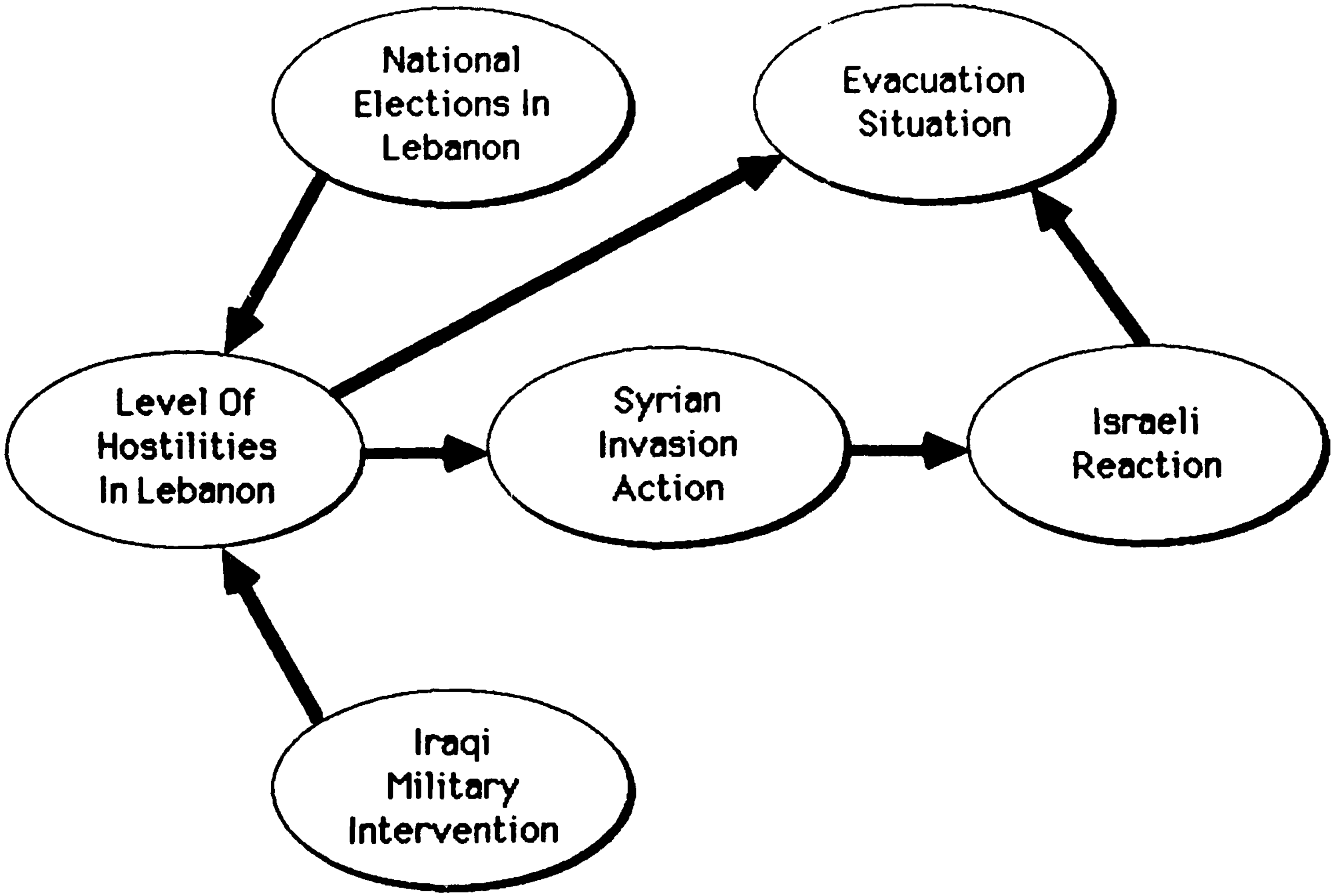


Figure 2.7: Lebanon Evacuation Likelihood Influence Diagram

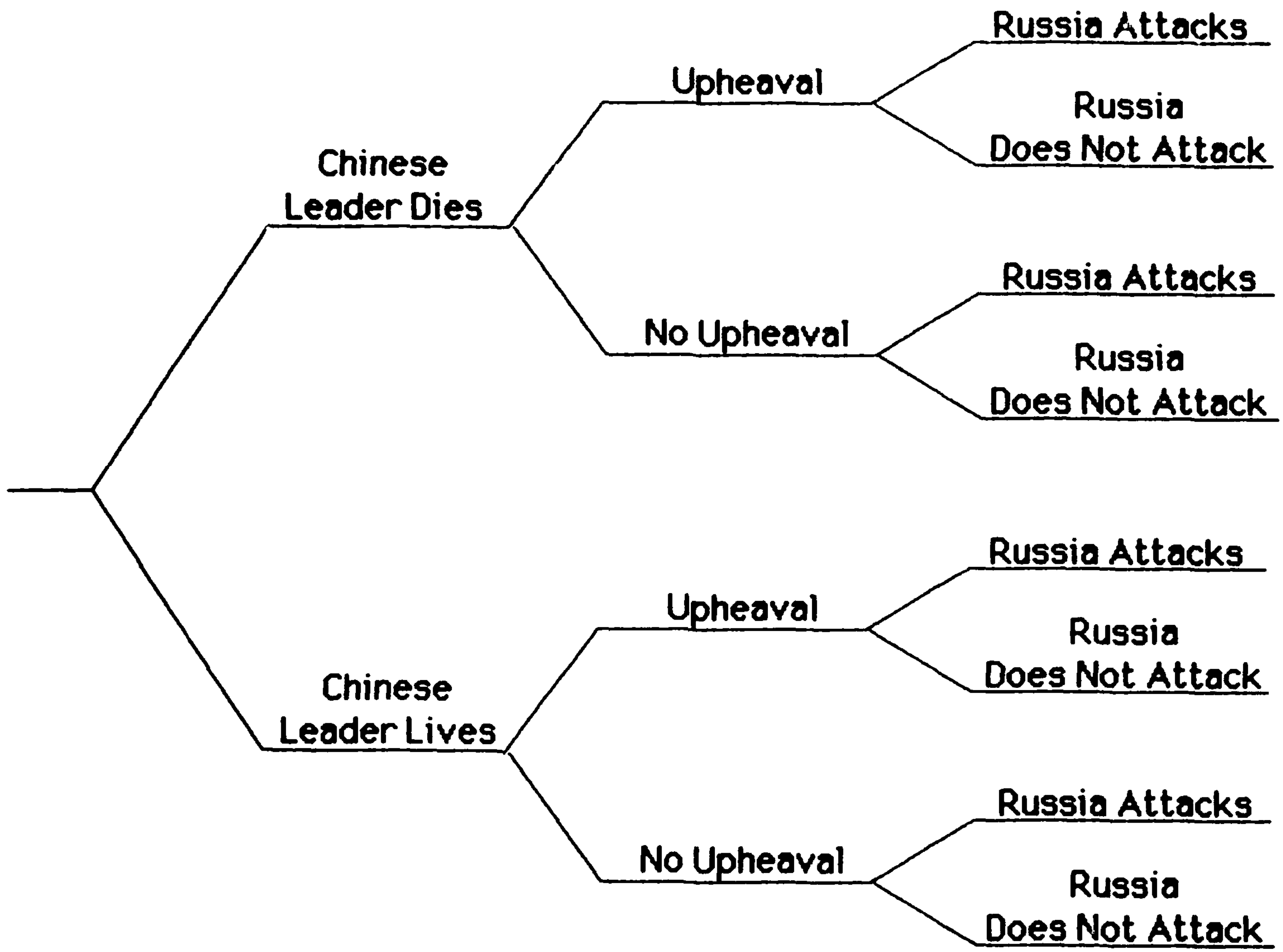


Figure 2.8: Soviet Invasion Likelihood/Probability Tree

2.2.2 Air Defense Intelligence Analysis - The larger strategic intelligence process -- comprised of space, missile and air defense -- assumes current and future collection, analysis and production technology. Covault (1985) presents the attack warning/attack assessment process in Figure 2.9, a process that features technology-based collection via sensors and intelligence.

Air defense intelligence focuses on the atmospheric threat, that is, the manned bomber and air-breathing, non-ballistic missile threat. As suggested above, however, while the air defense intelligence mission may well be segmented it cannot realistically be restricted to the atmospheric threat. Given the likelihood of an integrated attack it must be presumed by all strategic intelligence analysts that if one set of indicators begin to move, it is highly likely that the others are moving too.

Air defense intelligence is supported of course by powerful warning capabilities. The warning function, which assumes action and short lead-time, is the intelligence fail-safe. Ideally, however, assessments can be made long before an over-the-horizon radar detects a Blackjack bomber. Intelligence is intended to extend lead-time via analyses of phenomena likely to occur before the atmospheric threat becomes acute.

The need for accurate, timely and reliable air defense intelligence is critical since it is extremely difficult to

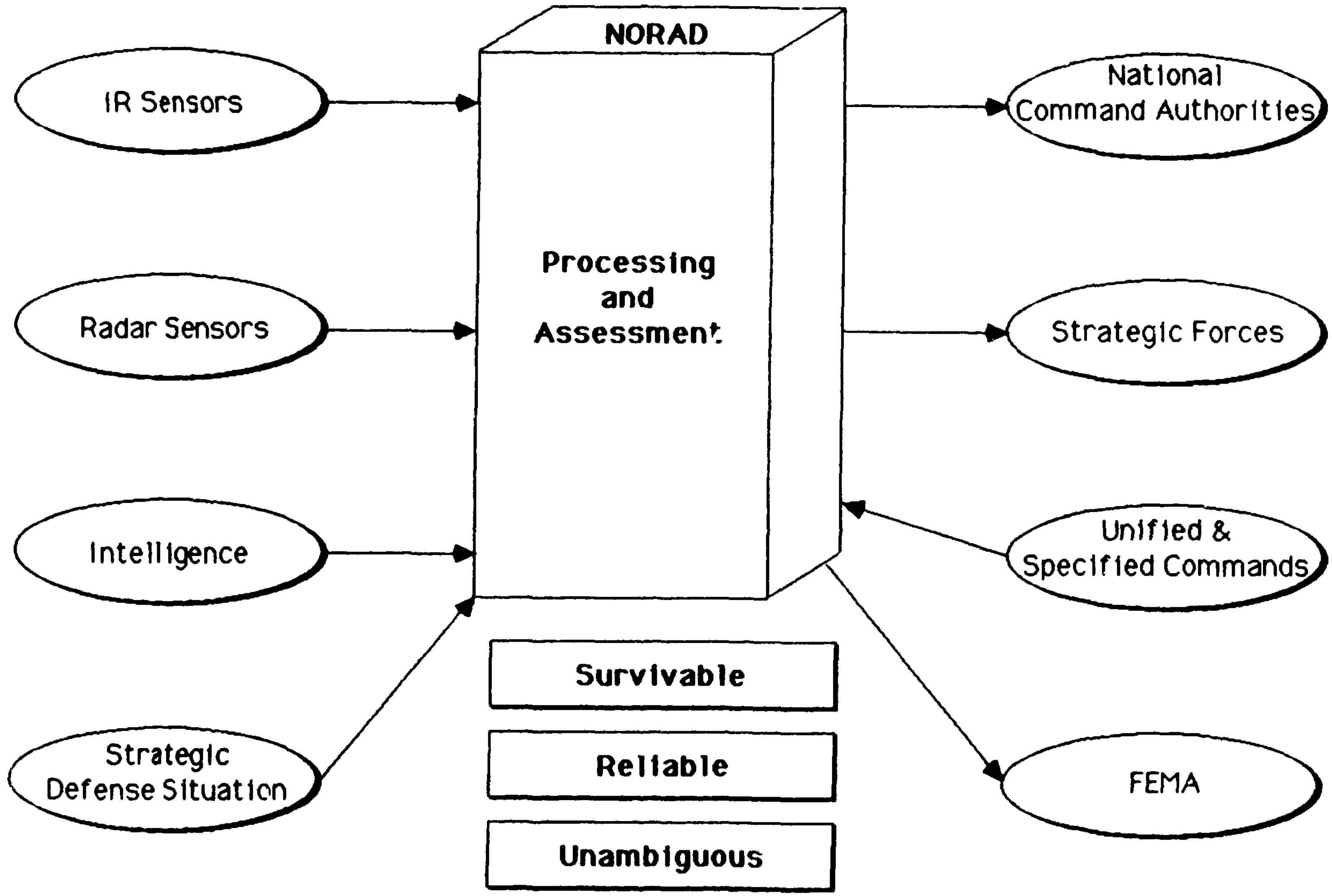


Figure 2.9: Covault's Attack Warning/Attack Assessment Process

detect and track manned bombers and cruise missiles "because they are not limited to ballistic trajectories" (Gumble, 1986). Over-the-horizon backscatter (OTH-B) radar capable of high frequency operation is one solution to the detection and tracking problem, though it is unlikely that the atmospheric threat can be eliminated in the near or even distant future.

Intelligence is necessary to mitigate the warning problem. The desire for long lead time presumes a multiple indicator/activity approach. Deductive inferential processes are implemented by the air defense intelligence analyst on a variety of interconnected levels. Economic, political and (especially) military indicators are observed and correlated. Unfortunately, there are precious few historical precedents available to the air defense analyst, precedents that could be converted into inference-making "templates." The United States does not possess perfect intelligence about Soviet manned bombers and cruise missiles. Given that exercise data is the best we can do, our inferences about indicators of atmospheric activity are twice-removed from those anchored in deep historical experience.

Models of expected precipitous behavior are used to filter, interpret and correlate air defense indicators; missile warning indicators are used to validate air defense inferences, and vice versa.

2.2.3 Air Defense Intelligence Requirements - From a systems design perspective, there are a number of requirements that together constitute a requisite set of functions and tasks that must be performed (either manually or, ideally, with computer-based support). In terms of the forms and components of strategic intelligence, Figure 2.10 highlights the most pertinent cells in the matrix.

Clarkson's functional outlines of the stages of strategic intelligence provide a template for the identification of air defense intelligence requirements, especially as they pertain to the design of a system intended to support intelligence analysts. Tables 2.4, 2.5, and 2.6 present a set of requirements necessary to develop an interactive system concept (see Section 5.0 for the conversion of these requirements into demonstration prototypes with reference to findings from cognitive science and advanced information technology).

Tables 2.4, 2.5, and 2.6 do not, however, explicitly recognize the interrelationships among indicators across strategic intelligence functions. Air defense intelligence analysts must correlate indicators with missile defense indicators; intelligence models must be integrated if they are to be effective in diagnosing deception.

The reason why the integration and synthesis of strategic models is so important is because of multiple potential origins of threat. A bona fide strategic attack, as suggested by Latham and

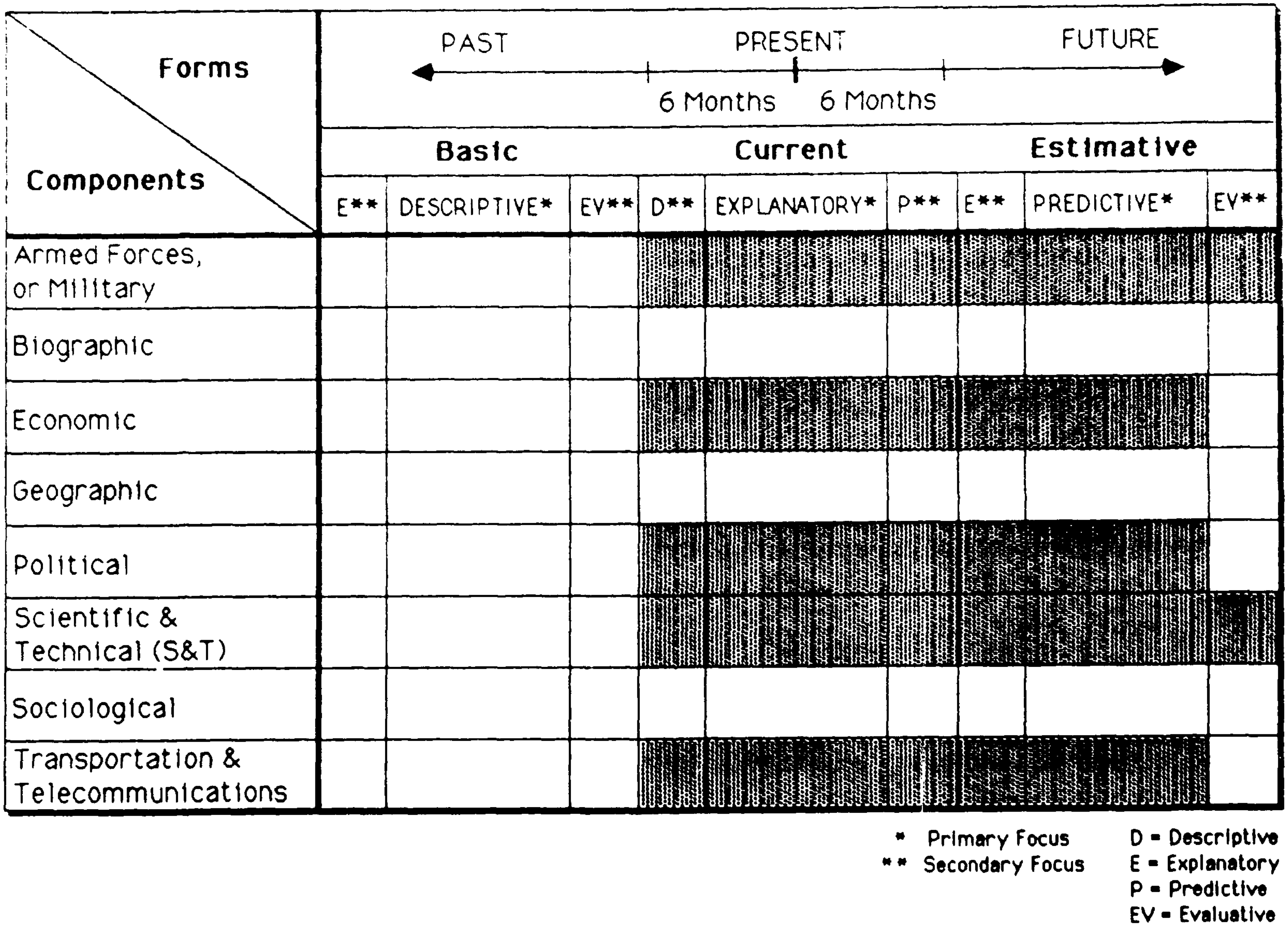


Figure 2.10: The Forms and Components of Strategic Air Defense Intelligence

Step 1:	Review incoming data	→ Data handling (management & display)
Step 2:	Sort incoming data	→ Data filtering, reduction, fusion, correlation
Procedure 1:	Geographic	→ Geographic and other data/knowledge base management (Procedures 1–6)
Procedure 2:	Military	
Procedure 3:	Political	
Procedure 4:	Economic	
Procedure 5:	Cultural	
Procedure 6:	Other	
Step 3:	Match sorted data against predetermined indicators	→ Pattern recognition algorithms, correlation, regression
Step 4:	Identify correlations	→ Subjective (qualitative) & quantitative models
Step 5:	Display correlations	→ Graphic, multimedia user-computer interface
Step 6:	Make preliminary evaluation of indicators	→ Deductive/inductive models
Procedure 1:	Assess relative levels of activity	→ Pattern recognition; analogy
Procedure 2:	Assign significance to activities	→ Historical models
Step 7:	Route results to next analysis stage	→ Analysis reduction models; templates
Step 8:	Review residual data	→ Integrated display technology
Step 9:	Move appropriate residual data forward for further analytic review	→ Data/knowledge/model communications; shared files; "audit trails"

Table 2.4: Strategic Monitoring and System Requirements

Analysis step	System requirement
Step 1: Match indicators from Monitoring stage against predetermined threat models	War gaming; historical analyses
Procedure 1: Call up preestablished threat models	Matching algorithms; data/knowledge/model storage
Procedure 2: Match indicators against models	Matching algorithms
a. Call out critical events/stages (or nodes) of threat models	Deductive/inductive models and analysis
b. Search for correlations to indicators	Correlation, regression and knowledge-based models
c. Identify correlations	Adaptive display technology and UCI
d. Review correlations against other critical events whose occurrence has been previously detected within developing situational context	Historical/analogical/"case" models; historical analysis
e. Assign confidence values to results of c and d	Qualitative/quantitative endorsement/utility models
f. Identify key events and activities whose occurrences have not been detected	Deductive reasoning models; "backchaining" algorithms
g. Identify further information needs	Data/knowledge base management; sensitivity analysis
h. Compare all preestablished threat models to which the data has correlated, establish: (1) Duplications (2) Similarities (3) Differences	Critical incident/deductive inference/cross-impact models; historical/analogical models
i. Explore for possible alternative explanations/ hypotheses for data	Inductive models; "forwardchaining" algorithms
Step 1: Move pertinent threat models to projection stage of analysis	Information/knowledge handling; templates
Step 2: Conduct novel threat analysis **Procedure 1**: Formulate new threat hypotheses **Procedure 2**: Display threat hypotheses **Procedure 3**: Compare residual data against hypotheses	Inductive models; "forwardchaining" algorithms; deductive models; "backwardchaining" algorithms; historical models
Step 4: Move appropriate novel threat models to projection stage of analysis	Data/knowledge/model communications; shared files; "audit trails"

Table 2.5: Strategic Threat Recognition and System Requirements

Step 1: Compare candidate threats in unimpeded, predictive domain	→ Comparative modeling, analysis
Procedure 1: Translate individual threats into predictive format based on information categories a. **Who** (or what) b. (Could do) **what** c. (To) **whom** (or what) d. **Where** e. **How** f. **When** g. **Why** (or because X conditions apply)	→ Multiple (qualitative and quantitative) forecasting models; conditional analysis
Procedure 2: Compare specificities of individual threat predictions	→ Diagnostic procedures
Procedure 3: Elucidate rationale behind specificities	→ Qualitative/quantitative data/knowledge capturing
a. Estimate conditions that would support various threat enactments, and their relative importance and interdependence (1) Political situation (2) Military capabilities (3) Economic conditions (4) Social/cultural conditions and forces (5) Decision maker/leadership perceptions and predispositions (6) Other	→ Inductive/deductive qualitative/quantitative modeling
b. If conditions now hold, estimate earliest possible occurrance in future of threat enactment	→ Point forecasting models
c. Identify any missing conditions d. For missing conditions, estimate earliest occurrance in future e. Estimate earliest point in future pertinent threats could occur after missing conditions occur	→ Alternative scenario generation sensitivity analysis
Procedure 4: Indicate sources (e.g., outside expertise)	→ Validity/reliability templates
Procedure 5: Indicate/summarize assumptions **Procedure 6:** Indicate/summarize uncertainties and data requirements **Procedure 7:** Across predictions, and added to previous comparisons, isolate and identify by information category the following: a. Duplications b. Similarities c. Differences	→ Data/knowledge/inference reduction procedures
Procedure 8: Compare predictions in terms of probability against selected timelines	→ Probability models
Step 2. Compare candidate threats in influenced predictive domain **Procedure 1:** Consider potential U.S. and friendly decision maker influences on development of situations a. Identify friendly influence options **Procedure 2:** Translate influenced threat models into predictive format (as in Step 1 above) **Procedure 3:** Repeat rest of procedures in Step 1 **Procedure 4:** Make grand comparison of unimpeded and influenced predictions **Step 3.** Perform similar procedures for unimpeded and influenced forecests	→ Same as above (Step 1)

Table 2.6: Strategic Projection and System Requirements

Herres above, will most likely be ground, air, sea and space launched. Air defense intelligence analysis cannot be conducted independent of ground, sea and space-based behavior. Any system designed to support air defense intelligence analysis must by function also support ground, sea and space intelligence analysis -- or at least have access to such data, models, and analytical systems (see Section 5.0).

Air defense intelligence must also satisfy one additional requirement: easy transition to warning and operations. The intelligence/warning/operations process does not always proceed smoothly. Disconnects often exist between the form and content of intelligence estimates and inferences, disconnects that prevent operations personnel from absorbing the essence of the analysis.

There are "culture" problems, organization problems, and even doctrinal problems that constrain the communication bandwidth between intelligence and operations personnel (see Section 2.4 for more detail). An effective support system must widen the communications bandwidth via an understanding of intelligence, warning, and operations requirements.

2.3 Air Defense Operations

The transition from intelligence to warning to operations is often far from smooth. Yet operations are dependent upon intelligence and warning triggers, just as intelligence should be produced with explicit reference to operational realities. This section examines the air defense operations process and identifies a set of operational requirements necessary for the design and development of computer-based systems intended to support intelligence, warning and operations personnel.

2.3.1 Generic Operational Decision-Making - There are any number of decision-making models and paradigms. These models and paradigms share several things in common. They generally offer a sequence of stages or steps that decision-makers normatively execute. Built into the models are assumptions about how decisions can and should be made. Note, for example, the following two decision process models in Figure 2.11 from Easton (1979). The model on the left is one that assumes decision-makers will "optimize," while the other assumes "satisficing" (see Section 3.0 for additional insight into decision process models and satisficing).

Wohl's (1981) Stimulus-Hypothesis-Option-Response (SHOR) model represents yet another perspective (see Figures 2.12 and 2.13). Wohl's model expands the generic decision process model to include insight into specific decision-making functions and the kind of information necessary to implement a decision's generic elements. His domain is tactical Air Force planning and decision-making, but the model is applicable to a wide variety of decision modeling problems.

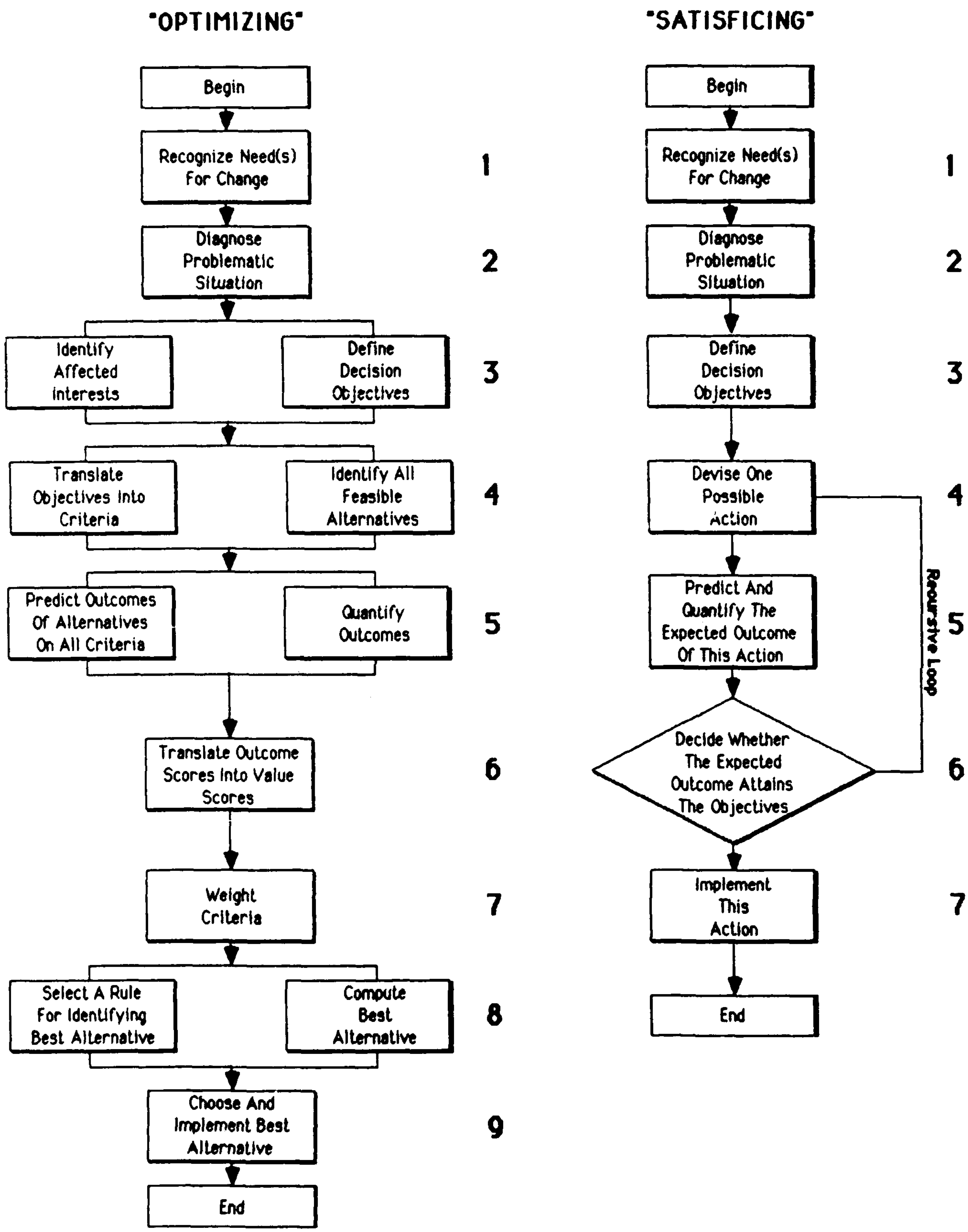


Figure 2.11: "Optimizing" and "Satisficing" Decision Process Models

GENERIC ELEMENTS	FUNCTIONS REQUIRED	INFORMATION PROCESSED
Stimulus (Data) **S**	**Gather/Detect** **Filter/Correlate** **Aggregate/Display** **Store/Recall**	**Capabilities, Doctrine; Position, Velocity, Type; Mass, Momentum, Inertia; Relevance and Trustworthiness of Data**
Hypothesis (Perception Alternatives) **H**	**Create** **Evaluate** **Select**	**Commander's Catechism** Where am I? Where is the enemy? What is he doing? How can I thwart him? How can I do him in? Am I in balance? How long will it take me to...? How long will it take him to...? How will it look in...hours? What is the most important thing to do right now? How do I get it done?
Option (Response Alternatives) **O**	**Create** **Evaluate** **Select**	
Response (Action) **R**	**Plan** **Organize** **Execute**	**The Air Tasking Order** Who What When Where How How Much *The near-real-time modification/update*

Figure 2.12: Wohl's SHOR Model

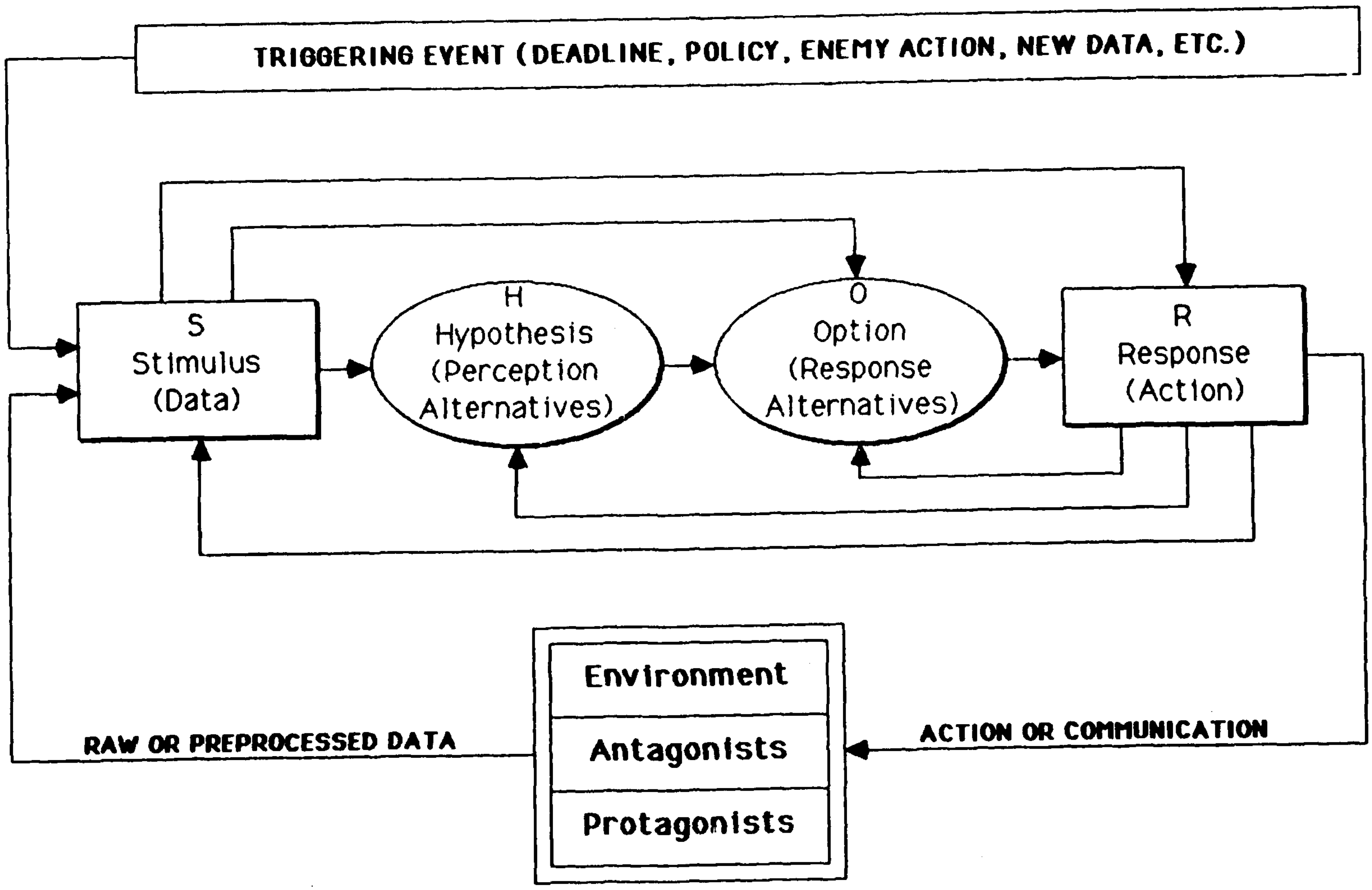


Figure 2.13: SHOR Processes

A variety of other analysts have approached decision-making from another perspective. Instead of modeling the process, some have modeled the range of problems that operational decision-makers face. Hopple (1986) combines Wohl's model with decision problem characteristics to develop the matrix in Figure 2.14, while Andriole (1989a) has developed a three dimensional matrix that defines decision problems according to the nature of tasks, decision-makers ("users"), and the organizational-doctrinal setting in which the problems are addressed (see Figure 2.15). Hermann (1969) has developed a "situational cube" that defines decision problems according to their location along decision time, threat and awareness continuua, as suggested in Figure 2.16.

Biddle (1989) has developed a list of decision/task attributes that help identify the range of decision problems faced by operational personnel. Table 2.7 presents this list and suggests how decision-making processes will vary according to the nature of the task to be completed.

Various methods and approaches have been advanced to describe and prescribe how decision alternatives can be compared. While we are all susceptible to biases and other cognitive predispositions (see Section 3.0), we also search for ways to compare alternatives in order to select the "best" one. Decision analysts suggest multi-attribute utility theory as one approach (see Figure 2.17); there are others. Humans seek ways to

DECISION PROCESS MODEL TASK TYPOLOGY	CLOSED	OPEN			CRISIS
		Info Input Uncertainty	Conseq's of Action Uncertainty	Both	
Stimulus					
Hypothesis					
Options					
Response					

Figure 2.14: Extended SHOR Model

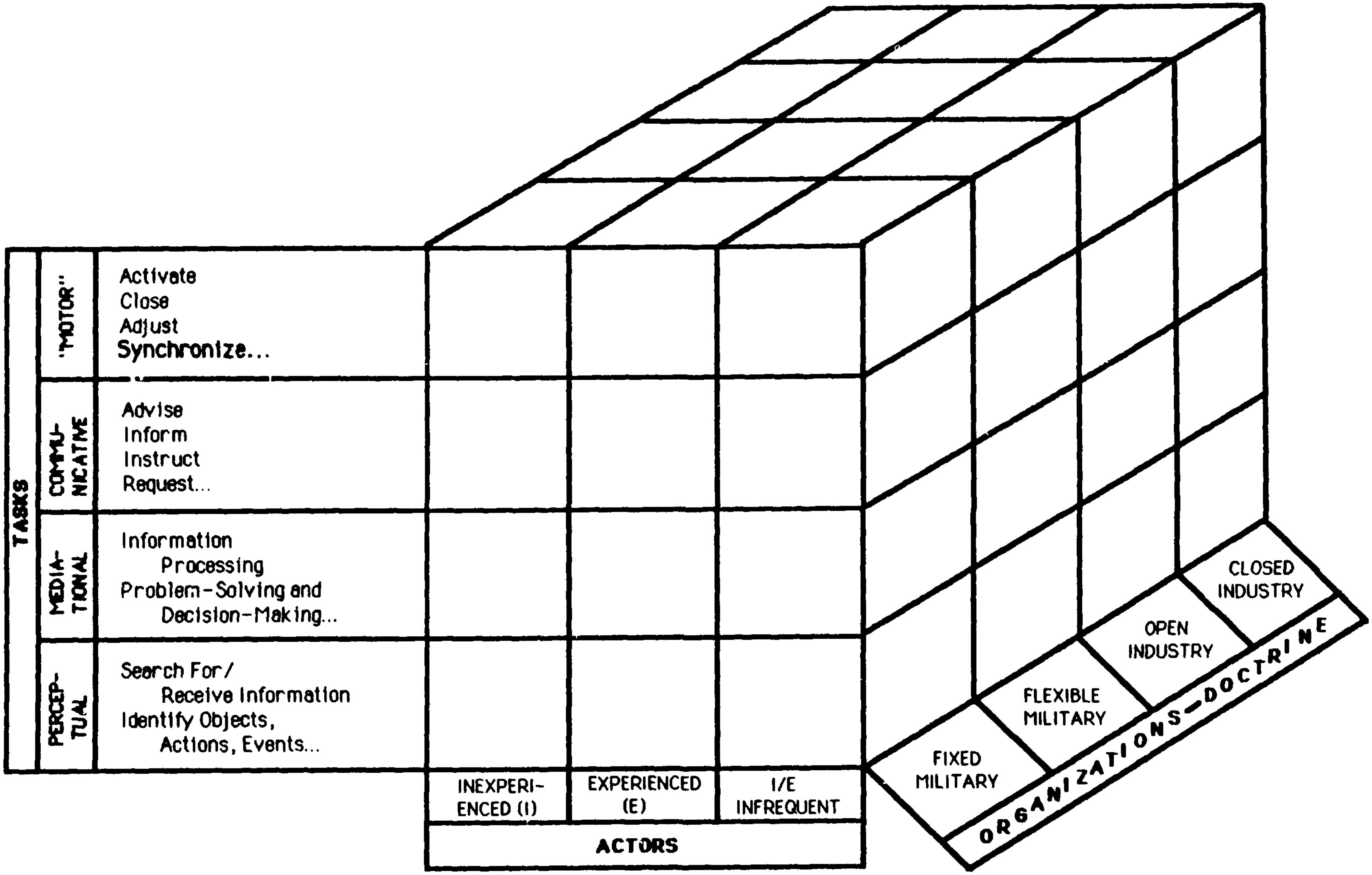
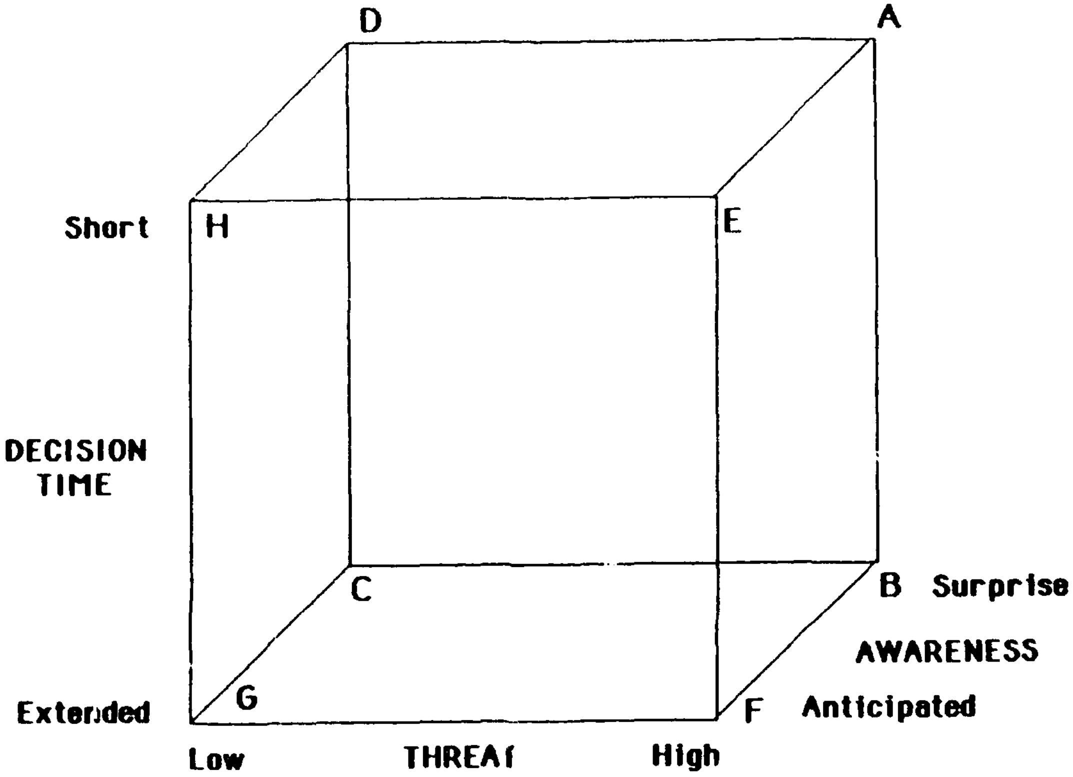


Figure 2.15: Andriole's Decision Problem Matrix



A) Crisis	= high/	short/	surprise
B) Innovative	= high/	ext./	surprise
C) Inertial	= low/	ext./	surprise
D) Circumstantial	= low/	short/	surprise
E) Reflexive	= high/	short/	anticipated
F) Deliberative	= high/	ext./	anticipated
G) Routinized	= low/	ext./	anticipated
H) Administrative	= low/	short/	anticipated

Figure 2.16: Hermann's Situational Cube

- **Level of Abstraction of the Task**

  - Skills, Rules, Knowledge
    - -- Does the task require explicit plan development and selection?
    - -- Is the task solvable by application of standard operating procedures?
    - -- Does the task require specifically identified procedures or can it be performed with little thought?

  - Deduction, Induction, Abduction
    - -- Does the solution of the task require the development of new data or information (induction)?
    - -- Does the task rely on already developed information for its solution (deduction)?
    - -- Is it necessary to generate explanations for a series of observations?

  - Perceptual, Mediational, Communication and Motor
    - -- Sensory Dominant - Perceptual
    - -- Information Processing and Decision Making Tasks
    - -- Communication Dominant
    - -- Mechanical (Skill Like) Processes

- **Level of Structure to the Task**

  - Level of Structure
    - -- Highly structured, solution processes well understood and commonly implemented in an automated system
    - -- Less well structured than above but solution processes still well understood and have been successfully automated previously
    - -- Relatively unstructured problem but solution processes still tractable
    - -- Unstructured problem, solution processes poorly understood

  - Bounds of the Problem
    - -- All variables are known and understood
    - -- Unexpected variables seldom impact solution processes
    - -- Unexpected variables often impact results
    - -- Currently impossible to bound the problem (Impossible to separate from the environment)

- **Organizational Aspects of the Problem**

  - Safety/Responsibility/Tradition/Politics require that a human manage the process
  - Safety/Responsibility/Tradition/Politics are not overriding factors

- **Data Aspects of the Problem**

  - Amount of Data Required
    - -- Massive amount of data required; beyond capability of human to absorb or manipulate
    - -- Large amount of data required; possibly could be assimilated by dedicated human operator
    - -- Minimal data requirements; easily mastered by operator

  - Accuracy of Available Data
    - -- Available data is totally accurate or accuracy is not necessary to develop a correct solution
    - -- Available data is generally accurate
    - -- Available data is suspect

  - Precision Required of the Data
    - -- High precision required of input data to achieve solution; precision beyond capacity of human to manipulate
    - -- Average precision required of input data
    - -- Precision of data not a factor in solution to problem

  - Periodicity of Data
    - -- Data arrives periodically in known format, and in known ranges
    - -- Data arrives within general constraints of time and format
    - -- Data arrives randomly and unexpectedly

  - Amount of Data Available vs. Amount of Data Required
    - -- All required data is available and manipulatable
    - -- All critical data is available and usable
    - -- Decisions must be made without knowledge of necessary data

  - Fuzziness of Data
    - -- Data sets are crisp and accepted as an accurate representation of reality
    - -- Most data is understood and stable
    - -- Data is not well understood and/or is unreliable

  - Specificity of Data
    - -- The data is naturally or easily quantifiable
    - -- The data is difficult to quantify without losing critical information or making difficult assumptions
    - -- The data cannot be legitimately quantified

  - Storage, Recall, and Manipulation of Data Required
    - -- Massive amounts of data are required to be stored, recalled on short notice, and manipulated
    - -- Quantity and manipulation of data are not a factor in the problem solution

- **Time Requirements of the Problem**
  - Time Requirements
    - -- Real-time problem
    - -- Severe time constraints
    - -- Time constraints do not impact on problem
  - Computational Intensity
    - -- Solution to problem requires unacceptable amount of time, effort, or precision to be done manually
    - -- Problem difficult but tractable to solve manually
    - -- Little computation involved in solving problem

Table 2.7: Biddle's Task Taxonomy

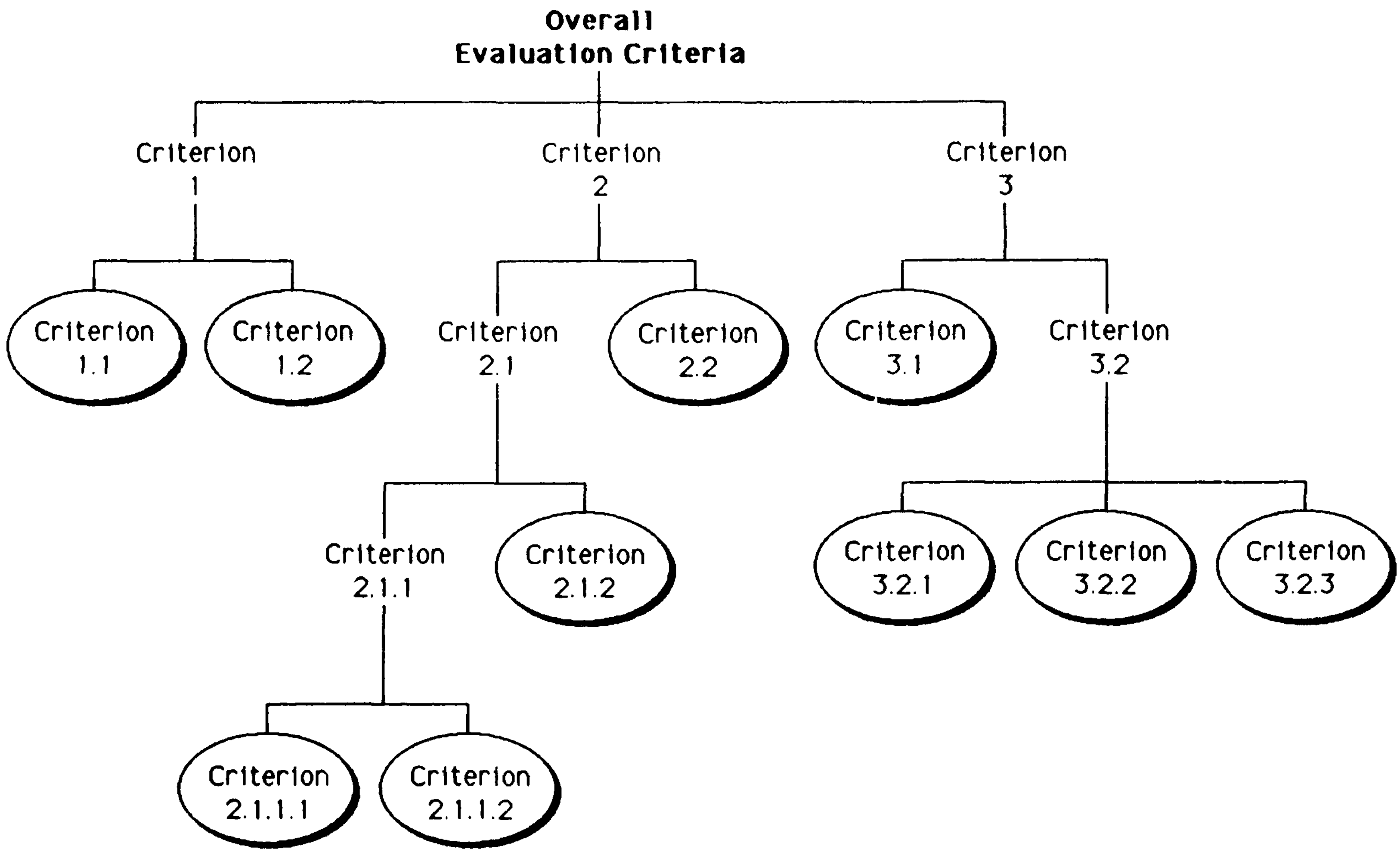


Figure 2.17: Multi-Attribute Utility Assessment Model

optimize, "satisfice," and survive in a variety of operational environments; the generic decision models presented above are just that. In spite of their analytical origins, they are adaptive to decision situations, makers, and constraints. They are also -- ultimately -- only compasses to domain specific research.

2.3.2 Air Defense Operations - Like a great deal of military decision-making, air defense operations are to an extent template-driven. There are a series of if-then procedures that determine at least the subset of decisions and plans that should be implemented given a set of environmental conditions. Strategic and tactical decision-making is frequently template-driven and frequently routinized via pre-conceived decision options.

Operational environments like air defense intelligence and operations (as well as missile and space defense) are thought to be boundable. A finite number of threats is assumed to drive a finite number of options. The overall strategic defense of the United States is anchored in a set of pre-determined responses to a relatively finite range of adversary actions (and reactions).

Any requirements analysis of an assumed bounded domain must first address the nature of the boundedness and the finite assumptions that define it. There are situations, however, that will fall outside the problem boundaries, situations that any "system" must be capable of addressing. To a great extent, the problem is analogous to the difficulties inherent in the movement from deductive to inductive reasoning. Many of our strategic and tactical systems are quite capable of responding deductively to sets of stimuli, but only remotely capable of handling unpredictable events. Our analysis of strategic air defense assumes, on the one hand, that sets of responses to expected event stimuli exist and, on the other, that any advanced system concept must deal directly with unexpected event stimuli.

2.3.3 Air Defense Operational Requirements - McFarren, et al. (1988) have modeled the air defense operations process in a series of modified flow/Petri diagrams that represent the functions, tasks, and sub-tasks that together constitute air defense operations. Several of these diagrams appear in Figures 2.18, 2.19, 2.20 and 2.21 (the complete set of operations diagrams appear in Appendix A). Such diagrams permit the dynamic analysis of the air defense operations process and together represent air defense operations requirements. We have built directly upon this work and have extended the task/process representation via findings in cognitive science and the capabilities of advanced information technology (see Section 5.0). We have integrated assumptions about the bounded/ unboundedness of the domain and placed operational requirements along the air defense intelligence/warning/decision-making continuum.

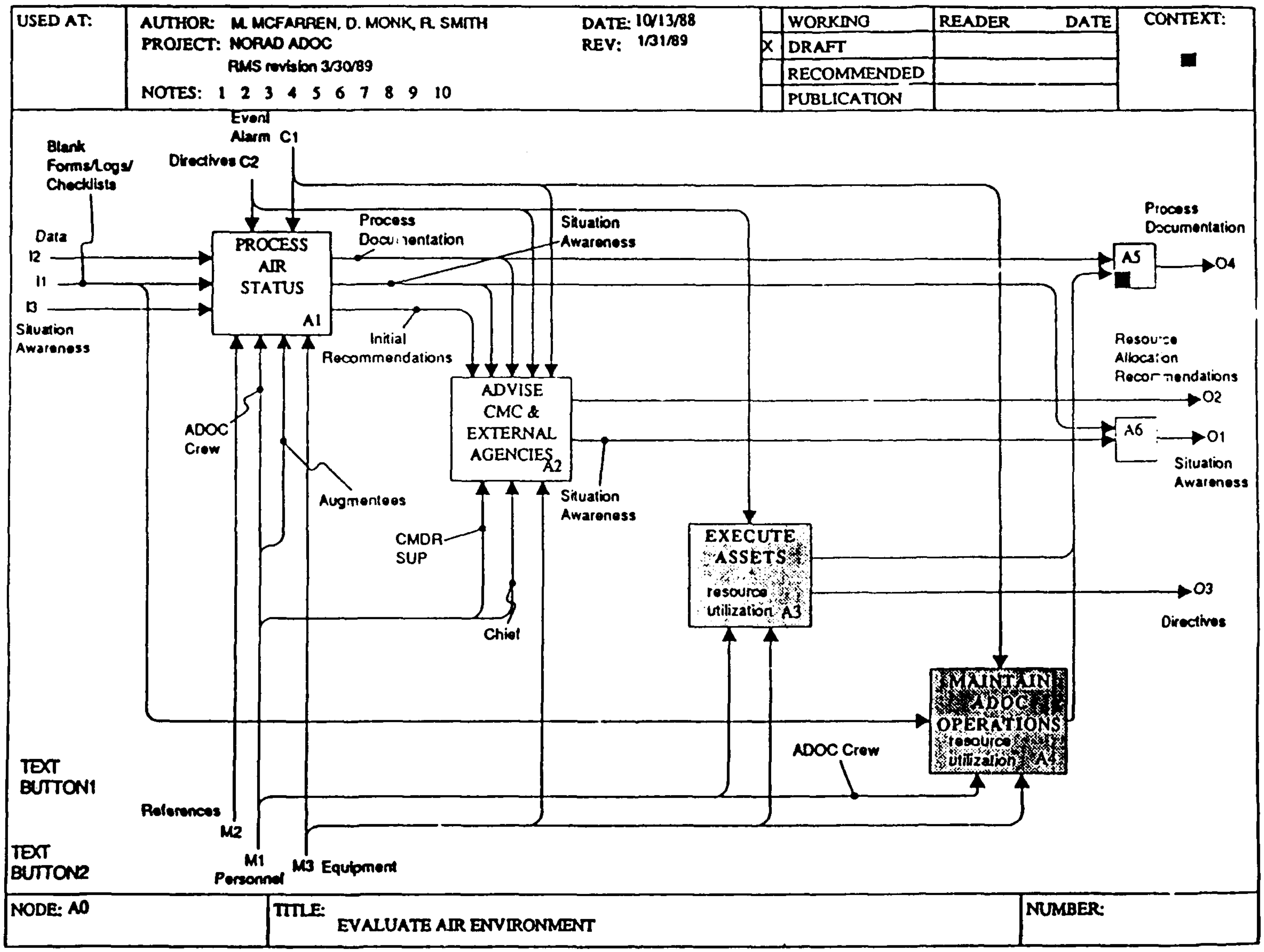


Figure 2.18: McFarren's IDEF ADOC Model: Example 1

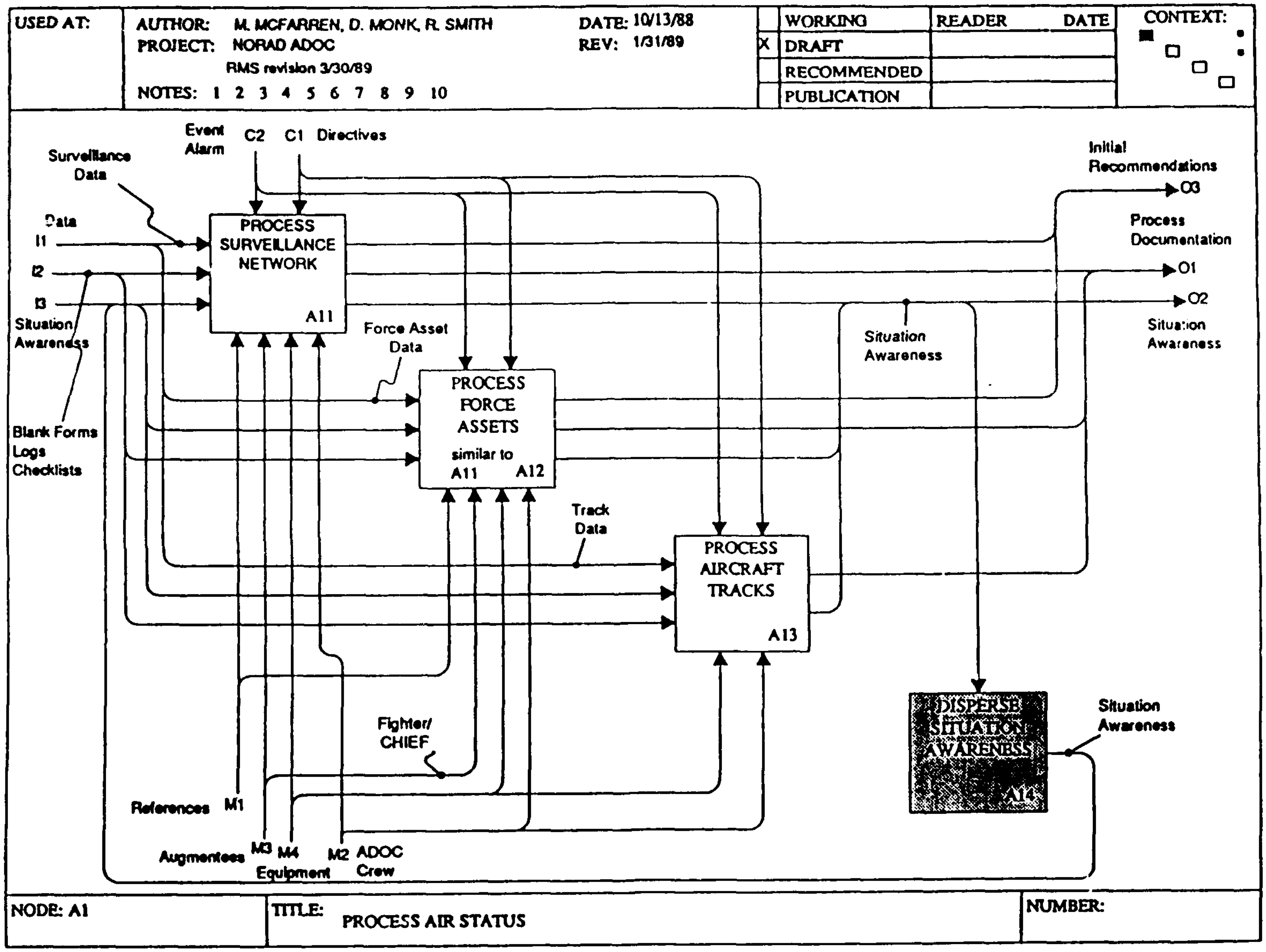


Figure 2.19: McFarren's IDEF ADOC Model: Example 2

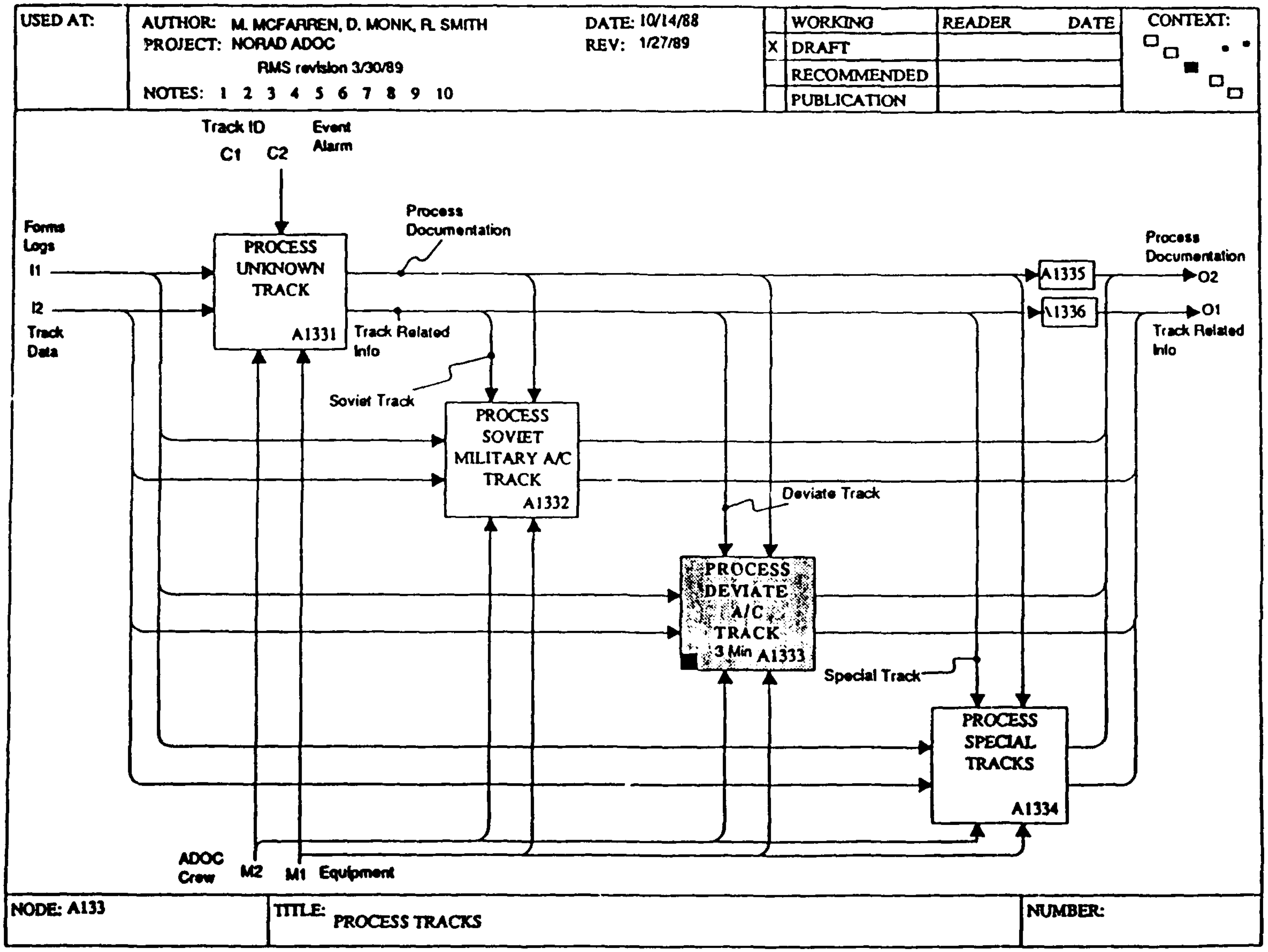


Figure 2.20: McFarren's IDEF ADOC Model: Example 3

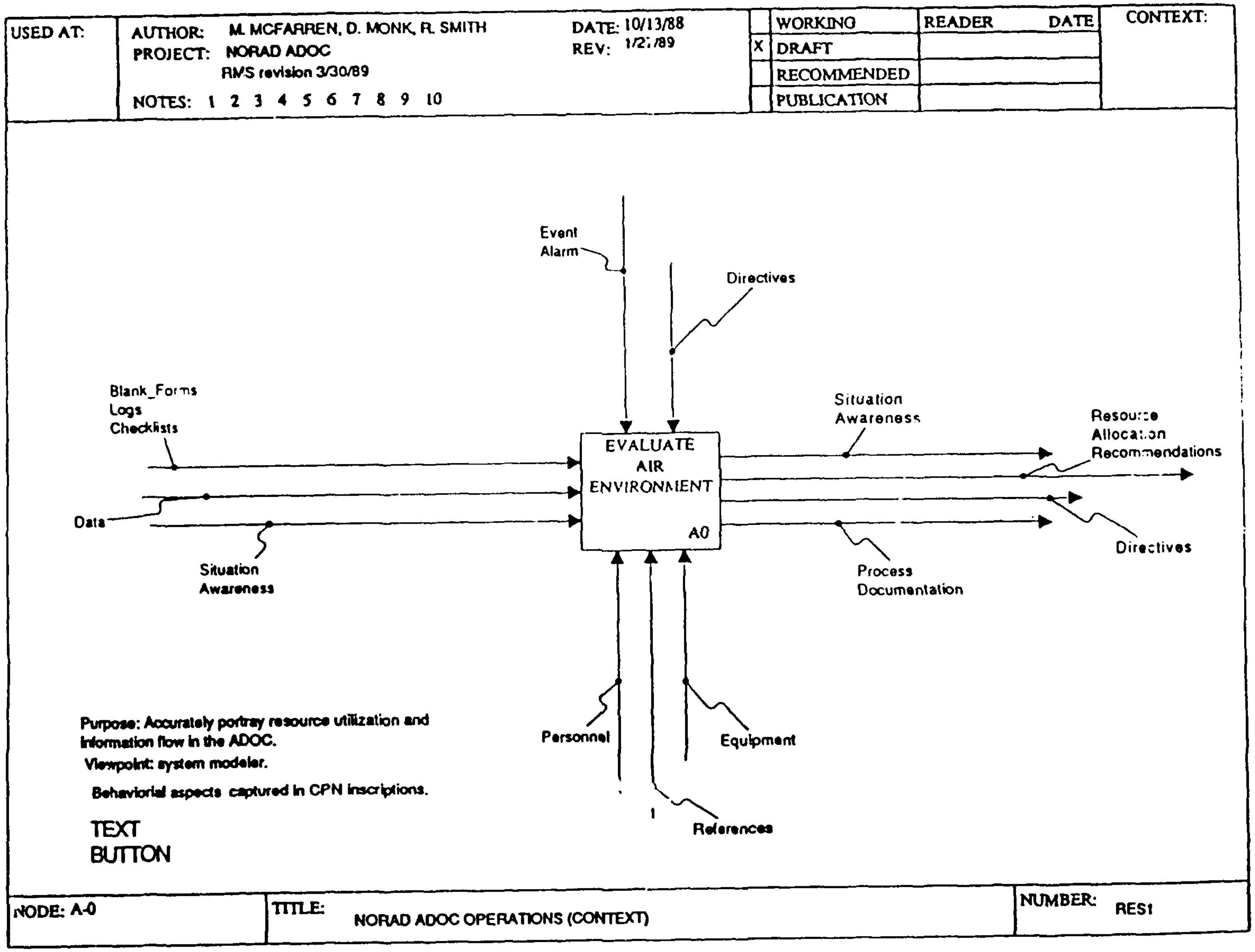


Figure 2.21: McFarren's IDEF ADOC Model: Example 4

2.4 The Air Defense Intelligence/Operations Interface

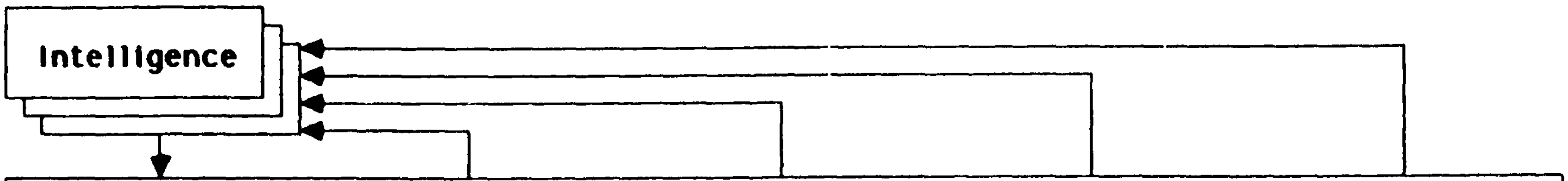
As suggested throughout this report, we regard the air defense process as a self-contained continuum consisting of intelligence, warning and decision-making processes and as part of the much larger strategic intelligence and operations process. We have argued that it is impossible to think about air defense operations independent of intelligence estimates and that it is impossible to think about air defense independent of missile warning, SLBM warning and space defense. This perspective complicates our research since it requires the multiple level modeling of strategic defense.

The system concepts described in Section 5.0 are anchored in these assumptions. The intelligence/operations interface -- in air defense and in other intelligence/operations domains (like missile defense) -- is conceptually and functionally linked. Our demonstration prototypes suggest how information technology -- tempered with findings from cognitive science -- can be leveraged to widen the communications bandwidth among all of the analysts along the continuua.

Requirements for the design of systems intended to address the interface must be derived first from intelligence and operations requirements and then from models of how the two processes are linked. The McFarren, et al. (1988) modeling technique used to model the Air Defense Operations Center (ADOC) could certainly be applied to the intelligence side of the process and the intelligence/operations interface. An IDEF model of the entire process (at all strategic defense levels) would contribute significantly to our understanding of the individual and combined processes.

We focus here on what intelligence needs from operations and on what operations needs from intelligence. Section 3.0 discusses the cognitive needs in detail; suffice it to say here that optimal operational decision-making requires an understanding of the intelligence analysis and production process, and that effective intelligence analysis and production can be enhanced via an understanding of the uses made of intelligence by operations analysts.

Functionally, the intelligence/operations interface can be described in matrices, as suggested in Figure 2.22 modified from Fitzgerald, et al. (1988). Belden (1977) has developed a "decision stairway" that integrates intelligence and operations into the likelihood of war (Figure 2.23), while Brown, et al. (1975) demonstrates in Figure 2.24 how decision analytic models can incorporate intelligence into operational decision-making processes. But all of these notions and models assume communication between intelligence and operations analysts, communication that can be enhanced via the marriage between cognitive science and information technology.



Decision Responsibilities

WARNING	EVALUATION	FORCE MANAGEMENT	BATTLE MANAGEMENT	RECONSTITUTION
Are there changes in status that indicate a potential attack? Has a hostile event occurred? Has the event been confirmed? What is the nature of the event? Are there potential follow-on threats? What geographical area is affected? Is the event a missile or space event? Other? Does NORAD concur? Should a warning message be issued?	Has more than one event occurred? Is an attack in progress? What is the nature of the attack? What geographic area is affected? Does NORAD concur? Is it a space threat? Should an attack assessment message be released? Should a CINC assessment be issued? Are there follow-up threat projections?	Is the status of forces acceptable? What is the impact of degraded forces? Are there circumstances preventing readiness? Are the uses of existing assets being maximized? What is the current status of Blue Forces? What damage has been inflicted upon Blue Forces? Can existing assets be used to support threat/crisis/war? Have OPLANS been developed to cover existing threat? Are there follow-up threat projections? Was system performance satisfactory for tests and exercises?	Are there OPLANS to cover the threat/crisis event? What level of alert/state of readiness should be declared? What plan of action should be followed? Are assigned forces in state of readiness? Can assets be deployed/modified to support the plan? What is the projected threat? Can assets be reconfigured within an acceptable period of time? What is the current status of enemy forces? What damage has been inflicted upon the enemy? Is current configuration of assets providing maximum support to mission? Should command be transferred to mobile command center?	Are any assets capable of supporting the mission? Which assets should be reconstituted? What actions can be taken to restore operations? What is the residual enemy threat?

Figure 2.22: Intelligence/Operations Interface

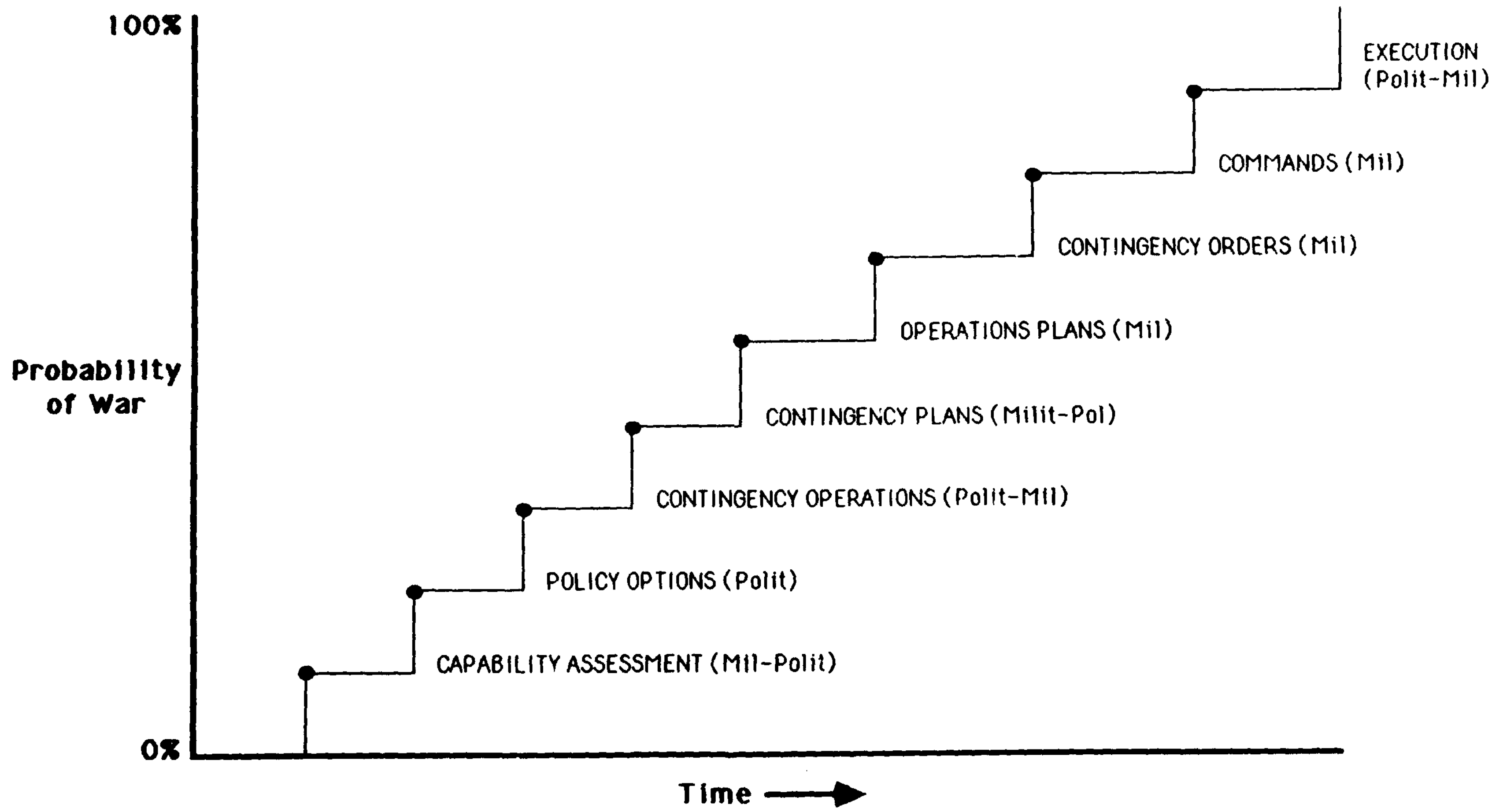


Figure 2.23: Belden's "Decision Stairway"

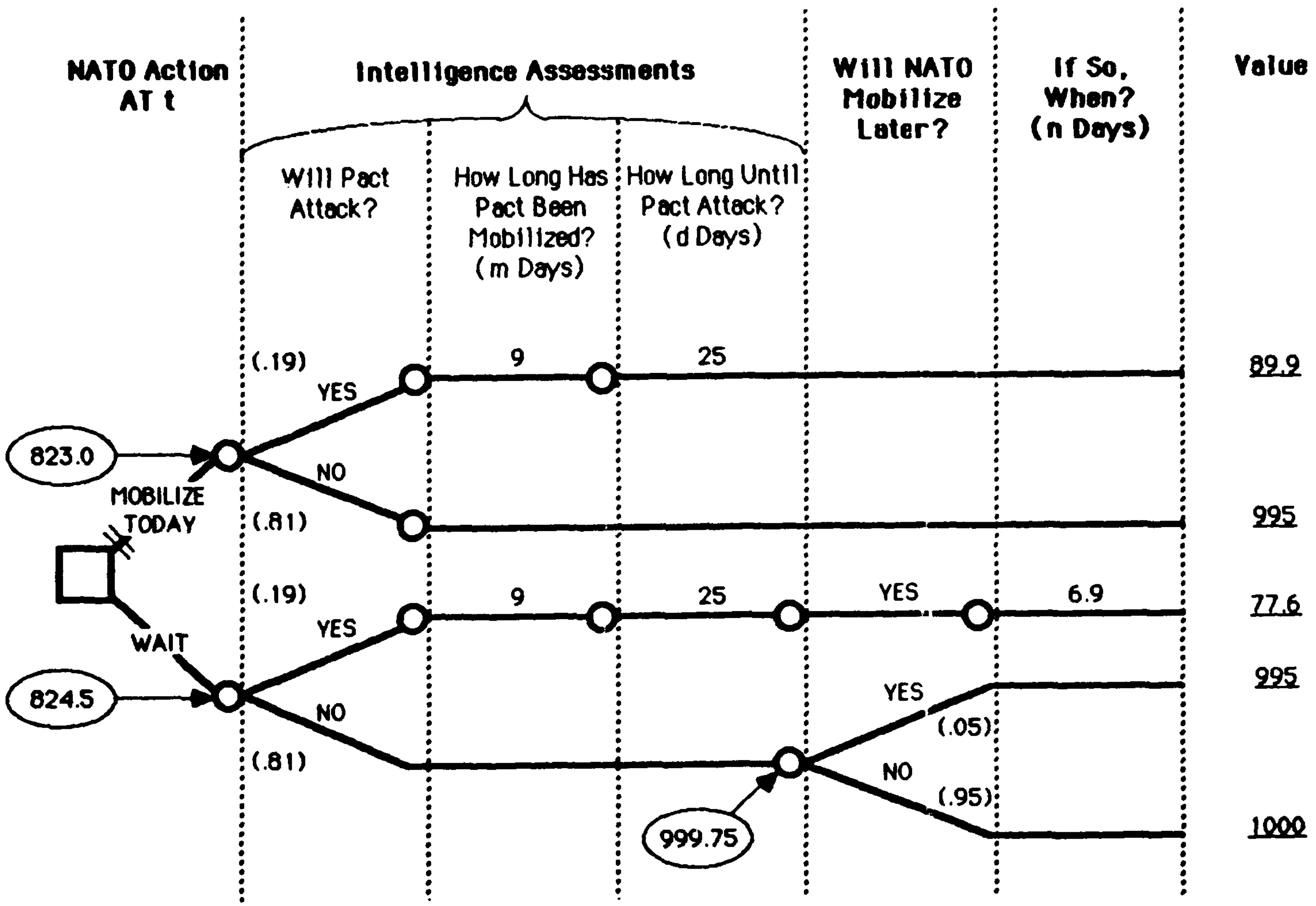


Figure 2.24: Integrated Intelligence/Option Selection Process

2.5 Air Defense System Concept Design

Air defense intelligence and operations, and the intelligence/operations interface, constitute the domain from which we have extracted a set of descriptive requirements. But we have also extended the requirements into the realm of the prescriptive. It should be noted that conventional systems design does not generally allow for the alteration of established modus operandi or doctrine. However, given the nature of the research at hand and the premium placed here upon innovation, we have implemented an "unconventional" design strategy and developed some system concepts that do not explicitly track with doctrine. Nor are the proposed user-computer interfaces (UCIs) conventional, since they are intended to demonstrate what is possible, not what exists or might incrementally be introduced.

3.0 APPLIED COGNITIVE ENGINEEERING

3.1 Cognitive Engineering in Perspective

Cognitive engineering is a relatively new field of inquiry that calls for the design and development of computer-based information systems consistent with what we know about how humans process information and make decisions. According to Norman (1986), cognitive engineering is "... a type of applied cognitive science, trying to apply what is known from science to the design and construction of machines." It represents the attempt to base system design on cognitive research findings regarding how people think; to aid -- not replace -- the human problem-solver; to design systems that utilize human strengths and compensate for our cognitive limitations; to more systematically integrate display formats and analytical methods with intuitive thought. Put quite simply, the goal of cognitive engineering is to have human cognitive processes, not computer technology, drive the human-computer interaction and problem-solving processes.

This section of the report overviews the findings from a number of different areas of cognitive research that are potentially applicable to the cognitive engineering of advanced information systems. In contrast to many important cognitive reseach efforts, we do not focus on the cognitive engineering of the user interface for the sole purpose of better using a software package, such as a text editor (Card, Moran, & Newell, 1983) or a word processor (Norman, 1986) or a spreadsheet (Olson and Nilson, 1987). Instead, our focus is on enhancing organizational problem-solving; that is, designing the user interface to advanced information systems so that they improve human ability to perform the complex inference and decision-making tasks found in organizational settings (Adelman, 1990). Our particular organizational focus is strategic command and control and, specifically, strategic air defense.

For expository purposes, we categorize strategic air defense problems and tasks by the two principal organizational units: intelligence and operations. The goal of intelligence is effective situation assessment; that is, monitoring the strategic environment and warning friendly forces of changes in sufficient time for effective action. The goal of operations is the development and execution of effective actions for the situation at hand. The kinds of intelligence tasks toward which our review of the cognitive literature is directed include discriminating between "signals" and "noise" in the target environment(s); assessment of events and conditions; inferences about possible enemy intentions and courses of action; and identification of high probability crisis situations. Operations tasks include, for example, assessment of friendly forces; option generation; evaluation of alternative options; and the selection and implementation of a given option.

Consistent with the above discussion, the cognitive research areas are categorized under the headings of intelligence and operations. In addition, since effective communication within and between intelligence and operations is essential to high levels of organizational performance, the third (and last) section of our review will consider the cognitive research on understanding and communicating problem-solving processes.

It is important to note that for each cognitive research area we will briefly overview the types of tasks used in performing the research. Although we realize that the reader's primary concern is learning about the findings of different areas of research, there is substantial empirical research (e.g., Hammond et al., 1975; Hogarth, 1981; Payne, 1982) demonstrating that human information processing and decision-making, as found in intelligence and operations, are extremely sensitive to task characteristics. Carroll (1989) has even gone so far as to question the viability of a cognitive engineering discipline because "the science base in which design deductions must be anchored is too general and too shallow vis-a-vis specific contexts and situations in the world."

Although we disagree with Carroll, we caution readers against blindly generalizing basic research findings to complex organizational settings. The focus of the larger project, for which this review is but a part, is directed toward (a) identifying display technology that, on the basis of the review presented herein, should enhance cognitive processing, and (b) developing storyboard representations demonstrating the use of cognitively-selected display technology. Further research would need to develop actual prototype systems and perform empirical evaluations to determine whether performance is indeed improved, as hypothesized, in a strategic air defense setting. We focus on the different tasks used in basic research as a means of more effectively moving toward that end.

3.2 Intelligence: Situation Assessment

This section overviews the following areas of cognitive research, all of which are applicable to the inference processes inherent in situation assessment:

- Social judgment theory;
- Cognitive heuristics and biases; and
- Analogical reasoning.

3.2.1 Social Judgment Theory (SJT) - SJT was developed by Kenneth R. Hammond and his colleagues and students, and extends the theory of probabilistic functionalism developed by Egon Brunswik, a perception psychologist, to the realm of judgment and decision behavior. For an overview, the interested reader is referred to the paper by Hammond et al. (1975) and the edited volume in Hammond's honor by Brehmer and Joyce (1989). For its potential application to intelligence analysis, the reader is referred to Adelman et al. (1981) and Phelps (1983).

Figure 3.1 represents the extension of Brunswik's lens model to the case of intuitive prediction. The goal of human judgment (Ys) is to accurately predict environmental criteria (Ye). These criteria (Ye) may be the causes of observed effects or future states of the world. In the domain of strategic intelligence, this may be the enemy's actual intent or action; for example, whether the enemy actually intends to or already has launched an attack. Ys represents the judgmental counterpart to Ye. In strategic intelligence, for example, it may represent the analyst's (or commander's) judgment as to whether or not the enemy actually intends to or has already launched an attack.

People use information or cues (Xi) to make these judgments. The cues may be acquired from the immediate environment and our memory of past events. The cues are processed (i.e., utilized) by the person according to decision heuristics to produce the judgment (Ys). As will be discussed throughout this review, people utilize a large repertoire of decision heuristics to combine information into a judgment. Moreover, in an effort to be accurate, people try to utilize the cue information ($r_{s,i}$) in a manner that matches the information's environmental validity ($r_{e,i}$). That is, people try to rely on valid predictors of environmental criteria (Ye). In strategic intelligence, this is equivalent to saying that analysts attempt to utilize the best predictors of enemy intent. To the extent that they are able to do so, the more accurate their judgments (Ys) of the environmental event (Ye) will be.

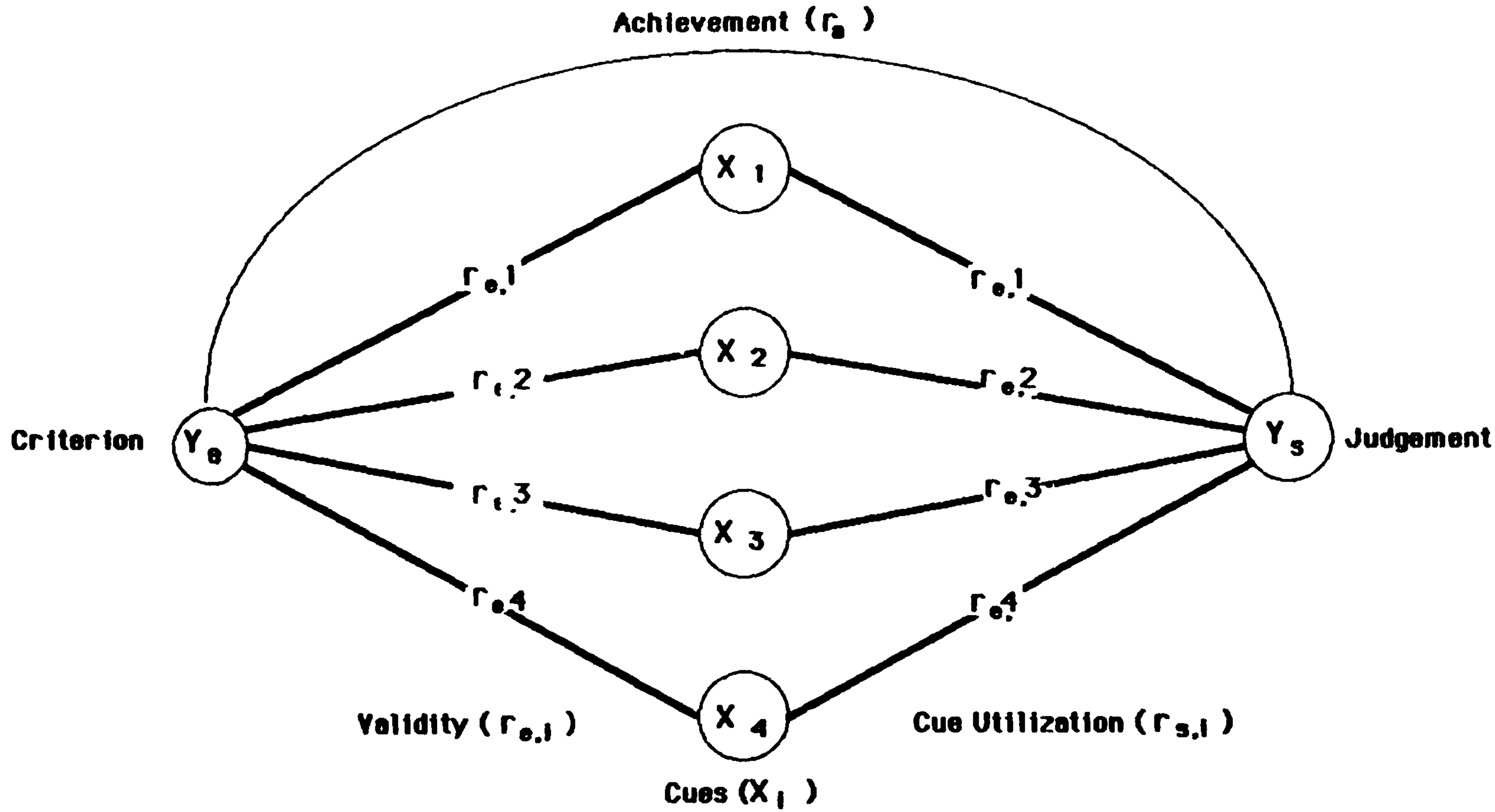


Figure 3.1: The Lens Model Representing the Task and Person

SJT research has identified three findings of particular importance to the cognitive engineering of advanced information systems for supporting strategic intelligence. *First, specific task characteristics significantly affect people's ability to perform complex inference tasks. Second, people have poor insight into their inferential process. Third, information systems providing cognitive feedback can significantly improve task performance*. Before considering these findings in more detail, we first turn to discuss (a) the characteristics of inferential tasks, particularly as studied within the SJT paradigm, and (b) the lens model equation, which has been developed to quantify the relation between the environmental and cognitive systems represented in Figure 3.1.

3.2.1.1 *Task Characteristics* - SJT research has focused on why inferential tasks, like strategic intelligence, are difficult even for experts in their (appropriate) domain. In particular, we focus on five task characteristics here. First, by themselves, individual cues are seldom perfectly valid predictors of Ye. Rather, the relationship between individual cues and the environmental criterion is typically probabilistic (i.e., $r_{s,i}$ § 1). Consequently, any given piece of information is not, by itself, perfectly diagnostic of the event that caused it (or that which is to be predicted). This is compounded by the fact that, second, information is not always reliable. That is why there is always such a concern in intelligence analysis regarding the reliability of the source of the presented information. It is important to note that reliability and validity are two different concepts. A piece of information can be 100% reliable and either totally diagnostic (100% validity) or undiagnostic (0% validity) in predicting Ye. However, the less reliable the information, the less valid it is because of the inherent uncertainty (i.e., error) in the information itself.

In addition to the validity and reliability of the cues, the functional relations between individual cues and the criterion Ye may assume a variety of forms. For example, there may be a positive or negative linear relationship between values on a cue and the criterion. Or, in contrast, there may be nonlinear relationships, such as U-shaped, inverted-U shaped, or S-functions. Fourth, there are various heuristics for combining the multiple pieces of information (cues) into a judgment (e.g., additively or according to specific patterns). Moreover, it is seldom clear in complex inference tasks which combination rule is the best one for predicting Ye. Finally, overall task predictability when using all the cues is seldom perfect. Patterns of data (Xi) that may have correctly predicted Ye in the past may fail to do so in the future. Human judgment is thus not only difficult because of limited human information processing capabilities, but also because of the very nature of inferential tasks themselves.

3.2.1.2 Lens Model Equation - The Lens Model Equation (LME) presented below quantifies the relationships between the environmental and cognitive systems represented in Figure 3.1. Since linear models, such as multiple regression and analysis of variance, have been routinely used in SJT research, they will be assumed in the description of the LME parameters although, as will become clear, the parameters represent more general concepts:

$$r_a = GR_sR_e$$

The typical judgment task consists of presenting a person with a number of cases representing the judgment problem. Each case (or profile) for consideration consists of a mix of values on the several cues (Xi) being used to make a judgment (Ys) of the environmental criterion (Ye). r_a is the correlation between the person's judgments (Ys) and the environmental criterion (Ye) over a number of cases. Statistically, it represents the person's accuracy in predicting the criterion Ye.

In most SJT research, G represents the correlations between the "best fitting" (using a "least squares" procedure) linear model predicting the person's judgments and the "best fitting" linear model predicting the environment criterion. Conceptually, G represents the level of correspondence (or match) between the task and the person, and is considered a measure of knowledge. To the extent that a person can accurately assess the diagnosticity of individual cues, their functional relations with Ye, and the heuristics for combining cue information, the greater their knowledge (G) of the task and the better their performance (r_a).

R_s is the correlation between the person's judgments and the predicted values of the judgments based on the (linear) model of the person. It is typically considered as the overall consistency or "cognitive control" exhibited by the person in making his/her judgment because it is analogous to assessing whether a person will give the same judgment for the same information seen a second time. Finally, R_e is the correlation between the criterion and the predicted values of the criterion based on the (linear) environmental model. Consequently, it represents the overall predictability of the environmental system, and the extent to which a cause will always generate the same observable cues.

The parameters of the LME provide important insights into the nature of many types of judgment tasks and people's ability to learn and perform them well both in and outside of the laboratory. First, G (i.e., knowledge) and R_s (i.e., cognitive control) are statistically independent. Consequently, it is possible to perform quite poorly even if one knows what to do if one cannot do it consistently. Second, R_e sets an upper bound on achievement even if knowledge and cognitive control are perfect. In other words, task predictability is as important a determinant of judgment performance as our information processing capability and/or the support systems that we develop to improve it.

3.2.1.3 Important Findings - As suggested above, SJT research has identified three findings of particular importance to the cognitive engineering of advanced information systems for supporting strategic intelligence. First, specific task characteristics significantly affect people's ability to perform complex inference tasks (r_a). Moreover, the LME permits one to assess whether the reason is poor knowledge (G) and/or cognitive control (R_s). For example, Hammond (1971) demonstrated that it was extremely difficult for people to learn nonlinear relations (e.g., inverted U-shaped functions) versus linear ones. Moreover, Hammond and Summers (1972) showed that even when they learned the nonlinear relations as well as the linear ones (i.e., G was the same), achievement (r_a) was still lower for the nonlinear ones because of significantly lower cognitive control (R_s). That is, it was just harder for people to do what they wanted to do cognitively.

Adelman (1981) and numerous others have shown that cognitive control (R_s) and achievement (r_a) are significantly decreased by decreasing task predictability (i.e., lowering R_e). Yet, there is minimal (if any) affect on knowledge (G). This appears to occur because people act as if inferential tasks are perfectly predictable. More generally, people seem to rely on causal schemas (versus probability statistics) to explain observed events (i.e., Xi). Generalizing to the domain of strategic intelligence, this suggests that the inferential performance of analysts can be significantly hampered by the effective use of deception that adds extensive noise to the system and/or is designed to create incorrect causal patterns. Advanced information systems need to be engineered to help users ignore the noise $(1 - R_e)$ and stay focused on their knowledge of the relations between the observed data (Xi) and the (potentially) multiple causes (Ye) of it.

Although not performed explicitly within the SJT framework, Einhorn and Hogarth (1986) and Hogarth (1987) have further advanced this research by focusing on three critical aspects of causal reasoning. First, their research indicates that people make judgments of probable cause on the basis of a "causal field" that is basically analogous to a perceptual field. Judgmental, like perceptual processes are attuned to differences; therefore, the relevance of potential causes depends on whether they are considered as differences in the problem context. Second, people use various imperfect indicators of causal relations called "cues-to-causality." These cues include, for example, temporal order, covariation, contiguity in time and space, and similarity of cause and effect; and, third, the confidence people place in a causal explanation is affected by the extent to which they can imagine plausible scenarios for both it and alternative explanations. As Hogarth (1987) points out in his discussion of creativity in problem solving, "...use of both causal fields and the cues-to-causality help the mind establish order out of the mass of information with which it is confronted. On the other hand, this order is bought at the cost of being able to perceive alternative problem formulations (i.e., causal fields) and potential causal candidates."

The second important finding of SJT research is that people have poor insight into their inferential process. For example, it has been consistently shown that people think they use more information than they actually do, or that is required to accurately predict their judgments. In particular, people tend to underestimate the weight they place on important cues and overestimate the weight they place on unimportant cues when compared to the (highly predictive) weights obtained from a multiple regression analysis of their judgments (e.g., see Cook and Stewart, 1975). Moreover, experts appear just as susceptible to poor insight as novices (e.g., see Slovic et al., 1972). Poor insight will be considered in more detail in the Communication section, which is the last section of this review, because it has substantial implications for interpersonal understanding and group decision making. For a detailed review that addresses this issue beyond just SJT, see Nisbett and Wilson, 1977.

Third, information systems providing cognitive feedback can significantly improve task performance. Cognitive feedback is oriented to providing people with information regarding how they use the cues to reach a judgment (e.g., their weights and function forms) and how they should use the information (e.g., the task weights and functions). Hammond et al. (1975) have argued that one of the unique contributions of SJT research is the empirical demonstration that cognitive feedback results in significantly higher levels of performance than outcome feedback (i.e., receiving the correct answer). The reason is three-fold. First, as discussed above, people have poor insight into how they actually use information to make a judgment. Second, they have poor insight into how they should use the information. Newton (1965) showed that information about the task (i.e., the environmental side of the lens model) is significantly more beneficial than information about the person (i.e., the cognitive side of the lens) for performance in complex inference tasks; and third, as discussed above, people often get distracted by the noise in the system. Cognitive feedback keeps them focused on important cue-criterion relations.

SJT research has extended the focus on cognitive feedback to group decision making. This extension will be considered in the Communication section, which is the last section of this review. What is important to note here is that research has demonstrated that cognitive feedback of human inferential processes has significantly improved interpersonal understanding and subsequent performance over more traditional approaches, like talking about the problem without cognitive feedback. Moreover, this has been extensively demonstrated in the laboratory (e.g., Hammond and

Brehmer, 1973) and in real world applications (e.g., see Hammond and Adelman, 1976; Hammond and Grassia, 1985; Rohrbaugh, 1988).

In SJT research, the quantitative and qualitative characteristics of the task, that is, the environmental side of the lens model, is used as a standard by which to compare human information processing, that is, the cognitive side of the lens. High levels of achievement depend on (1) knowledge (G), that is, matching our use of the information to how we should use it, and (2) cognitive control, that is, implementing our knowledge in a consistent fashion. However, the types of tasks used in SJT represent just some of the many different types of tasks that have been used by cognitive scientists studying human inference. We now turn to consider other types of inferential tasks and, more generally, the results of research focusing on cognitive heuristics.

3.2.2 Cognitive Heuristics - Cognitive heuristic research has used probability and statistical theory as a normative standard for evaluating human inferential performance. Probability and statistical theory represent powerful rules for logically combining uncertain information into an inference. Moreover, many advanced information and decision systems used these rules. Therefore, from a cognitive engineering perspective, it is important to assess whether humans try to emulate these rules or use other types of processing heuristics. It is important to emphasize that we are not saying that people should use the rules of probability and statistical theory but, rather, whether they do so.

An overwhelming finding is that human decision behavior systematically deviates from (or is "biased" when compared to) a normative model that is assumed to be the optimal way to make the decision under investigation. According to Hogarth (1987) "people do not possess intuitive 'calculators' that allow them to make what one might call 'optimal' calculations. Rather, they use fairly simple procedures, rules or 'tricks' (sometimes called 'heuristics') in order to reduce mental effort." Judgmental heuristics, and the biases they often spawn, are the results of human effort to understand and master our environment given limited information acquisition, retention, and processing capacities.

Research has demonstrated that the perception of information is not comprehensive but selective. As Hogarth (1987) points out, it has been estimated that, for example, only about 1/70th of what is present in the visual field can be perceived at one time. How do we know what to select? The answer is that we anticipate information on the basis of our causal model of the environment. Similarly, memory is limited; we recall but a small part of the information we initially acquire. Moreover, current theories support the view that memory does not access information in its original form but, rather, works by a process of associations that reconstruct past events and fragments of information that are typically consistent with our causal model of the environment. Finally, research indicates that considerable mental activity involves processing information that is both acquired from the environment and recalled from memory to make judgments of probable cause. There are, however, significant differences in causal versus statistical (or normative) reasoning.

Kahneman, Slovic, and Tversky (1982) have compiled an anthology of research studies demonstrating that, when compared to the tenets of probability and statistical theory, humans have limited appreciation for the concepts of randomness, statistical independence, sampling variability, data reliability, regression effects, and the like, when making probabilistic judgments. All of these concepts are important when making the types of causal inferences inherent in intelligence. Although these concepts and cognitive heuristics can be represented in the lens model paradigm of SJT, the tasks used to investigate them and, in turn, orientation have been quite different in cognitive heuristics research. We first overview the kinds of tasks used in cognitive heuristics research and then consider important research findings.

3.2.2.1 Task Characteristics - The typical tasks used in cognitive heuristics research are simple word problems employing quantitative information that is optimally combined using the rules of probability and statistical theory. von Winterfeldt (1988, p. 467) has described the paradigm as follows:

"(1) A formal rule, known to the experimenter but not known or available to the subject is applied in formulating an intellectual task;

(2) Subjects are asked to solve the task intuitively (without tools); and

(3) A systematic discrepancy between the formal rule and subjects' answers is found."

The following example is a classic problem studied by Tversky and Kahneman (1980) and that is discussed in detail in Hogarth (1987):

> "A cab was involved in a hit-and-run accident at night. Two cab companies, the Green and the Blue, operate in the city. You are given the following data:
>
> (1) 85% of the cabs in the city are Green and 15% are Blue.
>
> (2) A witness identified the cab as a Blue cab. The court tested his ability to identify cabs under the appropriate visibility conditions. When presented with a sample of cabs (half of which were Blue and half of Green), the witness made correct identifications in 80% of the cases and erred in 20% of the cases.
>
> Question: What is the probability that the cab involved in the accident was Blue rather than Green?"

The typical response to this question is about 80%. This is consistent with the evidence that the witness correctly identified 80% of the cases in the court's test of his ability to correctly identify cabs. However, the correct answer to the problem is that the chance of the cab being Blue is 41%. The reason so many people are so far from the correct probability estimate, and even the correct color of the cab, is that they often fail to consider the "a priori" or base-rate information that 85% of the cabs in the city are Green, not Blue. Probability theory, and in particular Bayes' Theorm, requires that one sytematically use both the base rate information and the new evidence when making a probabilistic inference. Specifically,

$$p(\text{Blue}|\text{Say Blue}) = \frac{p(\text{Blue})\ p(\text{Say Blue}|\text{Blue})}{p(\text{Say Blue})} = \frac{(.15)\ (.8)}{.29} = .41$$

$$\text{where } p(\text{Say Blue}) = p(\text{Blue})\ p(\text{Say Blue}|\text{Blue}) + p(\text{Green})\ p(\text{Say Blue}|\text{Green}) = (.15 \times .80) + (.85 \times .20) = .29$$

It is important to note that when the same base rate information is given a causal meaning by rephrasing the problem to say "85% of accidents in the city involve Green cabs and 15% involve Blue cabs" the average response is 55%, much closer to that which is optimal according to Bayes' Theorem.

3.2.2.2 Important Findings - The above example illustrates that people give meaning to information in order to make causal sense out of it. Probability theory, however, does not necessarily do so, for probability theory is merely a set of rules that permit one to infer the relationship between probabilistic events if certain assumptions are met. In fact, Einhorn and Hogarth (1986) and Hogarth (1987) have argued that the nature of causal reasoning not only differs in important respects from the dictates of probability theory, but that certain aspects of probability theory are antithetical to causal reasoning. As they point out, for example, causal reasoning is generally unidirectional (e.g., X causes Y). On the other hand, in statistical logic the relation between two events can be, and often is, discussed in either or both directions. For example, in order to use Bayes' Theorem to calculate the posterior probability of a hypothesis given new data or information [i.e., $P(H|D)$], one needs to assess the likelihood of the data given the hypothesis [i.e., $P(D|H)$]; and, whereas statistical theory is based on the logical structure of information, causal reasoning is responsive to both structure and content in terms of the causal field, cues-to-causality, and the plausibility of alternative scenarios and causal explanations. In summary, although it may not be normatively correct when compared to probability and statistical theory, people use heuristics that weight information on the basis of its perceived causal meaning not its statistical diagnosticity.

The heuristics that humans use to attach meaning to information makes us susceptible to "biases," when compared to some normative (or presumed "optimal") standard, depending on how the problem is presented or "framed" (Tversky and Kahneman, 1981). This point was illustrated with the taxicab problem presented above. Substantial psychological research has been performed trying to identify the nature, cause, and implications of these biases. In an effort to synthesize this research, Hogarth (1987) has catalogued cognitive biases according to the following four information processing stages: acquisition, processing, output, and feedback. In the following subsections, we will list some of the biases that seem most relevant to intelligence (Table 3.1); those that are most relevant to operations will be considered later (Table 3.3).

Before doing so we want to note that the word "bias" has a negative connotation. Indeed, the research on cognitive biases has often been presented as a cataloguing of human fallibilities. However, the cognitive heuristics that spawn these biases have both strengths and weaknesses. On the positive side, they permit humans with limited information acquisition, retention, and processing capabilities to not only establish order and meaning out of the mass of information with which they are confronted, but to develop new and creative ways of ever improving (and hopefully, never destroying) our environment. On the negative side, they expose limitations in reasoning when compared to normative models of decision behavior. This research is particularly important to the design of advanced information systems because it suggests that how information is presented by these systems can significantly affect the adequacy of our thinking. Moreover, probability and statistical theory are not esoteric concepts; they provide us with powerful rules for enhancing causal inference under conditions of uncertainty. These rules can be and have been used to improve unaided human decision behavior (e.g., see Kelly et al., 1981). The long-term goal of cognitive engineering is the design of support systems that effectively combine human and computer strengths and, thereby, improve human decision behavior.

- **In "Information Acquisition"**
  - Availability of Instances in Memory
  - Selective Perception of Information
  - Focus on Confirming (vs. Disconfirming) Information
  - Vividness (vs. Abstractness) of Information
  - Data Presentation
    - **Order Effects (e.g., Information Presented First or Last)**
    - **Intact Displays (vs. Sequential Presentation of Information)**
    - **Seemingly Logical Displays**
- **In "Information Processing"**
  - Conservatism Bias
  - Representativeness Heuristic
  - Conjunction Fallacy
  - Inconsistency
  - Law of Small Numbers
  - Regression Bias
  - Task Characteristics Affecting Processes
    - **Time Pressure**
    - **Social Pressure**
    - **Information Overload**
- **In "Output"**
  - Question Format
  - Scale Effects
- **In "Feedback"**
  - Task Characteristics ("Outcome Irrelevant Learning Structures")
  - Misperceptions of Chance
  - Logical Fallacies in Recall
  - Hindsight Bias

Table 3.1: Cognitive Heuristics and Biases Relevant to Intelligence

3.2.3 Biases in Information Acquisition - Hogarth (1987) has suggested that, "the issue of bias in information acquisition can be conceptualized by enquiring when and why information becomes salient to an individual. This question can be further broken down by noting that information can be accessed from two sources: (1) the individual's memory; and (2) the task environment." First, we consider cognitive biases that are memory-based; second, we consider those that are facilitated by task characteristics; and third, we consider biases that are facilitated by the way that data is presented, which is a particularly relevant task characteristic for display technology.

We consider three memory-based biases that affect data acquisition. The first is the availability bias (e.g., see Tversky and Kahneman, 1973). Specifically, the ease with which specific instances can be recalled from memory affects judgments of the frequency of different events. In particular, publicity or extensive discussion of (or focus on) particular events, makes them more salient and, in turn, more available in memory. The second bias is selective perception (e.g., see Dearborn and Simon, 1958). In particular, people structure problems on the basis of their own experience such that anticipations of what one expects sometimes bias what one does see. The third bias, which is related to selective perception, is the confirmation bias (e.g., see Wason, 1960). In particular, people seek information consistent with their own views and hypotheses instead of seeking disconfirming information. Of particular interest is a recent set of experiments by Tolcott and his colleagues (1989a, 1989b) demonstrating the confirmation bias with Army tactical intelligence analysts.

We now consider two task-based biases affecting memory acquisition. The first is the frequency bias. Specifically, people often judge the strength of predictive relations by focusing on the observed frequency of events rather than their observed relative frequency. As Einhorn and Hogarth (1978) have shown, information on the non-occurrence of an event is often unavailabe and frequently ignored when available. Second, concrete information, that is, information that is vivid or based on experience or incidents, dominates abstract information, such as summaries and statistical base-rates. According to Nisbett and Ross (1980), concrete and vivid information contributes to the "imaginability" of the information and, in turn, enhances its impact on inference and decision-making.

There is a substantial amount of research suggesting that the way the <u>same</u> information is presented can significantly affect information acquisition. For example, research by Einhorn and Hogarth (1987) and Serfaty et al. (1988), the latter with experienced Army personnel, showed that the same information disconfirming an initial hypothesis had a significantly greater impact when it was presented at the end versus the beginning of a series. Russo (1977) has shown that intact displays containing all available information result in better performance than the sequential presentation of the same information. Yet, intact displays are not without their potential pitfalls. Fischhoff et al. (1978), for example, demonstrated that seemingly complete presentations of information via logical displays can blind experts, in this case auto mechanics, to critical omissions in the data. "All information presented seems so consistent that the individual is only able to come to one, possibly erroneous conclusion" (Hogarth, 1987). Such an effect is consistent with the confirmation bias. More generally, the way information is presented affects its saliency and, in turn, the information that is acquired to make causal sense out of the world.

3.2.4 Biases in Information Processing - Related to information acquisition is its processing; that is, the heuristics, rules, or more generally, ways that different pieces of information are combined into an inference or decision. Consistent with the paradigm for cognitive heuristics research, the literature is replete with processing biases compared with normative combination rules. Some of the biases most relevant to intelligence analysis and production are listed here.

Humans are conservative information processors compared to Bayes' Theorem (e.g., see Edwards, 1968). Even when the task is structured to make us focus on base rates, we do not revise our opinions on the receipt of new information as much as we should compared to Bayes' Theorem. This is not surprising, for Bayes' Theorem is neither intuitively obvious nor a trivial analytical calculation. Instead, we appear to use two very simple heuristics to revise probability estimates on the basis of new data. First, there is the representativeness heuristic (e.g., see Kahneman and Tversky, 1973), which was illustrated in the cab example. That is, we sometimes judge the likelihood of events by estimating their similarity to the class of events of which they are suppose to be an exemplar, such as the witness' 80% accuracy in the cab example. The second heuristic is anchoring and adjustment. Predictions are made by anchoring on a cue or value and then adjusting to allow for the circumstances of the present case. Einhorn and Hogarth (1985, 1987) have presented empirical findings supporting the use of anchoring and adjustment when people are forced to make probability estimates in the face of highly ambiguous data, and to explain the effect of information presentation order on inference, respectively.

A number of other processing biases relevant to causal inference have been identified in the literature. For example, there is the conjunction fallacy (e.g., Slovic et al., 1976). In probability theory, the joint probability of two events cannot be larger than the probability of the smaller of the two events (e.g., .1 x 1.0 = .1). Yet, substantial research shows that when word problems are framed to elicit causal reasoning instead of statistical reasoning, people estimate the joint probability of two events as being larger, not smaller, than the probability of the smaller event. In one experiment of potential interest to intelligence analysts, Tversky and Kahneman (1983) asked (in 1982) professional forecasters to assess the probability of "a complete suspension of diplomatic relations between the USA and the Soviet Union sometime in 1983." A second group of forecasters was asked to evaluate this outcome and "a Russian invasion of Poland." The second group's probabilities were higher than the first's, thereby violating the laws of probability theory.

SJT research informs us that people are often inconsistent in how they process information. In addition, we are subject to what Tversky and Kahneman (1971) have called the "law of small numbers" in contrast to the Law of Large Numbers. In particular, problems can be framed in such a way that people, including trained scientists, can give undue confidence to a (relatively) small amount of data -- and we are subject to regression biases. According to Hogarth (1987), "... extreme values of cues [without perfect predictability] (e.g., test scores) are typically accompanied by less extreme values of the criterion (e.g., performance measures). Thus, a sensible judgmental strategy is to regress predictions based on extreme observations toward the mean of the variable predicted. However, people frequently make implicit use of extreme values of predictive cues, together with consistency of data sources, to justify confidence in their predictions. Paradoxically, characteristics of information that inspire confidence are often inversely related to the predictive accuracy of that information. This has led to what Kahneman and Tversky [1973] have termed the "illusion of validity."

In closing this subsection, it is important to note that task characteristics can significantly affect causal inference. In particular, Payne et al. (1987) has shown that time pressure significantly affects the amount of information examined and the rules used to process it. Janis' (1972) classic work on "groupthink" shows how social pressure within highly cohesive, strongly directed groups can unduly influence inferences. As Janis and Mann (1977) point out, "when the degree of complexity of an issue exceeds the limits of cognitive abilities, there is a marked decrease in adequacy of information processing as a direct effect of information overload and ensuing fatigue."

3.2.5 Biases Due to Output or Feedback - As Hogarth (1987) suggests, "output biases appear to be triggered by the way in which people express judgement or choice . . . the importance of feedback in judgement relates to its effect on learning." Regarding the former, Hogarth (1975) has shown, for example, that probability estimates can depend on how people have been asked to respond and on the scale used to measure these responses. This output bias is so strong that Spetzler and Stael von Holstein (1975) strongly recommended that decision analysts use multiple methods to converge on probabilistic assessments of uncertainty. The reader should not think that this output bias is simply a function of using numbers instead of words to represent uncertainty. Moore (1977) found substantial differences in how experienced managers ranked expressions used to express uncertainty. In intelligence, Kent (1964) "... was so concerned with the fact that almost all intelligence analysis documents contained ambiguous verbal reports of uncertainty, that he proposed a set of rules for translating words into probabilities and vice versa ..." (von Winterfeldt, 1988). More generally, as Fischhoff et al. (1980) have shown, the way a person is asked to respond can significantly affect his judgment.

As the SJT research indicates, outcome feedback does not necessarily result in high levels of performance. Part of the problem is that inference tasks are seldom perfectly predictable (i.e., Re § 1); consequently, outcome feedback is seldom of perfect validity. In addition, as Einhorn and Hogarth (1978) have pointed out, it is often not possible to observe outcomes associated with the total range of judgments, and feedback is often delayed or affected by other events. In particular, recent research on dynamic decision making (e.g., see Sterman, 1989) has shown that delays in receiving outcome feedback can result in misperceptions that essentially make people insensitive to it. Such settings have been referred to as "outcome irrelevant learning structures" by Hogarth (1987).

In addition to task characteristics, people are not always effective in using feedback. For example, people often misperceive chance fluctations and, in some cases, erroneously attribute causation to chance events. A good example is the "gambler's fallacy" where people expect a chance event (e.g., Black in roulette) because they have just observed a large number of unexpected (but chance) events (e.g., a number of Reds). In addition, people cannot remember all the feedback they receive. This can result in logical fallacies in recall. In studying eyewitness testimony, Loftus (1979) has shown that recall can be influenced by post-event information and the way information is elicited from the witness. This appears to occur because memory is based on the reconstruction of events to make causal sense out of the world. Hogarth (1987) suggests that " . . . the paradox of memory is that long-term memory does not work by remembering what is actually recalled, but rather by remembering fragments of information that allow one to construct more complete representations of the information." Seen from this perspective, the hindsight bias, which is colloquially referred to as Monday morning quarterbacking or second-guessing, is not surprising. Perhaps what is suiprising, is the strength for, as Fischhoff (1975) found, people appear adept at interpreting new information as consistent with previously held positions.

3.2.6 Analogical Reasoning - Analogical -- or "case-based" -- reasoning is a knowledge representation and control methodology which can assist planners and designers in making complex, domain-specific decisions or problem assessments and recommendations based upon previous experiences and patterns of previous experiences. These previous experiences, or "cases," of domain-specific knowledge and action, are used in comparison with new situations or problems; and these past methods of solution provide expertise for use in those new situations or problems the system is built to handle. Schank and Abelson (1977), Kolodner, Simpson and Sycara-Cyranski (1985), among others, have examined the applicability of developing automated systems for reasoning based upon previous experience.

Reasoning by analogy is a natural process. Analogical reasoning can occur in every situation in which people are required to make judgments and predictions. These situations may be highly technical ones or be of a more mundane nature. A very simple example of the use of analogical reasoning may be seen when someone buys or sells a home. The realtor sets a price for a property not by using a formal model and calculating all of the variables, but by choosing a comparable sale and adjusting the price on the basis of small differences between the two properties (such as an extra bathroom or a location on a corner lot). Engineers have traditionally made use of analogies in prediction and design, typically by looking for structural comparisons. Intelligence analysts also reason analogically. Previous cases influence interpretations of current events.

This concludes our brief overview of cognitive science research on inference that may be applicable to the cognitive engineering of advanced information and decision systems for intelligence. We now consider research findings that may be applicable to operations and subsequently, to facilitating the communication between intelligence and operations. We again caution the reader that our overview is small and selective. Our goal is not to survey all potentially applicable areas of research. Rather, our goal is to commence the process of mapping computer technology to cognitive processes.

3.3 Operational Decision Making

This section overviews the following areas of cognitive research, all of which are applicable to the option generation, evaluation, and selection processes inherent in operations:

- Bounded rationality,
- Prospect theory, and
- Cognitive heuristics involving decision (versus inference) processes.

3.3.1 Bounded Rationality - The concept of bounded rationality is attributed to Nobel laureate Herbert Simon (e.g., see 1955, 1979; also Hogarth, 1987, and March, 1978, for general discussions), who argued that humans lack both the knowledge and computational skill required to make decisions in a manner compatible with economic notions of rational behavior. In order to deal with human and task limitations or bounds, Simon argued that humans simplified decision problems so that they can address them in a "reasonable" if not economically "rational" manner. In particular, Simon's approach was to specify what the rational economic model required humans to know and do, and then ask how they could cope with the task given their limited knowledge, memory, and processing capabilities. Therefore, the approach is conceptually similar to that described above for cognitive heuristics research.

3.3.1.1 Task Characteristics - The rational model's requirements are illustrated by the concept of a payoff matrix, an example of which is presented in Table 3.2. The rows of the matrix represent all of the different alternatives available to the decision maker for solving a particular decision problem. The columns represent all of the different states of the world, as defined by future events, that could affect the attractiveness of the alternatives. The $p_1 \ldots p_k$ values represent the probabilities for each state of the world. The cell entries in the matrix indicate the value (or "utility") of the outcome or "payoff" for each combination of alternatives and states of the world. Each outcome is presumed to represent a cumulative payoff comprised of perceived advantages and disadvantages on multiple criteria of varying importance to the decision-maker. Finally, the rational decision maker is required to select the alternative that maximizes expected utility, which is calculated for each alternative by first multiplying the values for the outcomes and the probabilities for the states of nature, and then summing the products.

	STATES OF NATURE			
Alternatives	$(p_1)S_1$	$(p_2)S_2$	●●●●●	$(p_k)S_k$
A	a_1	a_2	●●●●●	a_k
B	b_1	b_2	●●●●●	b_k
●	●	●	●●●●●	●
●	●	●	●●●●●	●
●	●	●	●●●●●	●
N	n_1	n_2	●●●●●	n_k

Table 3.2: Rational Economic Model in a Payoff Matrix

3.3.1.2 Important Findings - The rational economic model clearly assumes that the decision-maker has extensive knowledge and impressive unaided, computational power. In addition to Simon's research, substantial psychological research (e.g., see the reviews by Einhorn and Hogarth, 1981; Slovic, et al. 1977) indicates the inadequacy of these (and other) assumptions of the model. Therefore, how do we cope with the cognitive demands represented in the decision matrix? How does unaided human decision behavior remain purposeful and "reasonable" given the dynamic nature of the environment and our inherent information acquisition and processing limitations?

Simon suggested three simplification strategies. First, people simplify the decision problem by only considering a small number of alternatives and states of nature at a time. Second, people simplify the evaluation problem by setting aspiration (or acceptability) levels on the outcomes; and, third, people simplify the selection problem by choosing the first alternative that satisfies the aspiration level. In other words, people do not optimize (i.e., choose the best of all possible alternatives), but satisfice (i.e., choose the first satisfactory alternative). In this way, people can reduce information acquisition and processing demands and still act in a purposeful, reasonable manner.

The strategies in Simon's theory of bounded rationality are not, however, without their costs. First, as Hogarth (1987) has pointed out, research on creativity suggests that one of the biggest deficiences in human decision behavior is our failure to sufficiently imagine the range of alternatives at our disposal and the various events that could occur in the future. Second, aspiration levels may be unrealistically high or low. The former could well result not only in the elimination of potentially good alternatives early in the decision process, but the acceptance of a relatively inferior alternative later in the process because subsequent events have forced us to lower our aspiration level. In contrast, unrealistically low aspiration levels and the satisficing strategy may well result in the acceptance of relatively poor alternatives early in the decision process.

It is important to emphasize that bounded rationality represents a descriptive theory of human decision behavior. It does not specify how people should make decisions but, rather, presents a theoretical perspective on how people do make decisions given a complex, dynamic environment and limited information acquisition and processing capabilities. Moreover, subsequent research indicates that people are quite capable of using other, in some cases more complex strategies than the three proposed by Simon. In contrast, the rational economic model is now typically seen as a prescriptive not descriptive theory of decision making. It is typically referred to as decision theory (or expected utility theory or subjective expective utility theory), and it provides an axiomatic basis for specifying how people should make decisions, as represented in the decision matrix, given that they accept certain logically defined principles of behavior. Moreover, analytical procedures called decision analysis and various support systems have been developed to help people implement decision theory. Although there are many books on decision theory and decision analysis, the texts by Brown et al. (1974), Watson and Buede (1987), von Winterfeldt and Edwards (1986), among others, represent good introductions.

3.3.2 Prospect Theory - Kahneman and Tversky (1979) have proposed "prospect theory" as a descriptive theory of choice under uncertainty. Like Simon's bounded rationality, prospect theory is juxtaposed against expected utility theory. What is particularly important about prospect theory for cognitive engineering is that it distinguishes between two phases in the choice process. The first phase is called editing; its purpose is to simplify the presented information in the choice setting in order to enhance decision making. The second phase is called evaluation; its purpose is to analyze the edited choices (i.e., prospects) so that the decision maker can select the one with the highest personal value. What Kahneman and Tversky have shown is that the way the prospect information is presented to people significantly affects how they edit and evaluate it such that information that should result in the same choice from the perspective of expected utility theory actually results in different choices.

3.3.2.1 Task Characteristics - Subjects in the experiments used to generate prospect theory are faced with simple prospects (or choices) that have a correct answer based on expected utility theory. For example, the following prospect is taken from Kahneman and Tversky (1979):

Choice A: ($4000 with p = .8; $0 with p = .2) or
Choice B: ($3000 for sure; that is, p = 1.0)

The majority of participants will select Choice B. Yet, Choice A has the greater expected value; that is, $4000 x .8 = 3200). Now, consider the following prospect:

Choice C: (-$4000 with p = .8; $0 with p= .2) or
Choice D: (-$3000 for sure; that is, p = 1.0).

The only change in the second prospect is that the sign has been reversed so that one is now considering losses, not gains. However, in this case, the majority of the subjects picked Choice C. That is, they would now be willing to take a gamble instead of losing $4000 with a probability of .8 instead of taking a sure loss of $3000. Again, they have selected the choice with the lower expected value.

Numerous other examples have been used to demonstrate that people's choices are not always consistent with expected utility theory. More generally, Hogarth (1987) has pointed-out that, by and large, the research has been directed toward testing the general principles of decision theory, which assume that people express consistent beliefs in the form of predictive judgments and consistent preferences in the form of evaluative judgments. The principles regarding preferences include transitivity (if A is prefered to B and B to C, then A should be preferred to C); dominance (if alternative A is preferred to alternative B on all dimensions, then there should be no way that, in total, B should be preferred to A); and invariance (one's preference for two options should not be affected by the way one presents information about them). "Perhaps the most striking feature of these principles is that, whereas they are accepted as reasonable when stated in the abstract form, their implications are often violated in actual choices" (Hogarth, 1987). Prospect theory provides some insights as to why this occurs.

3.3.2.2 Important Findings - Kahneman and Tversky (1979) have hypothesized that the editing and evaluation phases that people use to make decisions under risk have distinct operations. For example, Kahneman and Tversky proposed six editing operations: coding, combination, segregation, cancellation, simplification, and dominance. With respect to "coding," people perceive outcomes as gains or losses from a referent point rather than final states (e.g., of wealth). The current position is usually considered as the referent point. However, the location of the reference point and, in turn, the coding of outcomes as gains or losses, can be affected by how the prospects are formulated, as well as by the person's expectations. This coding is particularly important in framing decisions because, as the example presented above indicates, people tend to be risk adverse when considering gains and risk seeking when considering losses, particularly if one of the prospects is certain. The research by Kahneman and Tversky (1979, 1981) and others (e.g., McNeil et al., 1982; Payne et al., 1980) indicates that (1) reference points can be manipulated, and (2) losses loom much larger than gains.

The other five editing operations are used to simplify the choice. For example, a prospect can be simplified by combining the probabilities associated with the same outcomes. However, this can sometimes result in inappropriate problem representations because, as the cognitive heuristics research indicates, people do not always implement probability theory correctly. Similarly, people appear to segregate the riskless from the riskless components of prospects (called segregation) and cancel-out aspects shared in common between prospects (called cancellation). Although quite reasonable operations for simplifying complex problems, they can result in different choices simply depending on how the problem is framed (e.g., see Hogarth, 1987).

Kahneman and Tversky have proposed two operations in the evaluation phase of prospect theory: a value function, which is analogous to the utility function in expected utility theory, and a decision weight function, which indicates the subjective importance of the probabilities in prospects. The value function codes the psychological value of gains and losses from the "coded" reference point. The function is steeper for losses than for gains, consistent with the observation that losses loom much larger than gains. We tried to capture this with the reversal illustrated in the above example. Moreover, outcomes near the reference point are given more value per unit change than units farther from the reference point. For example, assuming a reference point of $0 and a range from $0 to $1600, a $1 difference between $0 and $10 typically has more psychological value than a $1 difference between $1550 and $1560.

The decision weight function in prospect theory links the probabilities in prospects to choice. In particular, the function represents the finding that people seem to overweight low probabilities and underweight high probabilities when compared to expected utility theory. Interestingly, prospect theory only defines the decision weight function between probabilities of 0 and 1. These two probabilities are given weights of 0 and 1, respectively, indicating the special effect of certainty. We also tried to capture this in our example.

3.3.3 Cognitive Heuristics - We now briefly consider cognitive heuristics and biases that affect option evaluation, not inference. Of course, many of the biases considered earlier in this review, particularly those affecting data presentation, can affect option evaluation as well as inference. However, our emphasis here is on operations instead of intelligence;

consequently, we will only consider biases that are predominantly oriented to option evaluation, not inference. (Cognitive biases that may affect both intelligence and operations are listed in Table 3.3 for purposes of closure.)

Cognitive biases affecting evaluation more than inference are principally found in the information processing stages of "output" and "feedback" (Hogarth, 1987). Considering the output stage first, we previously noted that the manner in which a person is required to respond can induce bias. For example, the relative preference for gambles can be reversed when people are asked to express choices in different ways. Moreover, such preference reversals have even been demonstrated in a Las Vegas gambling casino (Lichtenstein and Slovic, 1973) and, more recently, with computer-based information displays (Johnson, et al., 1988). In addition, people engage in wishful thinking. That is, contrary to expected utility theory, people's beliefs and preferences are not always independent.

As we also previously noted, feedback concerning the outcomes of our judgment can induce bias too. This bias might occur either as a result of (1) how we interpret outcomes or (2) the nature of the environment itself. For example, regarding the former, people have a tendency to attribute success to their skill and failure to either chance or the situation with which they were faced. Ironically, people tend to attribute other people's failure's to personality traits, not the situation. Such success/failure

- **In "Information Acquisition"**
  - Availability of Instances in Memory
  - Selective Perception of Information
  - Focus on Confirming (vs. Disconfirming) Information
  - Vividness (vs. Abstractness) of Information
  - Data Presentation
    - **Order Effects (e.g., Info. Presented First or Last)**
    - **Intact Displays (vs. Sequential Presentation of Info.)**
    - **Seemingly Logical Displays**
- **In "Information Processing"**
  - Representativeness Heuristic
  - Anchoring and Adjustment Heuristic
  - Inconsistency
  - Task Characteristics Affecting Processes
    - **Time Pressure**
    - **Social Pressure**
    - **Information Overload**
- **In "Output"**
  - Question Format: Preference Reversals
  - Wishful Thinking
- **In "Feedback"**
  - Task Characteristics ("Outcome Irrelevant Learning Structures")
  - Logical Fallacies in Recall
  - Hindsight Bias
  - Success/Failure Attributions

Table 3.3: Cognitive Heuristics and Biases Relevant to Operations

attributions appear to be part of a more "fundamental attribution error" (e.g., see Nisbett and Ross, 1980) where people tend "..to ignore powerful situational determinants of behavior." Considering the latter, outcomes often yield inaccurate or incomplete information concerning predictive relations. As Einhorn and Hogarth (1978) have discussed in detail, in most decision making settings one can seldom (if ever) learn how good one's judgment is (e.g., as operationalized statistically by a correlation) because our decisions and subsequent actions make it impossible to know what the effect of other decisions and actions would have been.

This concludes our brief overview of cognitive science research on option generation, evaluation, and selection that may be applicable to the cognitive engineering of advanced information and decision systems for operations. We now consider research findings that may be applicable to facilitating communication of cognitive processes between intelligence and operations. In particular, we take the perspective that strategic decision-making can be facilitated by using computer technology to represent and communicate the cognitive processes of intelligence and operations personnel.

3.4 Toward Facilitating the Communication of Cognitive Processes Between Intelligence and Operations

This section of the review has three subsections. First, we present three decision making paradigms, including one explicitly developed to represent military decision-making, that incorporates situation assessment and subsequent decision-making as part of decision-makers' problem-solving behavior. These paradigms provide theoretical support for the importance of trying to improve the communication of cognitive processes between intelligence and operations. Second, we present some findings from problem-solving research indicating a strong relationship between problem definition (i.e., situation assessment) and option generation, evaluation, and selection. This research provides empirical support for trying to improve the communication of cognitive processes. Third, we overview some SJT research demonstrating that computer technology can, in fact, be successfully employed to communicate inference processes and, thus, improve interpersonal understanding and decision-making. This position is also supported by the use of computer technology to support group decision-making in decision conferences, an area of applied research that will also be briefly considered.

3.4.1 Decision-Making Paradigms - Simon (1960) has used three categories to describe decision making activities: intelligence, design, and choice. "Intelligence" refers to the activities inherent in problem identification, definition, and diagnosis. It is, as Huber (1980) points out, the conscious process of trying to explore the problem in an effort to find-out the current state of affairs, and why it does not match our desires. "Design" refers to those activities inherent in generating alternative solutions or options to solving the problem. It involves "... identifying items or actions that could reduce or eliminate the difference between the actual situation and the desired situation" (Huber, 1980). "Choice" refers to those activities inherent in evaluating and selecting from the alternatives. It is the action that most people think of when one makes a decision.

As Huber (1980) and others (e.g., Andriole, 1989b; Sage, 1986; Wohl, 1981) have pointed-out, decision-making activities are a subset of problem-solving activities. For example, the first three steps in Huber's five-step problem-solving paradigm are those activities that require (1) problem identification, definition, and diagnosis; (2) the generation of alternative solutions: and (3) evaluation and choice among alternatives. These steps are conceptually identical to Simon's decision-making categories. The fourth step in Huber's paradigm involves activities inherent in implementing the chosen alternative. The fifth step involves activities inherent in monitoring the implemented action in an effort "... to see that what actually happens is what was intended to happen" (Huber, 1980). If there is a significant mismatch between the actual and desired state of affairs, one returns to step #1, exploring the problem.

Wohl (1981) has presented a paradigm within the context of military tactical decision-making that expands on the activities in Simon's and Huber's frameworks. The anatomy of Wohl's SHOR (Stimulus - Hypothesis - Option - Response) paradigm is presented in Figure 3.2. Intelligence activities are differentiated between the Stimulus and Hypothesis elements of the SHOR paradigm. In particular, the Stimulus element is comprised of data collection, correlation, aggregation, and recall activities; it naturally includes many of the activities also included in Huber's last problem-solving stage, that of monitoring the situation. The Hypothesis element is that aspect of intelligence that involves creating alternative hypotheses to explain the possible cause(s) of the problem, evaluating the adequacy of each hypothesis, and selecting one or more hypotheses as the most likely cause(s) of the data. It is important to note that more than one hypothesis can be appropriately selected either because of the uncertainty and/or ambiguity in the data (Daft and Lengel, 1986), or because there is more than one cause of the problem (Hammond, 1966). Regardless, on the basis of the selected hypothesis (or hypotheses), the decision maker (and senior associates) generate options for solving the problem. The Option element explicitly differentiates between option creation, evaluation, and selection activities. Finally, on the basis of the selected option, the decision-maker (or decision-making team) takes action, which includes the planning, organization, and execution of a Response to the problem, analogous to the fourth step in Huber's problem solving framework. (Note: Wohl's distinction between the Hypothesis and Option components is

GENERIC ELEMENTS	FUNCTIONS REQUIRED	INFORMATION PROCESSED
Stimulus (Data) **S**	**Gather/Detect**	**Capabilities, Doctrine; Position, Velocity, Type; Mass, Momentum, Inertia; Relevance and Trustworthiness of Data**
	Filter/Correlate	
	Aggregate/Display	
	Store/Recall	
Hypothesis (Perception Alternatives) **H**	**Create**	**Commander's Catechism:** Where am I? Where is the enemy? What is he doing? How can I thwart him? How can I do him in? Am I in balance? How long will it take me to...? How long will it take him to...? How will it look in...hours? What is the most important thing to do right now? How do I get it done?
	Evaluate	
	Select	
Option (Response Alternatives) **O**	**Create**	
	Evaluate	
	Select	
Response (Action) **R**	**Plan**	**The Air Tasking Order** Who What When Where How How Much *The near-real-time modification/update*
	Organize	
	Execute	

Figure 3.2: Wohl's SHOR Model

analogous to Hogarth's (1987) general distinction between prediction and evaluation.)

The Option component follows the Hypothesis component in all three paradigms. Options are not generated in a vacuum. Rather, they are generated in response to our hypotheses with regard to what is happening to us, why it is happening, and its implications, though this does not imply that every option generation situation requires a causal focus. Rather, the paradigms imply that in many situations a causal focus is essential to good option generation and subsequent decision making. This is clearly the case in a military context. According to Fitzgerald and Grossman (1987), "The real objective of winning the information war is to enable a decisionmaker, from the warfare commander on down, to perceive his enemy's intentions, to assess his options accurately and to choose the optimal course of action" (underlining theirs). The purposeful, goal-oriented behavior of commanders is no different from that of executives or the man in the street (Beach and Mitchell, 1987) or, for that matter, the rat in the runway (Tolman and Brunswik, 1935). We now turn to the problem-solving literature for empirical support indicating a strong relationship between problem definition (i.e., situation assessment) and option generation, evaluation, and selection.

3.4.2 Problem Solving Research - Direct support for the premise that situation assessment affects option generation and evaluation comes from the problem-solving research using protocol analysis. According to Newell and Simon (1972), "this pattern of symptom-remedy has by now become familiar to us in a variety of contexts. It is means-ends analysis, for the moves generated are relevant to 'remedying' the feature that serves as symptom."

3.4.2.1 Task Characteristics - The typical procedural approach in problem-solving research is to ask people to talk out loud as they attempt to solve a provided problem. Numerous different types of problems have been studied (e.g., chess, programming, physics, logic, cryptarithmetic) as well as alternative representations of the same problem structure, called "problem isomorphs" by Simon and Hayes (1976). The reason for having people talk out loud is to trace their problem-solving behavior as it occurs; thus, it is not susceptible to logical fallacies in recall or the hindsight bias (e.g., see Ericsson and Simon, 1984). The audio tapes are transcribed for subsequent analysis, which is why the approach is often referred to as protocol analysis. The typical protocol analysis has been used to infer decision processes by constructing problem behavior graphs (Newell and Simon, 1972), which resemble flowcharts composed of nodes (knowledge states) connected by arrows (process operations).

3.4.2.2 Important Findings - Problem-solving research is vast and has generated numerous important findings. Of importance here, however, is the identified strong relationship between the Hypothesis and Option components in Wohl (1981) paradigm. For example, in their review and discussion of de Groot's (1965, 1966) process-tracing analysis of novice and expert chess players, Newell and Simon point out that, " ... during the first moments -- for example, 15 seconds more or less -- during which he is exposed to a new position, a skilled human player does not appear to engage in a search of move sequences. Instead, he appears to be occupied with perceiving the essential properties of the position . . . which will suggest possible moves to him and help him to anticipate the consequences. He appears to be gathering information about the problem, rather than seeking an actual solution." In short, the human problem-solver is testing hypotheses to explain the data or "defining the situation" (p. 761). Once he has done so, possible solutions are generated and evaluated, apparently in depth. Again, to quote Newell and Simon, "humans playing chess spend much of their time searching in the game tree for the consequences of the moves they are considering . . . The search is highly selective, attending to only a few of the multitude of possible consequences." People do not search for a complete list of options, but rather, a quality one based on their assessment of the situation and their goals.

From the perspective of previous option generation research, what is particularly interesting about the problem-solving research reviewed by Newell and Simon (1972) and Ericsson and Simon (1984) is the finding that expertise is related to a person's ability to generate correct problem representations, that is, the correct hypotheses or causes for the observed data. Continuing with the chess example, de Groot (1966) demonstrated that chess grandmasters were significantly better able than good, but weaker players to reproduce a chess board after an extremely brief exposure (3-7 seconds). However, this capability was totally dependent on the meaningfulness of the chess board; the superiority vanished if the chess pieces were randomly distributed on the board. Chase and Simon (1973) replicated and extended this finding. Better players are better able to infer causes (i.e., possible opponent strategies), but only for meaningful data.

More recently, a process-tracing study by Isenberg (1986) found that action plan effectiveness was directly related to the amount of analogical reasoning performed by 12 general managers solving a Harvard Business School case. Bouwman (1984), who analyzed the protocols for three Certified Public Accountants and five graduate students evaluating financial cases, found that " . . . experts regularly summarize the results, and formulate hypotheses. Such 'reasoning' phases further direct the decision making process." A longitudinal, process-tracing study by Schweiger, et al. (1985), which used the UCLA Executive Decision Game as the task, found that subjects who engaged in causal reasoning performed significantly better than those who did not. In Cohen's (1987) study of Air Force pilots, he found that "the pilot who adopts a worst case strategy is not really suppressing uncertainty; he knows perfectly well that other outcomes are possible. Rather, he is adopting assumptions which enable him to focus on a concrete, causally modeled state of affairs as opposed to an abstract, non-realizable average or expected value. He may subsequently wish to undo these particular asumptions and explore another set, which implies another concrete, causally modeled state of affairs."

In sum, the problem-solving literature strongly suggests that a causal focus has a significant effect on decision behavior and quality. Option generation, evaluation, and selection is a direct function of situation assessment. From the perspective of strategic decision-making, the quality of operations is dependent on understanding the inference processes in intelligence.

Effective intelligence is, in turn, dependent on understanding what type of information is important, and when it needs to be received, by operations personnel. (See Adelman and Thompson, 1989, for the description of an approach to measuring the performance of tactical intelligence units from the users' perspective.) SJT research has shown that computer technology can be effectively used to improve the interpersonal understanding of cognitive processes and, in turn, group decision-making.

3.4.3 Social Judgment Theory - Considerable SJT research has focused on interpersonal learning where two or more persons work together to perform a task. Figure 3.3 presents the "triple system case" where one system is the task and the other two systems represent the cognitive systems of two cooperating group members. As can be seen, the triple system case (Figure 3.3) is a natural extension of the double system case (Figure 3.1). The Lens Model Equation (LME) can be used to assess the task performance parameters of each person and, more importantly here, the agreement between them. That is, r_a can be used to represent the overall level of agreement in the judgments of the two persons. G can be used to represent the similarity in the judgment processes of the two persons. Rs_1 and Rs_2 can be used to represent the cognitive control of each person's judgmental process.

Consequently, low agreement in a cooperative decision-making task can be the result of dissimilar cognitive process and/or low cognitive control. Dissimilar cognitive processes are typically the result of poor interpersonal understanding of how each person is combining information to make a judgment. Cognitive technology can enhance this understanding, as well as cognitive control, and hence agreement and subsequent performance. Before considering this important finding in more detail, we briefly overview the characteristics of SJT tasks studying interpersonal understanding and agreement.

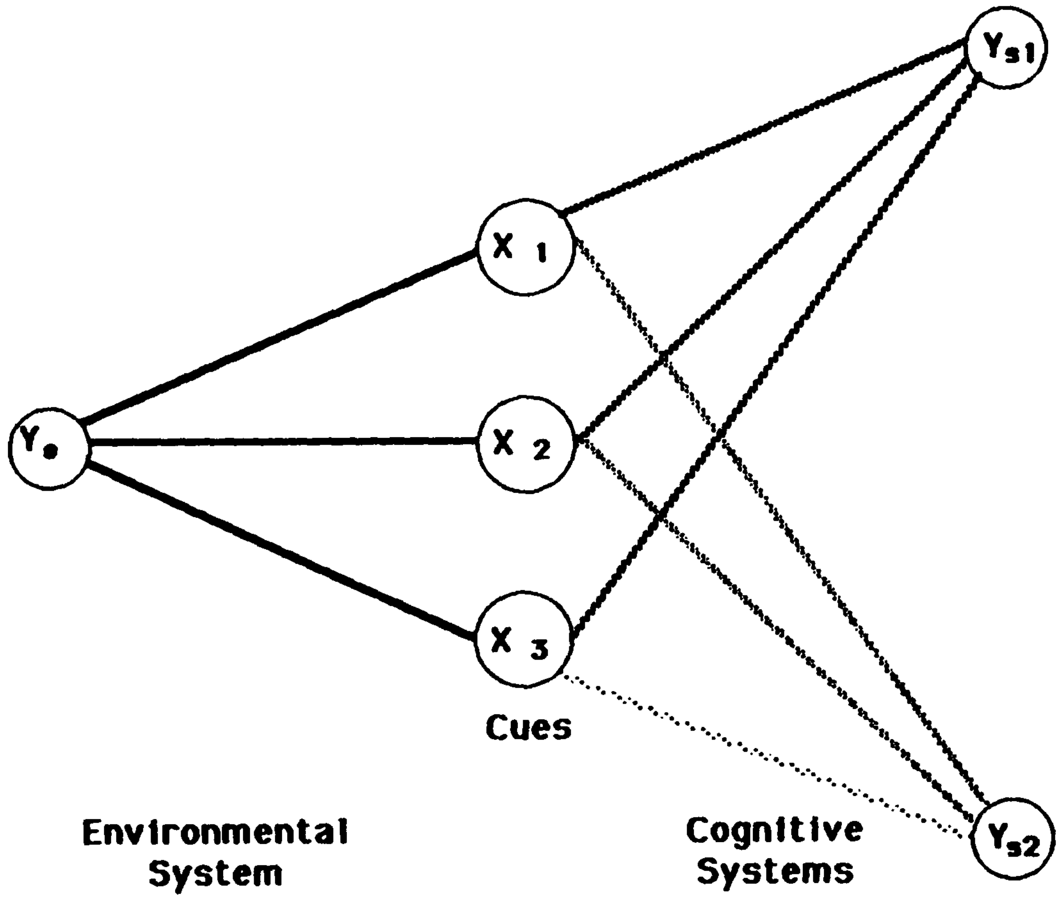


Figure 3.3: The Lens Model Representing the Task and Two Persons

3.4.3.1 Task Characteristics - As discussed earlier in this review, cognitive technology has been used to improve understanding and communication in both the laboratory (e.g., see Hammond and Brehmer, 1973) and in real world applications (e.g., see Hammond and Adelman, 1976; Hammond and Grassia, 1985). In this section, we first overview the characteristics of tasks used in laboratory research and then, those used in real applications.

Brehmer (1976) and Rohrbaugh (1988) have reviewed a host of laboratory studies evaluating the potential value of cognitive technology to improving understanding and reducing conflict. The basic approach is to first separately train members of the eventual decision-making group to have different strategies, called "policies," for making inferences and/or decisions. For example, Person #1 may be trained to place a high relative weight and a negative linear function on Cue A, but no weight on Cue B when making judgments. In contrast, Person #2 may be trained to put no weight on Cue A, but a high relative weight (with an inverted-U shaped function form) on Cue B. Then, after each person is trained to a level of proficiency in making judgments their way, the persons are brought together to make group judgments.

In the group task, the task side of the lens model is structured so that each person must modify his judgment policy by learning from the other person in order for the group to perform well. Continuing with the above example, the group task may require that equal weight be placed on Cues A and B; that a negative linear function form be used to relate values on Cue A to levels of Desirability; and that an inverted U-shaped function form be used to relate values on Cue B to Desirability. Control groups would have to learn to make group judgments by talking with each other and getting outcome feedback; that is, by the typical approach. The cognitive technology (or "cognitive feedback") group would be shown each person's judgment policy; that is, they would receive in both pictorial and textual form a description of how each person combines information to make a judgment.

The approach is quite similar in real world applications, except there is no need to train group members to have their own judgment policy; they come with one. The first step, therefore, is to uncover them. This is accomplished by having the group members identify the cues that are important to the problem. Once consensus is reached on the cues, each group member is asked to evaluate a set of cases comprised of different values on the cues. These cases may be real ones (if there are not excessively high correlations between cues) or hypothetical ones that represent real cases if a sufficient number of the latter are not available. The values on the cues represent the values on the independent variables in a multiple regression equation. The judgments of the group members represent the dependent variables. Each group member's judgments are regressed on the independent variable values in order to obtain a "best fitting" model that represents his judgment strategy for combining cue information into a judgment. With the use of software designed for personal computers (Milter and Rohrbaugh, 1988), each person can make his judgments on-line and be immediately shown the model representing his judgment policy. If aspects of the model (e.g., relative weights, function forms, or combinational rules) are found unacceptable, changes can be made on-line. This new policy can then be applied to the cases so that the person can evaluate its implications. The initial stage is concluded when each group member has a model that he thinks accurately represents his policy for making judgments.

The cognitive feedback stage can proceed in a number of different ways, but it typically follows the approach used in the laboratory research. Group members are first shown their judgment policies so that they can compare their similarities and differences. Then they are shown how the different policies result in different judgments for specific cases so that group members better understand the implications of the different positions. Third, the group members try to define a consensus strategy for making future judgments. This group policy is then applied to the previously evaluated (and sometimes new) cases so that the group members can evaluate its implications. Subsequent changes to the group policy can be made and the policy reapplied to the cases until a mutually acceptable position is reached.

It is important to note that there are many variations to the above approach. For example, with respect to strategic intelligence and operations, it may be inappropriate to focus on attaining a group policy. Cognitive technology could still be used, however, to externalize how intelligence and operations personnel are combining information to reach a judgment. Operations personnel could improve their understanding of how intelligence personnel are making their judgments without delegating any decision-making authority. Similarly, cognitive technology could be used to externalize what information operations personnel consider most important, and thereby help guide the intelligence collection process without usurping the managment responsibilities of intelligence personnel.

Second, it is important to emphasize that the SJT approach represents only one approach to modeling cognitive processes for the purposes of improving communication. In particular, decision analysis has been extensively used in a decision conferencing setting to facilitate group decision making (e.g., see Adelman, 1984; Weiss and Zwahlen, 1982). Decision analysis is comprised of a variety of different techniques for representing individuals' inferences and valuative judgments. Dating from its application by members of the Commander-in-Chief of the European Command (EUCOM), who were faced with the decision of whether or not to evacuate US nationals from Lebanon in 1976 (Kelly, Andriole, and Daly, 1981), decision analysis, and the software used to support it, have been effectively used to conduct decision conferences with decision making groups for almost fifteen years now. More recently, group decision support system technology has been proposed (e.g., see Andriole, et al., 1990); DeSanctis and Gallupe, 1987) as a more general approach to incorporating many different techniques for facilitating group decision making. In addition, artificial intelligence techniques have been used to capture expertise in the form of expert systems. However, one thing that SJT, decision analysis, group decision support systems, and artificial intelligence all have in common is the importance of providing information about cognitive processes ("cognitive feedback") as a means of improving decision making. As such, they represent cognitive engineering approaches to improved group decision-making.

3.4.3.2 Important Findings - SJT research has led the way in demonstrating the importance of cognitive feedback to improving interpersonal understanding and group decision making. These findings are important to consider when designing computer technology to enhance group decision making. Reviews of the laboratory research can be found in Brehmer (1976) and Rohrbaugh (1988); reviews of applications can be found in Adelman (1988), Hammond and Grassia (1985), and Hammond, et al. (1977). Some of the important findings are considered, in turn.

First, interpersonal understanding is often made difficult simply by the nature of people's judgment policies. For example, people have great difficulty in learning another's policy if that person uses nonlinear function forms, complex rules for combining information, or has low cognitive control. In short, the same things that make it difficult for people to learn the complex inference tasks represented by the "environmental system" in the lens model, also make it difficult for us to learn about and understand one another.

Second, discussion is an ineffective medium for interpersonal understanding. First, we have poor self in-sight into how we make judgments. As Hammond (1976) points out, "... verbal representations of introspective reports of covert mental operations are poor representations because of the well-known inaccuracy of introspection; that is, despite the best of intentions, any introspection regarding the basis for a judgment may simply be an incorrect description of the cognitive activity that took place . . . [moreover,] persons making the introspection will not have the conceptual or technical ability required to describe their judgment processes completely; indeed they will not even know what a complete description should consist of."

Second, language, for all its beauty and versatility, is often an ambiguous medium for communication. As noted in the review of research on cognitive biases, Kent (1964) and Moore (1977) have shown that people attach very different meanings to the same expressions of uncertainty; Fischhoff, et al. (1980) and others have shown that the answer one gets depends on how one asks the question. Moreover, in addition to being ambiguous, Hammond and Boyle (1971) note that language is linear, " . . . linear in the sense that it generally conveys relationships singly and in sequence. Severe demands are thus made on the learner's ability to remember and to integrate sequentially presented relationships. Consequently, even if a verbal description of policy is accurate (which is unlikely, because of the quasi-rational nature of policy judgments; see Summers, Taliaferro & Fletcher, 1970) the listener is unlikely to be able to use effectively the information available to him (see Miller, Brehmer, & Hammond, [1971])."

Third, ambiguity in language is confounded by inconsistency in judgment. SJT research clearly shows that inconsistency in judgment (i.e., less than perfect cognitive control) is the typical state of affairs. Even if one can perfectly describe one's judgment policy, one cannot perfectly implement it. Focusing on outcome feedback (i.e., the other's judgments) versus cognitive feedback (i.e., the other's policy) is an ineffective form of learning. Moreover, inconsistency between the judgments one makes and the descriptions one gives often causes confusion and sometimes distrust. The problem is potentially compounded by logical fallacies in recall and the fundamental attribution bias of focusing on the person rather than the situation.

The third major SJT finding is that cognitive feedback improves interpersonal understanding and group decision-making. In particular, using computer technology to communicate cognitive processes addresses each of the above three limitations with language. First, by presenting a model to represent one's judgment policy one overcomes the lack of self insight. One can explicitly show people the relative importance they placed on the different pieces of information, the function forms relating values on each cue to their judgments, the combination rule that appeared to best predict their judgments, as well as measures of cognitive control. Second, this information can be presented pictorially; it does not have to (although it can) be presented mathematically. Different sizes, colors, graphs, etc. can be used to represent different cognitive processes. Third, these pictorial representations can be used to represent similarities and differences in the judgment policies of different persons.

For illustrative purposes, Figures 3.4 and 3.5 show how cognitive feedback was pictorially presented to union and managment negotiators in Balke, et al. (1972). Specifically, Figure 3.4 shows how the width of the lines in the lens model was used to represent the relative importance each negotiator placed on the four cues in the contract dispute. In addition, whether the lines were solid or hollow was used to represent positive and negative linear function forms, respectively. Figure 3.5 shows how graphics were used to represent differences in the function forms used by the negotiators. The representation of nonlinear functions is particularly important since these are so difficult to learn with just discussion and outcome feedback.

In closing this section it is important to emphasize the vast

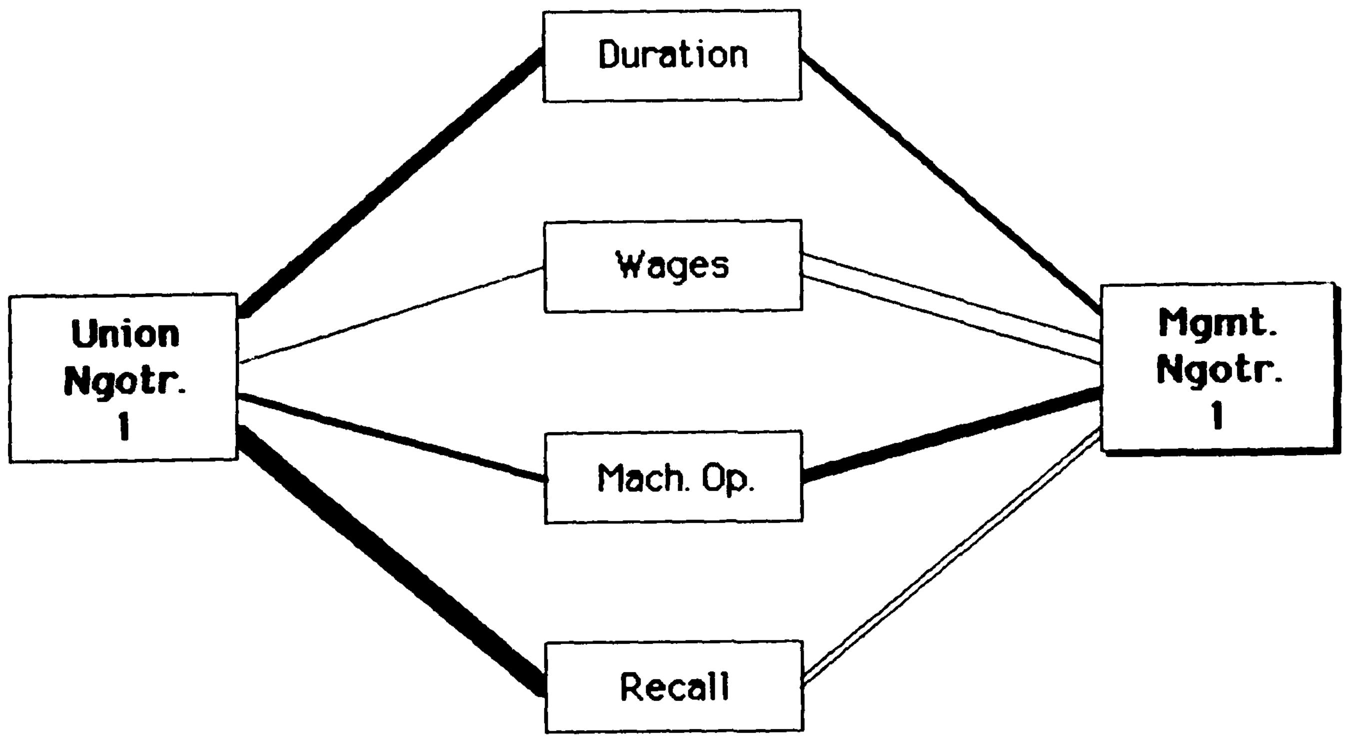
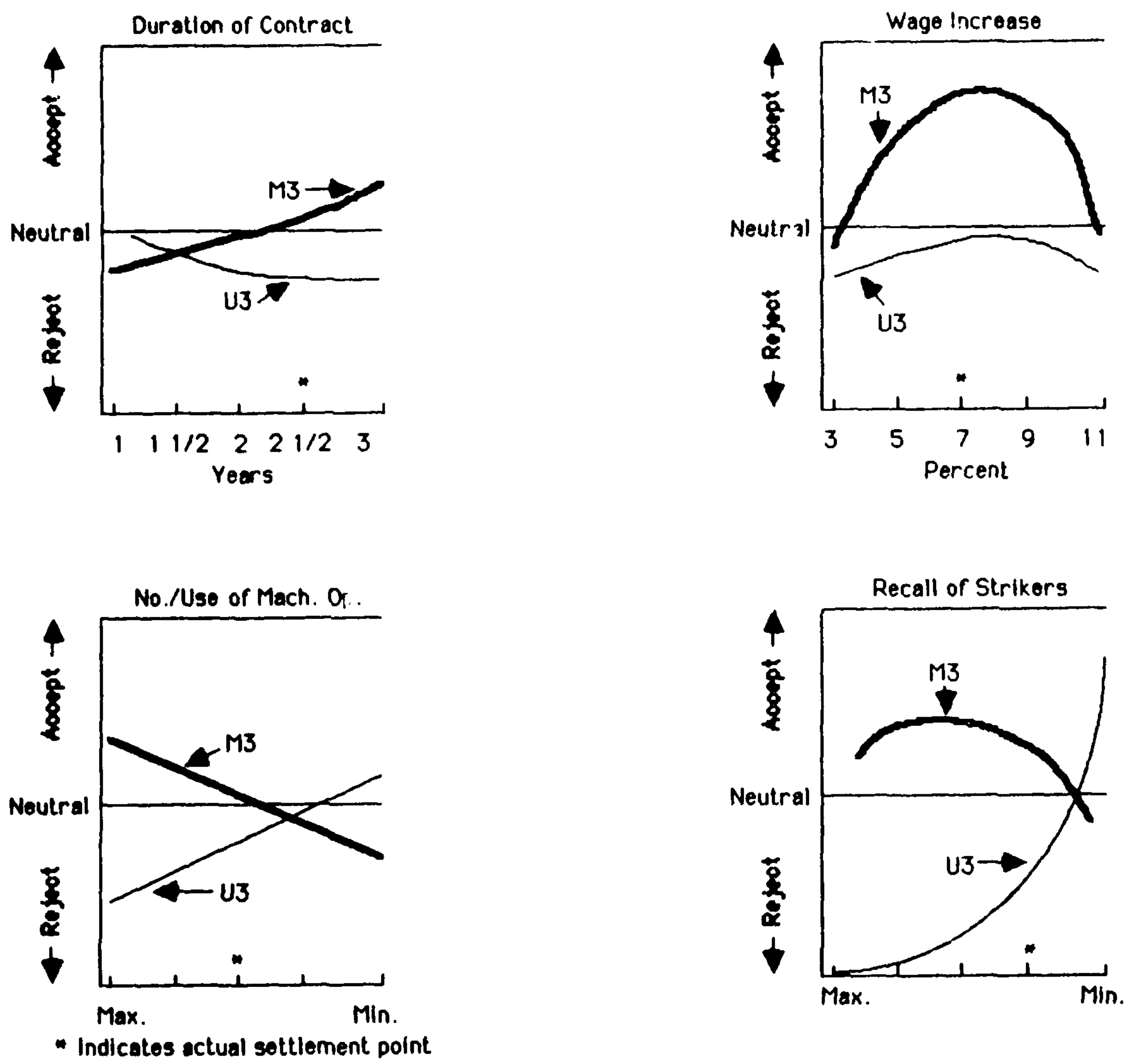


Figure 3.4: Graphic Relative Importances (Balke et al., 1972)



(Balke et al., 1972)

Figure 3.5: Function Forms/Factors Differences

cognitive engineering potential that now exists for developing computer systems that can enhance the interpersonal understanding of cognitive processes and, thereby, facilitate decision-making. Our understanding of how people make decisions and the analytical methods for supporting them have expanded greatly within the last ten to twenty years. At the same time, the capabilities of computer technology have, it seems, exploded while the costs have decreased. These capabilities now include hypermedia, multimedia, simulation, animation, cost-effective color, sound, multi-dimensionality, and true multi-tasking, among others. The task before us is to now learn how to tailor the use of these capabilities so as to enhance how people think, communicate, decide, and act.

4.0 ADVANCED INFORMATION TECHNOLOGY

4.1 Emerging Tools, Techniques and Models

The field of information technology -- broadly defined -- is evolving at a feverish pace. "New" technology can become obsolete in a few short years. The good news is that advanced information technology is providing a whole host of new applied opportunities. System concepts that were once thought to be beyond technical or financial reach are now realistic options. User requirements that call for animation, simulation, color and multimedia technology can often now be cost-effectively satisfied.

The hardware and software communities are providing newer and more powerful systems every quarter. The challenge to system designers is to assess this progress and select from the set of options those tools, models and techniques that fit the problem in question. Faster processors only make sense when speed is necessary. Elaborate interfaces should only be used when users require such communication and when the substantive domain is well served by the interface strategy. There is an important theme here: if a system will be used for word processing documents of fifty or less pages then Intel 80386 or Motorola 68030-based architectures are unnecessary. The distribution of computing power should correspond closely with intended and anticipated system use; our use of advanced information technology should be appropriate and cost-effective.

This section of the report examines some information technology that holds great promise for the design and development of interactive systems intended to support analytical problem-solving. The specific technology discussed here includes:

- Hypertext;
- Multimedia;
- Animation;
- Simulation;
- Interactive (color) graphics;
- Deductive inferential knowledge bases; and
- Adaptive and direct manipulation interfaces.

As suggested in Section 1.0, we believe that enormous leverage can be gained via the cognitive engineering of these tools and that -- by and large -- they have been grossly under-exploited by modern systems engineers.

4.2 Hypertext

Hypertext is several things to many people. Nelson (1987) defines it as " . . . a combination of natural language text with the computer's capacity for interactive branching, or dynamic display . . . of non-linear text." Yankelovich, et al. (1985) believe that hypertext permits " . . . authors or groups of authors to link information together, create paths through a corpus of related material, annotate existing texts, and create notes that point readers to either bibliographic data or the body of the referenced text"; while Casabianca (1988) sees it simply as "non-sequential reading and writing."

Hypertext is a software incarnated concept that permits near free-form browsing though complex data and knowledge bases. The simplest example is keyword searching through mounds of information about, say, the US Civil War. Keywords -- identified by the user via some direct manipulation of text embedded objects like Lincoln, Grant and Lee -- would lead the user directly to those pages and paragraphs that contained information about the individual men (or user specified combinations of the three). This kind of searching requires the data or knowledge base to be arranged in some sort of order. Frisse (1988a) suggests how simple structures, sequences, and hierarchies can be used to organize data, information and knowledge. Figure 4.1 (from Frisse [1988a]) illustrates the various relationships.

Figure 4.1 and the above definitions all suggest that hypertext is a management system that " . . . lets you connect . . . information using associative links" (Fiderio, 1988). A related perspective sees hypertext as an " . . . approach to information management in which data is stored in a network of nodes connected by links" (Smith and Weiss, 1988). Smith and Weiss, among others, define the concept broadly where nodes " . . . can contain text, graphics, audio, video, as well as source code or

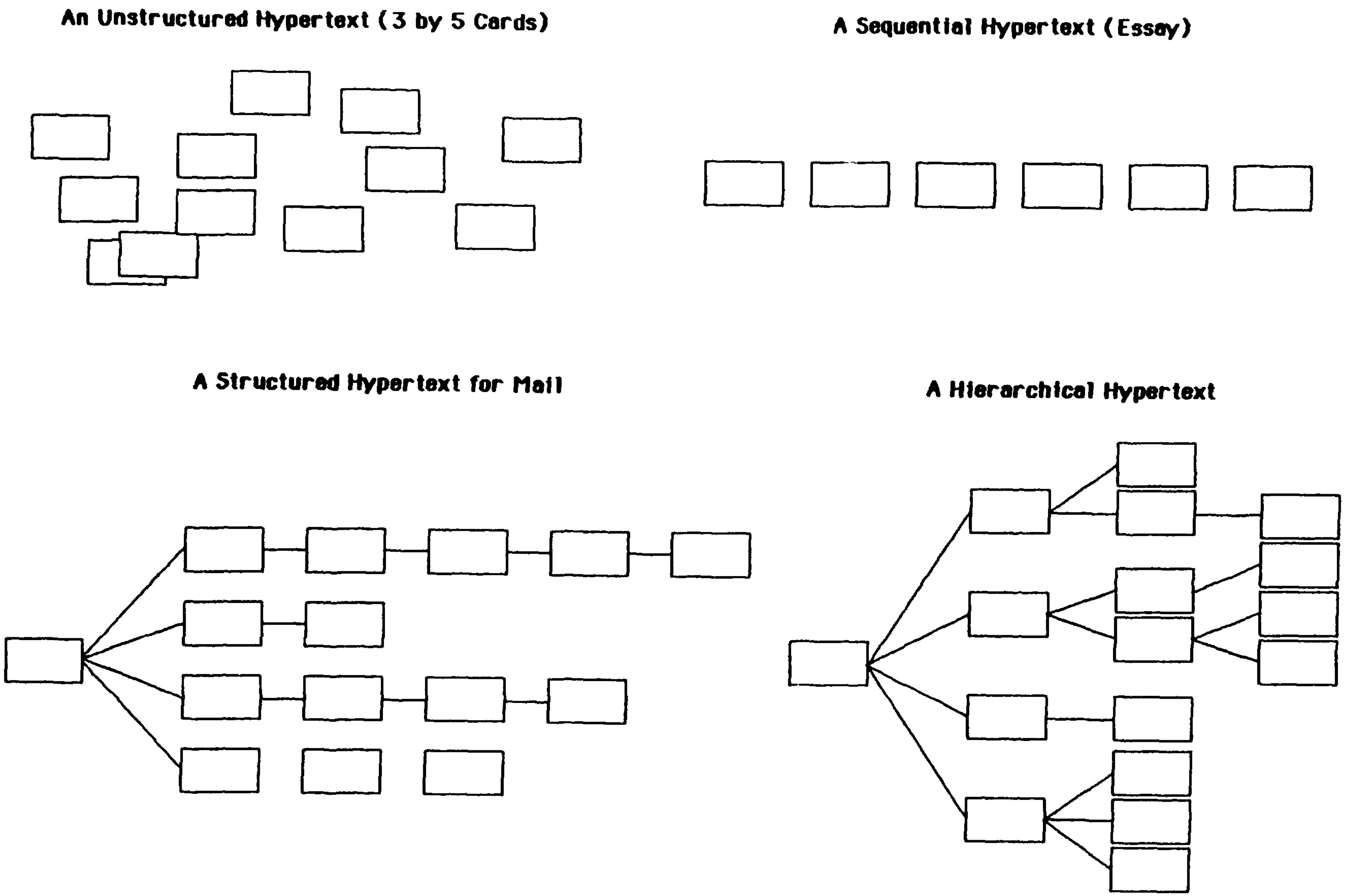


Figure 4.1: Hypertext Structures

other forms of data." In an impressive application of the (broadly defined) technology, Halasz (1988) begins the shift from hypertext to hypermedia via a set of notecards that permit browsing through a large data base of NATO missiles. Figure 4.2 illustrates what a notecard from the data base looks like, while Figures 4.3 and 4.4 suggest how users can browse through the data base.

Hypertext and hypermedia (which presumes more than textual data) provide systems designers with the capability to link users to large complex data, information and knowledge bases. At the most basic level, hypertext technology can be used to reduce the search time through compendia and encyclopedias (Frisse, 1988b). More sophisticated use can easily permit users to develop relationships, associations and hypotheses among objects and, as a result, conduct complicated on-line analyses.

There are currently a number of vendors that provide hypertext (and hypermedia) applications software; there are just as many that will build a custom hypertext-based front-end to your data or knowledge base. The technology has arrived in concept and application; it is now possible to implement hypertext and hypermedia systems on low-end microcomputers. In fact, Apple Computer, Inc. has been giving away its Hypercard system for several years now.

Hypertext and hypermedia represent capabilities that can be applied as stand-alone solutions to data management problems or

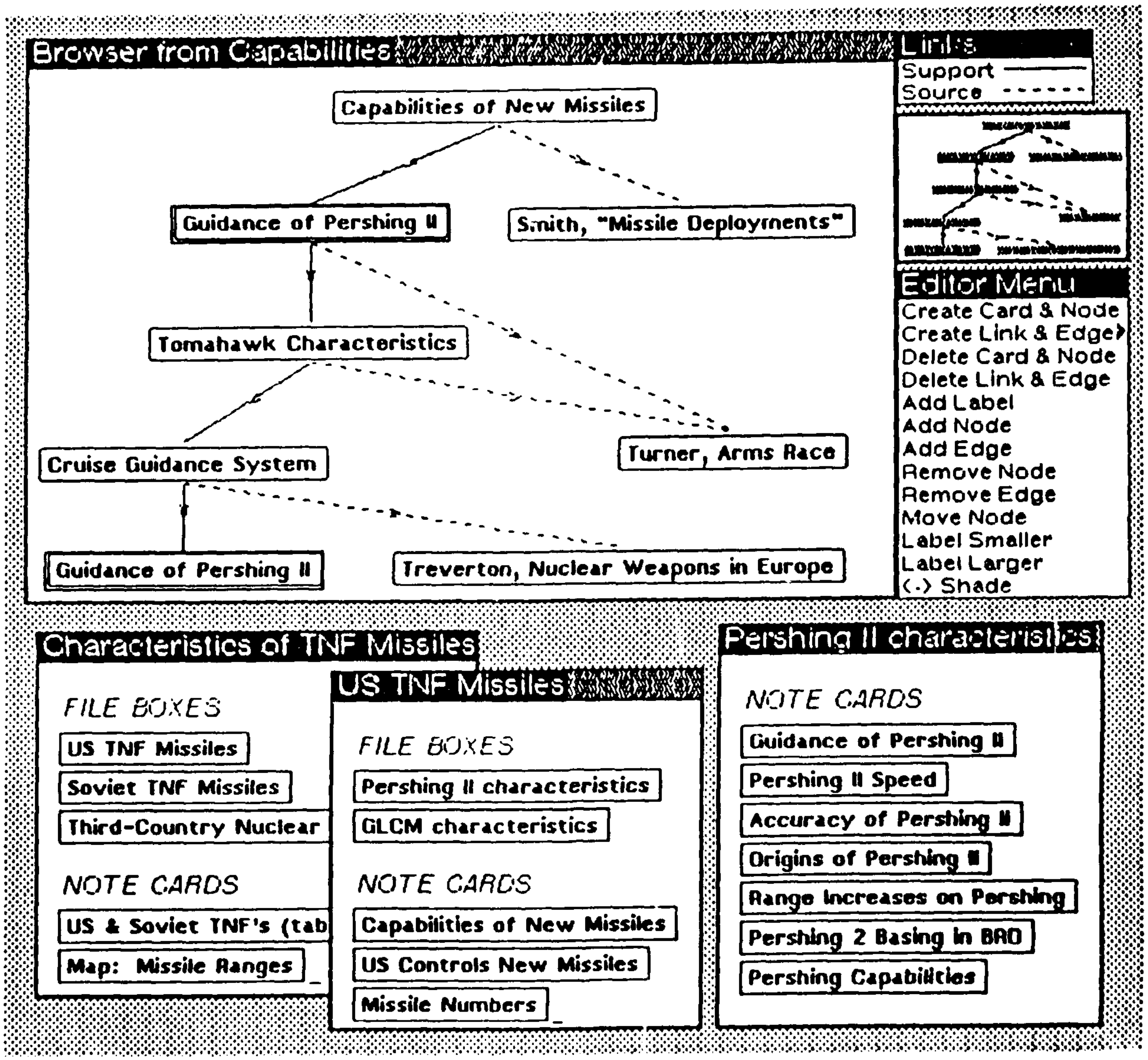


Figure 4.2: Hypertext Notecard: 1

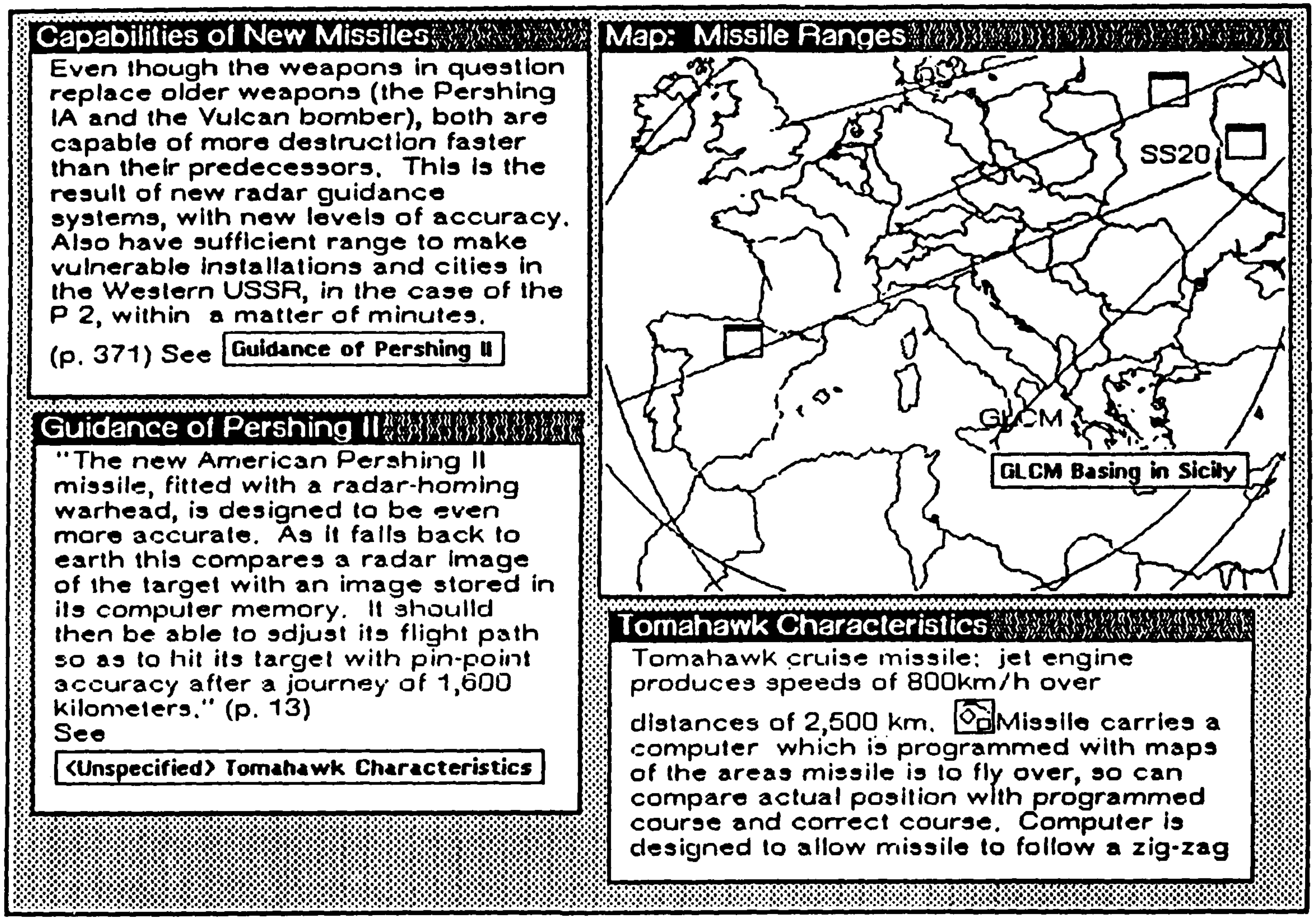


Figure 4.3: Hypertext Notecard: 2

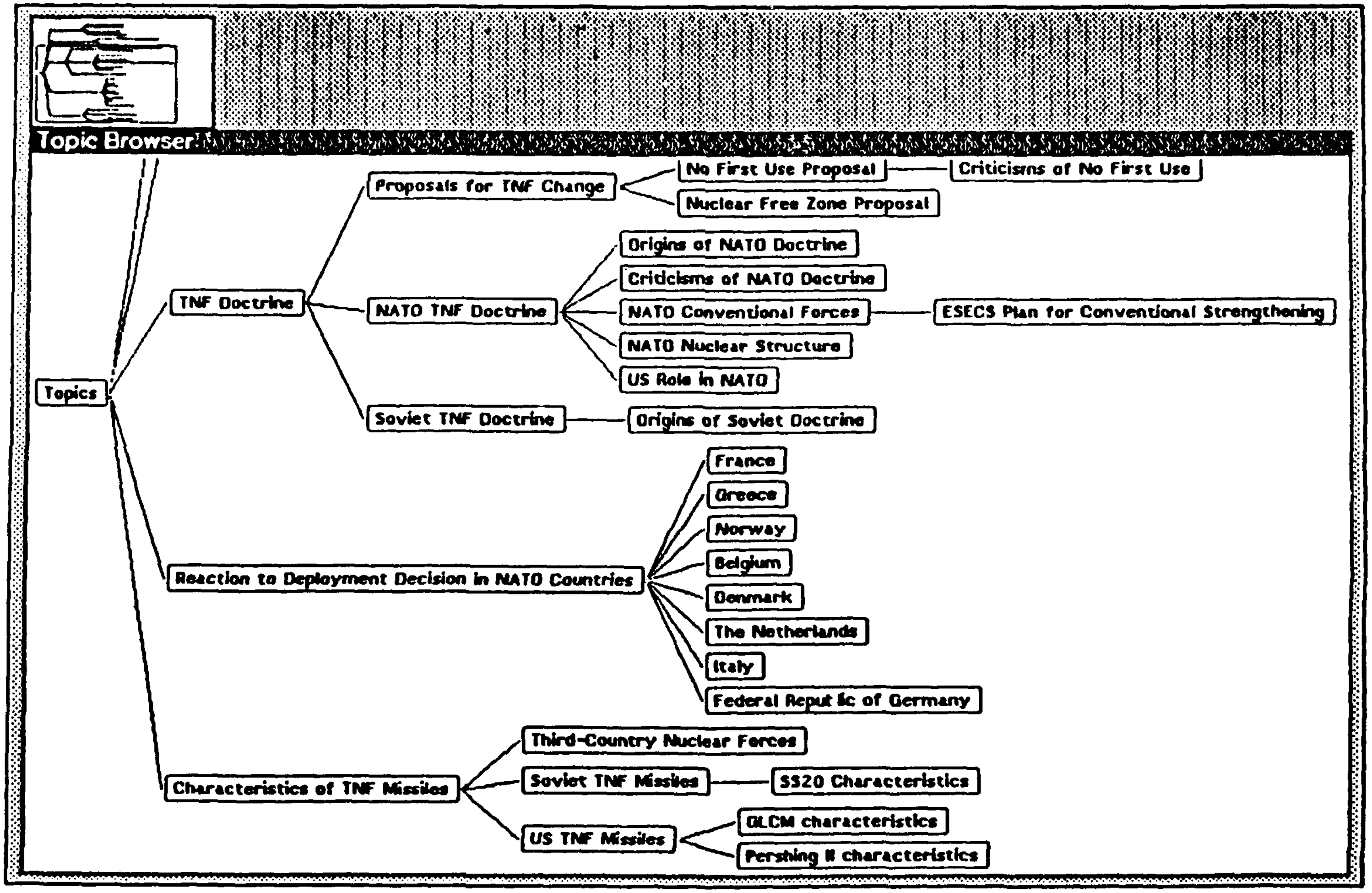


Figure 4.4: Hypertext Notecard: 3

as embedded solutions to larger analytical problems. Hypertext is a generic technology that can be applied to a variety of problems. It will change the way we "read" and think about reading. It will change the way we design management information and decision support systems. It will also reduce our apprehension about the design of user-computer interfaces between inexperienced browsers and huge data bases. Like the other technologies discussed in this section of the report, hypertext represents a generic solution to a variety of problems that must be defined as amenable to the characteristics of hypertext and hypermedia. The research reported here argues that "amenable" can be defined via realistic interpretations of findings in the cognitive and related sciences.

4.3 Multimedia

As suggested above, definitions abound new information technology areas. Multimedia technology is understood here as the associative organization of multiple media, such as text, graphics, sound, and video. Aiken (1989) presents a framework for envisioning the range of multimedia possibilities (see Figure 4.5). Multimedia thus represents the marriage between hypertext and hypermedia, that is, the organization of data, information, and knowledge in a variety of forms accessible in near free-form fashion.

Five years ago multimedia technology was expensive and

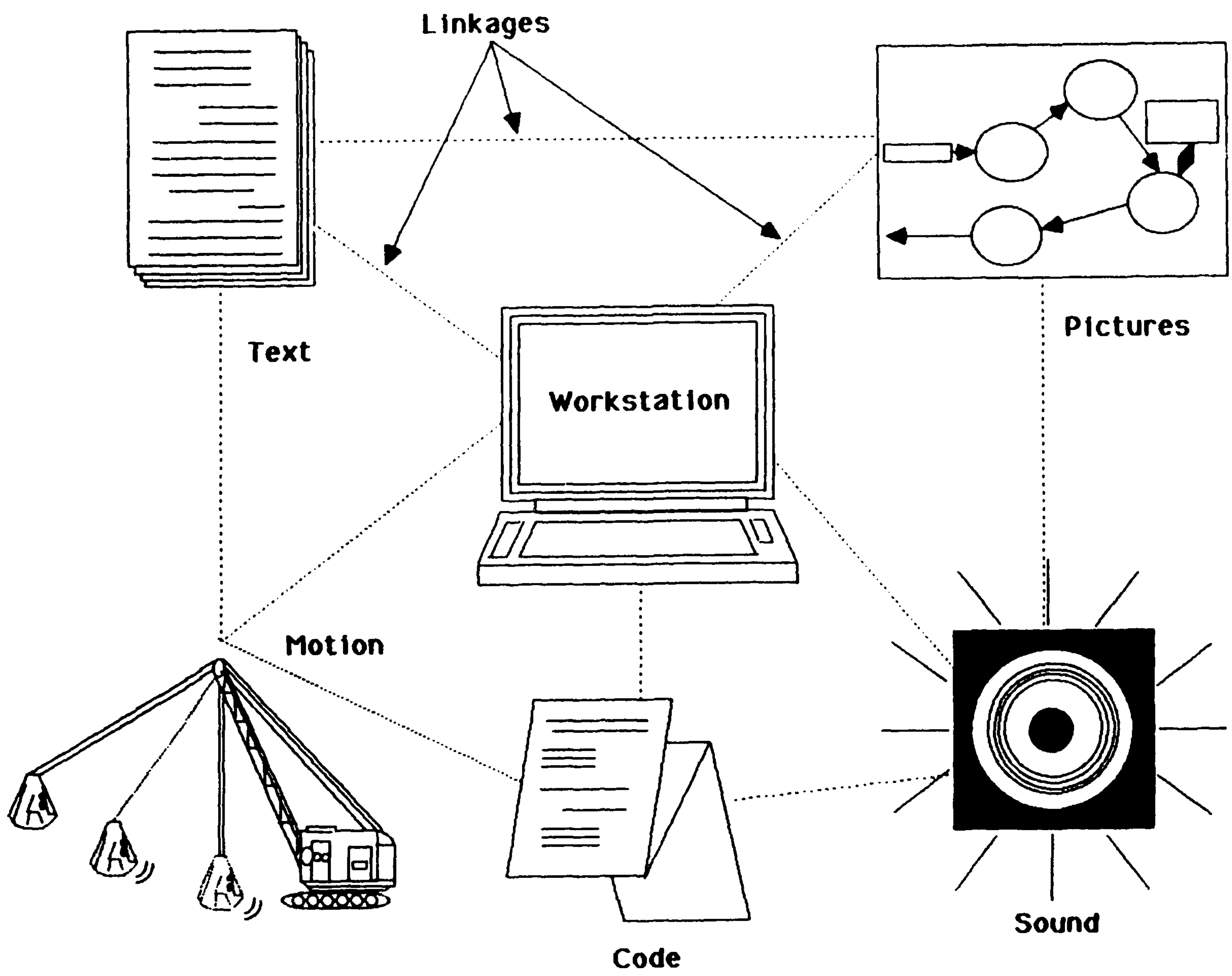


Figure 4.5: Aiken's Multimedia Concept

unreliable. More importantly, there were few application concepts. Early video disk research mapped a good deal of the interactive video terrain, but until recently very few designers considered how video, text, graphics and sound could be synchronized for user-computer interaction or problem-solving purposes. Without question, the rise of multimedia applications correlates with the fall in computing and storage costs. Color, interactive graphic, sound and video media are now often cost-effective as is the direct manipulation interface technology that permits smooth multimedia access.

Apple's Hypercard system represents an early multimedia environment. Hypercard permits the integration of graphics, text, sound, video (via hooks to other applications programs and storage devices [like CD-ROM players]) <u>and</u> the non-sequential browsing through its data and knowledge bases. Newer systems like Silicon Beach's Supercard adds color and some other multimedia capabilities. We are only a few years away from the widespread application of workstations like the one envisioned by Aiken (1989) in Figure 4.6.

Multimedia workstation concepts like Aiken's will permit systems designers to satisfy a larger range of user requirements than has been the case with traditional architectures. Systems engineers responsible for designing and developing military planning systems, for example, can exploit multimedia technology by providing geographical, graphic and video support to users,

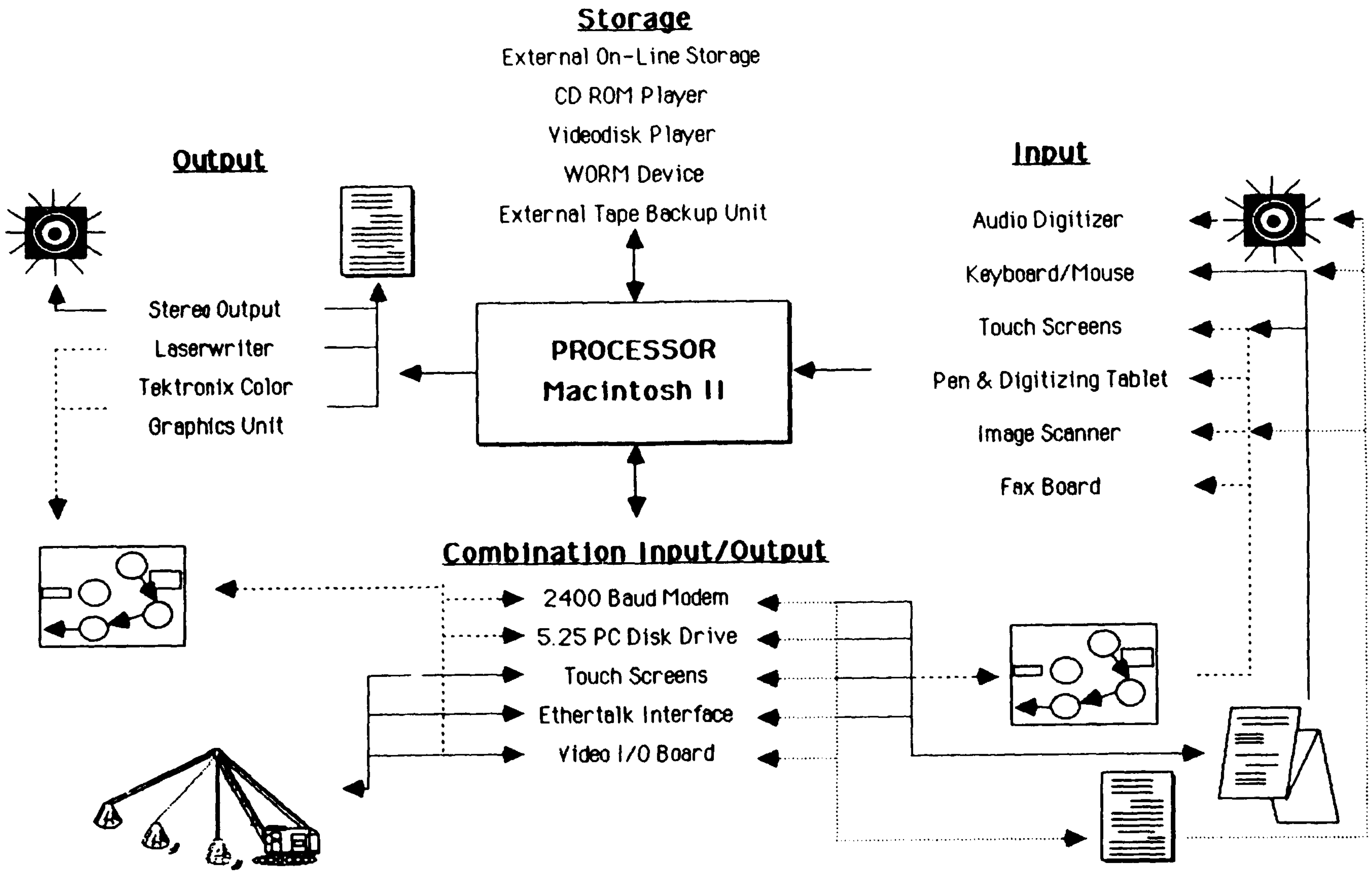


Figure 4.6: Aiken's Workstation Concept

support that would permit users to "see" the battlefield. Multimedia technology can also ease the interaction between users and the systems intended to support them. The use of color icons that symbolize relationships among system functions and contents, for example, reduces operator workload, just as the real-time conversion of text to graphics can accelerate problem-solving.

Like hypertext, multimedia is a generic technology solution, but -- like hypertext -- must be applied judiciously.

4.4 Animation and Simulation

Animation is a tool that extends the concept of interaction to include real-time movement of objects and the representation of dynamic processes. Examples of animation that come to mind immediately include the projection of trends over time, diagnostics, and dynamic "what - if" analyses.

Animation is movement technology; simulation is model-based. Until recently, simulations calculated a variety of events and conditions and then displayed the results to users eager to interpret the data. It is now possible to animate simulations; users can watch the simulation compute and see the results as they are converted to dynamic screen processes.

There are a number of general-purpose simulation programs that support animation. Stella (by High Performance Systems) and Extend (from Imagine That!) are two general-purpose simulation programs for the Apple Macintosh. There are also a variety of general-purpose animation programs for the Macintosh, including Dimensions (by Visual Information), Super 3D and Supercard (by Silicon Beach Software), and Macromind Director (by Macromind).

Animation and simulation tools (as well as animated simulations) permit designers to convert static objects and processes into dynamic ones. Military planners can "see" routes as they are followed and obstacles as they appear along the route. The tracking of targets can be seen dynamically over time, as well as in response to hypothetical stimuli. Animation can communicate complex concepts to users; animated simulation can inform decision-making and problem-solving.

Animation and simulation expand our inventory of advanced information technology for systems design and development, but their use should be restricted to interface and computational requirements that call for their unique capabilities.

4.5 Interactive (Color) Graphics

In the 1970s interactive graphics were slow and expensive. Consequently, unless requirements clearly called for graphics and/or color, they were not incorporated into the interface or as part of system output. When microcomputers became commonplace in the early 1980s, interactive color graphics were still relatively expensive. But when architectures become more powerful in the mid-1980s, color, graphics and the means to manipulate them became affordable. Concurrently, our insight into the optimal use of color and graphics increased dramatically. Schmid (1983), Schmid and Schmid, (1979), Durrett (1987), and Lewell (1985) all report progress in computer graphics technology as well as how it can be effectively applied. Cognitive psychologists have documented the impact of text-to-graphics conversion (Carroll, 1987), and the designers of popular applications programs (like word processors, spreadsheets, and data base managers) have begun to consistently exploit the use of interactive color graphics.

The use of color and graphics has been refined by the human factors community (Ramsey and Atwood, 1979; Smith and Mosier, 1984). Empirical analyses have yielded some guidelines for when and how to use color and graphics, given user and task requirements (Breen, Miller-Jacobs and Miller-Jacobs, 1987).

Color, graphics and interactive color graphics can be used to accelerate interaction, communicate events and conditions, and inform users about system status. Andriole (1986a) experimented with "graphic equivalence," graphic explanations and embedded process modeling for enhanced user-computer interaction in the domain of tactical planning. Figures 4.7, 4.8 and 4.9 illustrate how graphic displays can be used to convert text to graphics (Figure 4.7), to explain system output to users (Figure 4.8), and inform users of completed and remaining tasks via a graphic "process model" (Figure 4.9).

Windows, icons, pull-down and pop-up menus, among other graphic

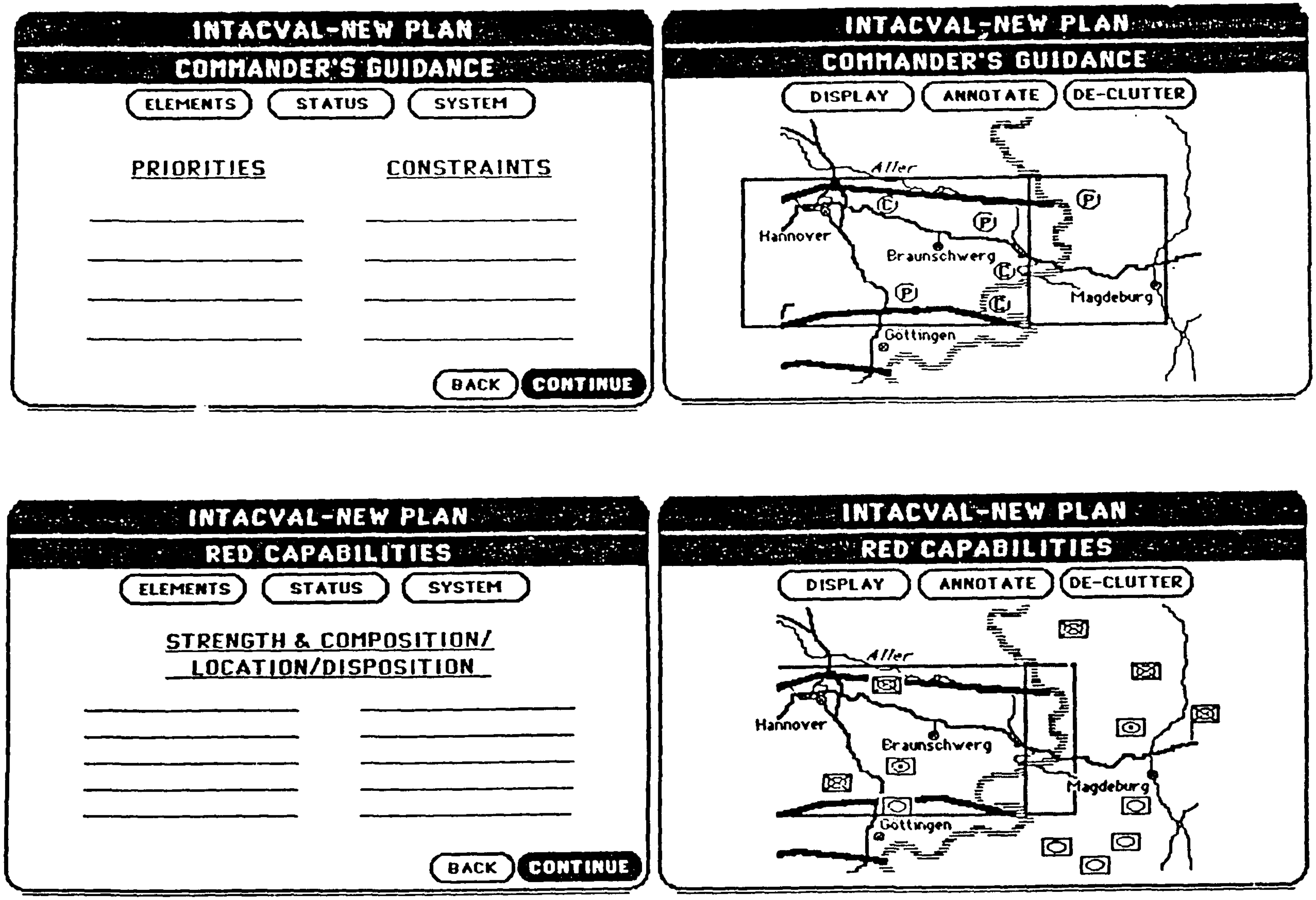


Figure 4.7: Text-To-Graphic Conversion

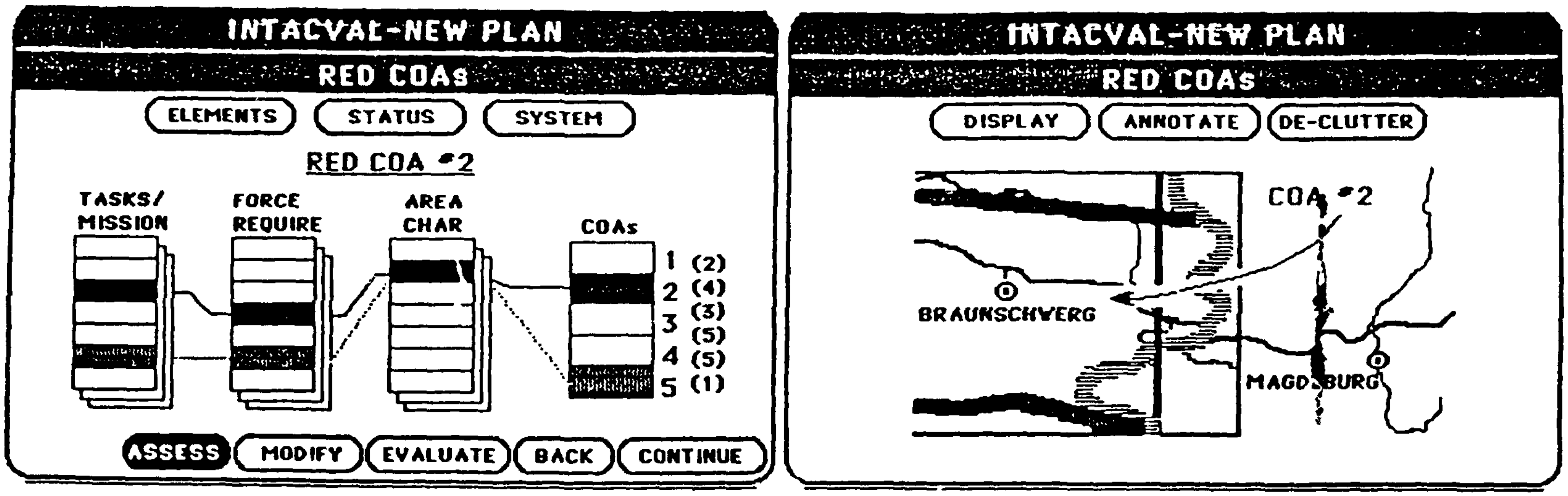


Figure 4.8: Graphic Explanation Concept

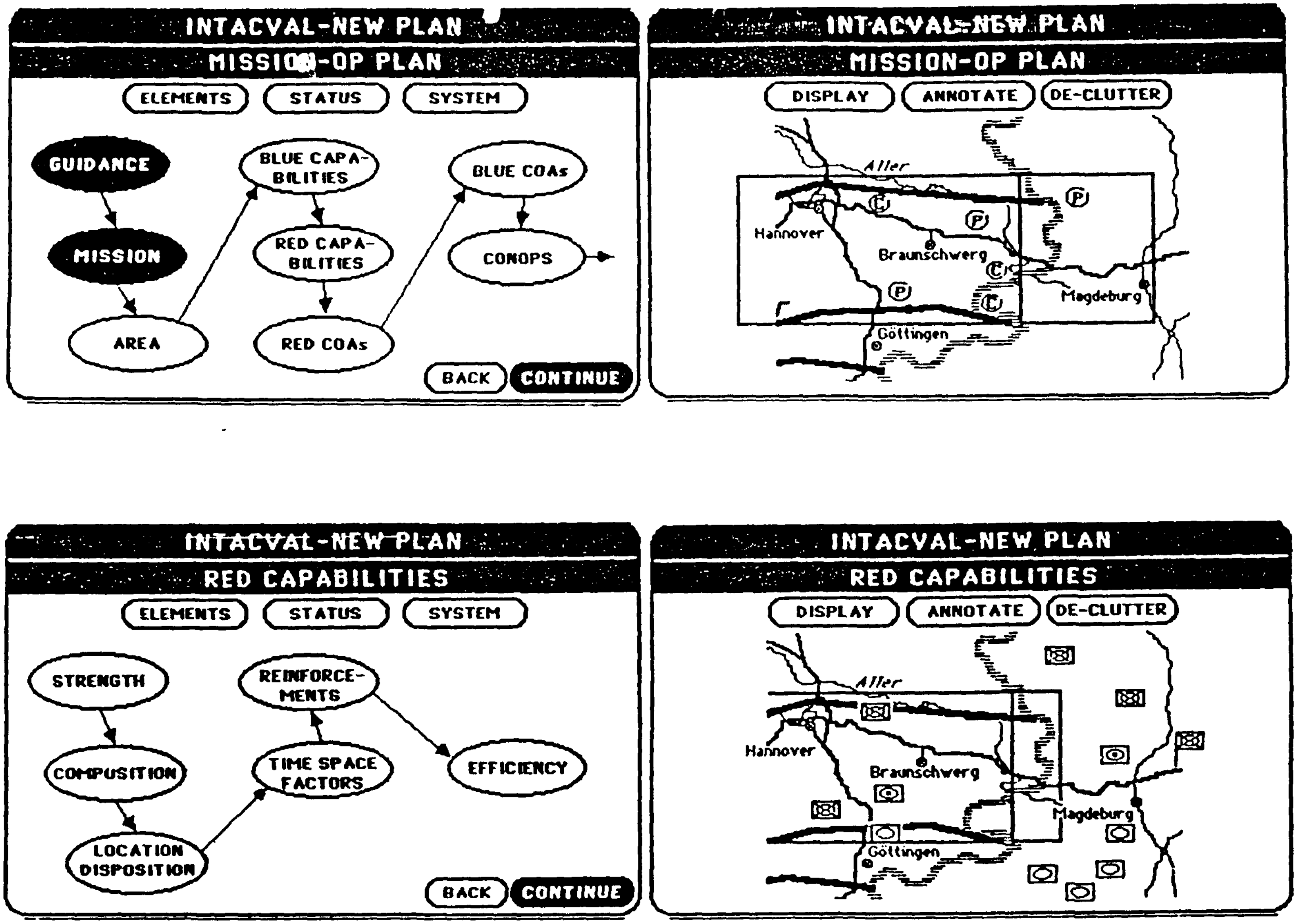


Figure 4.9: Embedded Process Modeling

techniques, have become popular over the past few years for several reasons. First and foremost, there are countless hypotheses about the compatibility between human information processing and the use of windows, icons, and other graphic navigational processes and cues. They are also cost-effective. Finally, the industry has longed for a common user interface -- an interface standard, if you will -- that would permit the development of integrated packages and second and third generation application programs without costly re-training. Hayes and Baran (1989) have organized the range of graphic user interfaces (see Figure 4.10). While it has taken some time, the MS-DOS (and now OS2) world is finally catching up to the standard-setting interface capabilities of the Apple Macintosh.

Color and graphics can separately or together play valuable roles in the systems design, display and user-computer interaction processes. When coupled with direct manipulation interface technology color graphics can enhance human performance by augmenting human information processing capabilities.

4.6 Deductive Inferential Knowledge-Based Expert Systems

Since the late 1970s the artificial intelligence (AI) community has attempted to design, develop, and apply expert knowledge bases in a variety of domains (Andriole, 1986b, 1988; Andriole and Hopple, 1988). The military has been particularly enamored with the potential of knowledge-based problem-solving, though its

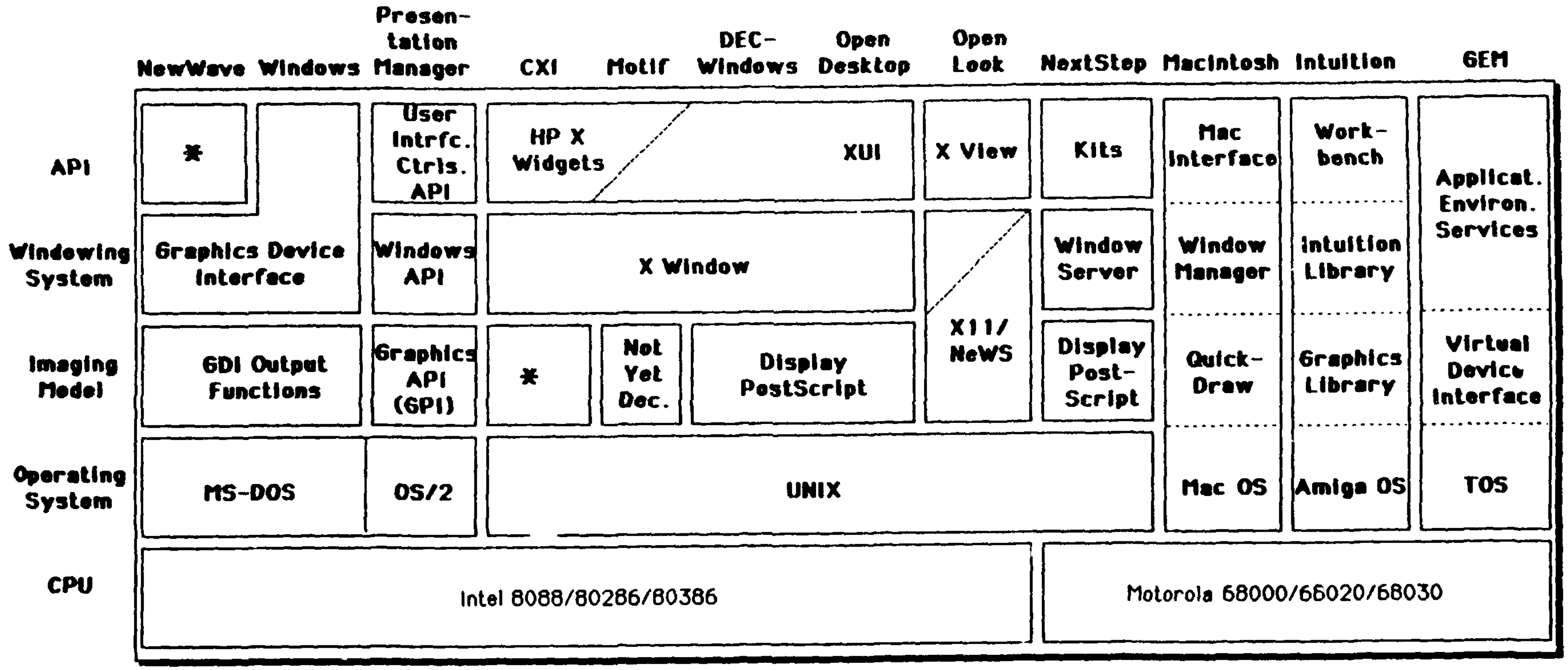


Figure 4.10: Hayes'/Baran Range of Graphic User Interfaces

expectations have rarely been satisfied. It is generally recognized today that the range of problems to which AI technology is applicable is far narrower than first believed. Well-bounded, deductive inference problems appear best suited to state-of-the-art knowledge representation and inference-making techniques. Problems that require induction and (especially) abduction are often too complex for current expert systems technology.

There are additional problems. Expert systems design and development requires access to articulate experts. Many expert systems are developed with one or two "knowledge czars" who are accessible on irregular bases and who sometimes have questionable expert credentials.

There are any number of problems that defy intelligent systems technology of any kind (including the current rage, neural networks). It is beyond the capability of today's technology to infer Soviet intentions toward Hungary in 1995 or identify the location and date of the next terrorist attack. Current AI technology can, however, perform routine diagnostic tasks, recommend maintenance procedures, and plan in well-understood and well-bounded domains.

Figure 4.11 presents some rules from an expert diagnostic system known as MYCIN. Developed by Shortliffe and Buchanon at Stanford University, MYCIN diagnoses bacterial infections and then prescribes medication. It is a "backward chaining" expert system

__If:__ (1) The site of the culture is blood, and
(2) The identity of the organism is not known, and
(3) The stain of the organism is Gramneg, and
(4) The patient has been seriously burned,

__Then:__ There is weakly suggestive evidence (0.4) that the identity of the organism is Pseudomonas

__If:__ (1) The infection which requires therapy is Meningitis, and
(2) The patient has evidence of a serious skin or soft tissue infection, and
(3) The organisms were not seen on the strain of the culture, and
(4) The type of infection is Bacterial,

__Then:__ There is evidence that the organism (other than those seen on cultures or smears) which might be causing the infection is Strephtococcus-Coagpos (.75) or Strephtococcus (.50)

Figure 4.11: Rules From MYCIN

that reasons from hypotheses to evidence and then back again. A large percentage of the successful expert systems are of the MYCIN type.

Figure 4.12 presents some rules from an expert system developed by Decisions and Designs, Inc. that helps with the deployment of early warning aircraft. "If - then" rules are the mainstay of many expert systems. When procedures can be reduced to a manageable set of validated rules, then prospects are good for the development of a practical expert system. But when the domain and inference-making process are complex or in any way inexplicable, then conditions are by no means ideal for expert systems development.

While knowledge-based systems technology represents a powerful tool, there are clear limits to its applied potential. Rather than rush to domains that call for AI we should filter requirements through a large methods filter prior to selecting just the right tools, techniques or methods -- as suggested by Figure 4.13.

Figure 4.13 implies that there are a variety of information technology-based analytical methods available to the modern systems engineer. Figure 4.14 from Hopple (1986) identifies numerous qualitative and quantitative methods anchored to a greater or lesser extent in advanced information technology. Analytical methods -- regardless of whether they are "intelligent" or not -- constitute important members of our

If: A threat is present but its location is not known,

Then: Put 2 early warning aircraft into the air and increase *the number of caps per craft to about 4* and *separate* the craft by about 120 degrees

If: A threat is present and its location is known,

Then: Put 2 early warning aircraft into the air and increase the number of caps to about 4

If: One craft is currently airborne

Then:

If: Aircraft *number* 2 *can* intercept farther out than craft number 1

Then: Intercept with number 2 and use number 1 as a backup

Figure 4.12: Rules For Early Warning Aircraft Control

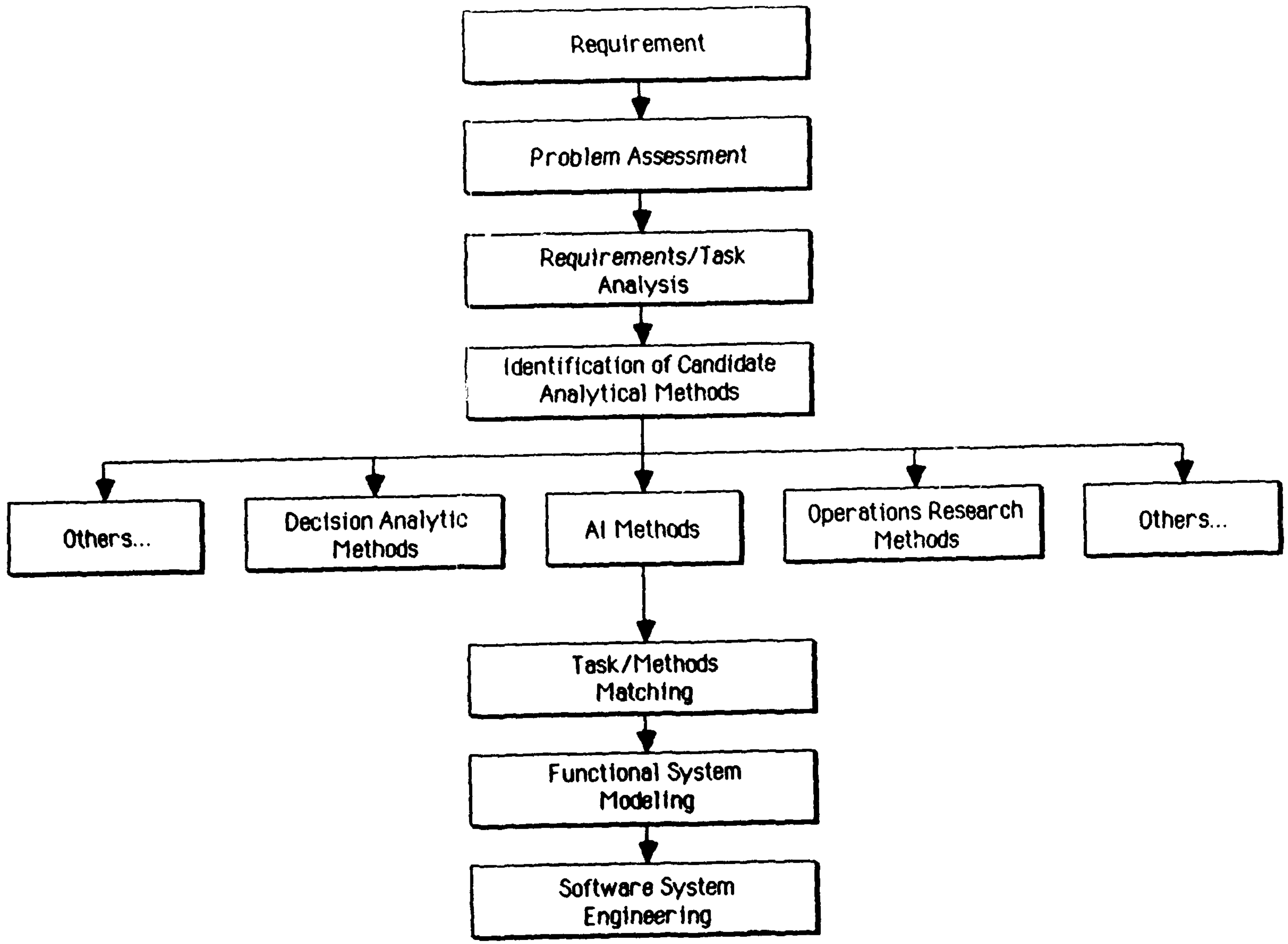


Figure 4.13: System Requirements/Methods Matching

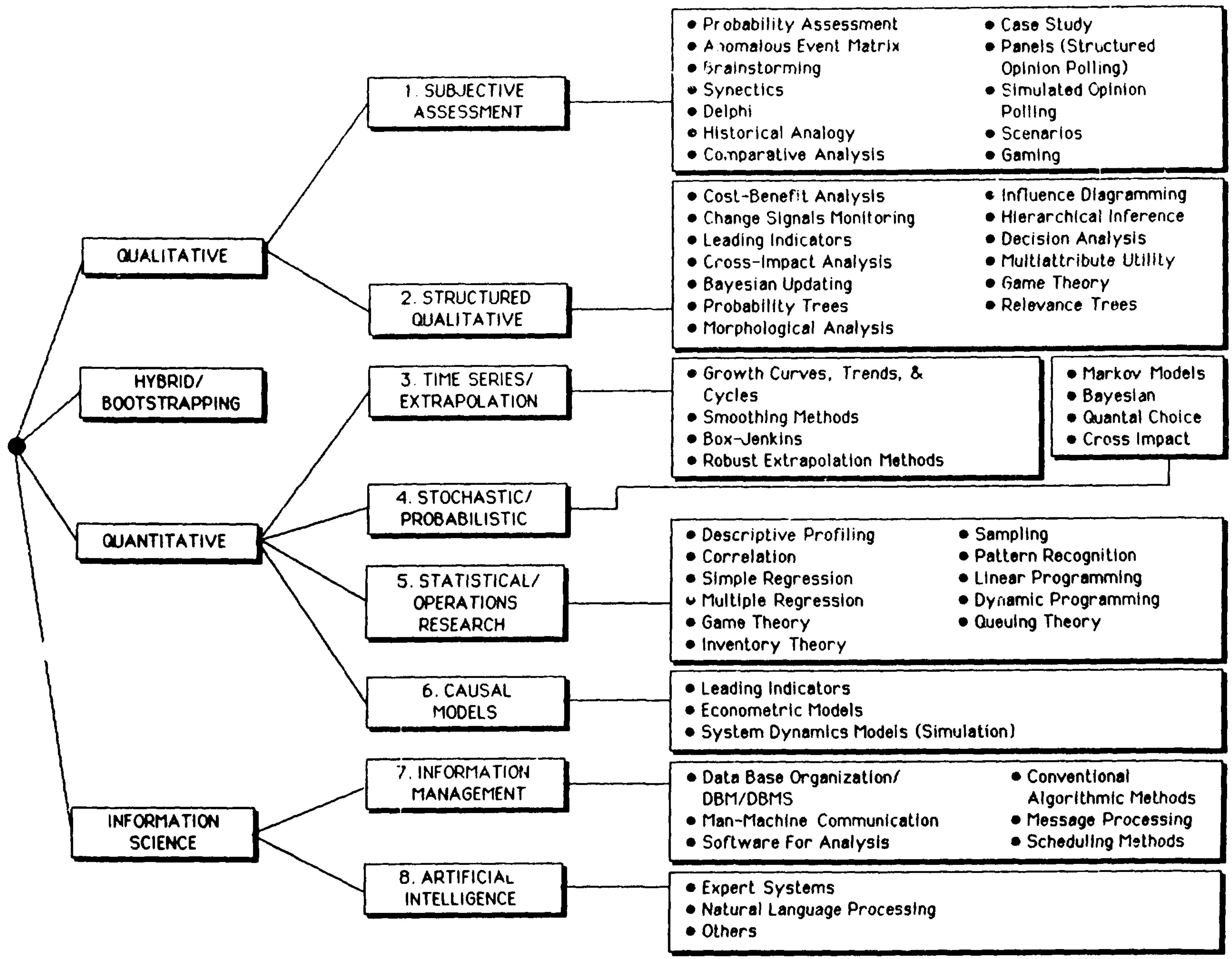


Figure 4.14: Hopple's Analytical Methods Taxonomy

information technology inventory. But here too compatibility with users, the tasks to be performed on the system, and what we know about cognitive information processing will determine where and how the methods should be applied.

4.7 Direct Manipulation Interfaces and Input Technology

Nearly all of the above information technologies, tools, methods and techniques assume direct manipulation. The state-of-the-art in input technology provides users with the capability to identify and retrieve data, select and execute functions, and observe system processes via a variety of interaction routines and input devices. The now famous "point and click" process implemented via mice and trackballs is direct manipulation at its best. There are additional options made possible by new input technologies such as touch screens, "datagloves," voice recognition systems, and even special purpose input devices for the manipulation of three dimensional objects (Williams, 1988; Tello, 1988). When these input technologies are combined with human factors and cognitive science guidelines powerful user-computer interaction results.

We are today on the threshold of a new era in human-computer communication where the communications bandwidth will widen in response to the confluence of human factors, cognitive science and advanced information technology.

4.8 Adaptive Human-Computer Interfaces

Norcio and Stanley (1988), among others, have recently examined the potential for real-time human-computer adaptation. According to Norcio and Stanley (1988), an adaptive interface needs four distinct kinds of knowledge:

- Knowledge of the user;
- Knowledge of the interaction process;
- Knowledge of the task/domain; and
- Knowledge of the system.

All of this knowledge is intended to orchestrate the interaction process and permit the system to adapt to user preferences and on-line interaction behavior, the demands of the current task, the nature of the larger problem area, and its own interaction and processing capabilities. The goal of the adaptive interface research community is to field systems that respond to their users, changes in the problem-solving environment, and the nature of the domain during the human-computer interaction process. While a variety of research questions exist (Greenberg and Witten, 1985), progress has been made in recent years (Rouse, 1981; Carbonell, 1983); we will no doubt see the real-time adaptation concept broaden considerably in research and practice over the next few years.

4.9 Additional Information Technology

This review of advanced information technology has deliberately focused on those methods, tools and techniques that hold great promise for enhancing analytical support and user-computer interaction. We have assumed progress in raw computing power, which is rapidly occurring in a number of areas. Workstation technology, for example, has made dramatic strides in the past five years. Movement from the Intel 8088 to the 80286 and 80386 processors (and from the Motorola 68000 to 68020 and 68030 processors) has provided "personal computer" and workstation users with enough power to perform many computationally intensive tasks, tasks that were impossible when the revolution in microcomputing began. Operating systems have evolved with the processor technology all the way to workstation-based UNIX multi-tasking. Next generation architectures promise even greater power and flexibility. The challenge will not involve exploiting 80486-based machines for enhanced word processing efficiency; instead, designers must turn their attention to substantive requirements and how new processing architectures can satisfy a growing range of applications.

Clearly there are tasks that call for additional computational power. Environments rich in data, information and knowledge, requirements that call for data fusion, and problems that require complex analyses will benefit tremendously from the new architectures. The contention here is that this power will be available and cost-effective, and that the real challenge lies in the extent to which we can leverage the power against new and especially vexing problems.

4.10 Opportunities

All of these technological "solutions" are essentially generic. There are computing situations that will clearly call for some or even all of them, and others that will require but one or two. As always, the key lies in the matching of the right technology to the right problem.

This report argues that the matching process can be informed via reference to research in cognitive psychology and cognitive science. Cognitive research can help with the conversion from requirements to system concept design; cognitive research can serve as a filter through which ideas about system operation, interaction and communication can be passed -- prior to implementation. At the most basic level, cognitive research can help leverage traditional human factors findings, but at a much higher level can direct the use of advanced information technology to assure cognitive compatibility and consistency between systems and their users. This latter leverage was the objective of the research described here.

The simultaneous revolutions in information technology and cognitive science are fueling the design and development of systems likely to ennance user-computer interaction and human problem-solving. The number and nature of applied opportunities is rising as rapidly as user expectations about synergistic human-computer behavior. There is every reason to believe that great progress can be made so long as we remain diligent about the integrity of the matching process. It serves no purpose to rush information technology into system concepts before it has been tested or made reasonably cost-effective; nor is it prudent to over-interpret findings from cognitive science. The prototype systems described below (see Section 5.0) were designed cautiously; at the same time, they suggest what can be achieved when cognitive science and advanced information technology are merged.

5.0 COGNITIVE SYSTEMS ENGINEERING OF ADVANCED INFORMATION TECHNOLOGY FOR STRATEGIC AIR DEFENSE

The previous sections of this report have examined the air defense domain, pertinent findings from cognitive science, and the range of information technologies available to the systems engineer. It is now time to merge all of the above into several working demonstration prototypes.

This section distills Sections 2.0, 3.0 and 4.0 into a set of prototyping guidelines.

5.1 Air Defense Intelligence, Operations and Intelligence/Operations Requirements

Air defense is part of the larger strategic defense process. The air defense process -- defense against atmospheric threats -- can be defined along an intelligence/warning/operations continuum. Intelligence analysts seek the longest possible lead time for warning analysts via monitoring military, political and economic indicators of likely air attacks as well as access to the indicator monitoring that occurs at other levels in the strategic defense process. Warning analysts convert intelligence estimates into likelihoods of specific threats consisting of location, timing and force structure. Operations personnel assess the environment, identify (pre-selected and new) options, evaluate the options, and recommend responses to perceived threats. Operations personnel are "asset managers" who must make tradeoffs among decision alternatives. The intelligence/warning/operations interface requirements communication and the sharing of data, information, and knowledge. It also requires a two-way understanding of the intelligence and operations environments.

5.2 High Leverage Findings from Cognitive Science

Section 3.0 provides a tour de force of the cognitive science literature. The survey and analysis provides insight into the kinds of cognitive processes that can dramatically affect human information processing, decision-making and problem-solving. The key findings include:

INFERENCE-MAKING FOR INTELLIGENCE ANALYSIS & PRODUCTION

- Inference-making performance is task dependent;
- Human information processors (HIPS) have poor insight into their own inferential processes;
- "Cognitive feedback" can significantly improve task performance;
- HIPS are susceptible to non-linear-based deception;
- HIPS use simple and complex "causal" schemas to explain behavior and make inferences;
- HIPS use "plausible scenario generation" to test and generate hypotheses;
- HIPS often reason from experiences, analogies or "cases";
- HIPS rely on "cues-to-causality" to explain current and future behavior;
- HIPS process less information than they think they use to make inferences;

- Experts are as susceptible to poor insight about their inferential processes as novices;
- HIPS are unsure about how to optimize data, information and knowledge in inference-making;
- HIPS are prone to "cognitive reductionism" to reduce workload and overall mental effort;
- The perception of information is not comprehensive, but highly selective;
- HIPS tend to under-emphasize "base-rate" information;
- HIPS weight the importance of information on the basis of its perceived causal meaningfulness not based upon its statistical diagnosticity;
- HIPS are susceptible to the "availability bias," or the tendency to recall recent or highly publicized events;
- HIPS selectively perceive data, information and knowledge on the basis of experience;
- HIPS are susceptible to confirmation biases that filter incoming information according to pre-conceived ideas and views;
- The way information is presented often determines how it is perceived;
- HIPS tend to be conservative inference-makers;

DECISION-MAKING FOR STRATEGIC OPERATIONS

- Human decision-makers (HUDMS) tend to simplify decision problems by setting outcome aspirations;
- HUDMS often choose the first decision alternative that satisfies the outcome aspiration(s);
- HUDMS often simplify decision problems by only considering a small number of alternatives;
- HUDMS use analogies to generate and compare options;
- HUDMS weight criteria to rank-order decision alternatives;

- HUDMS selectively perceive data, information and knowledge, focus on confirming (versus disconfirming) information, and tend to anchor their judgments;
- HUDMS tend to attribute decision outcomes to chance or the complexity of the problem (not their own decision-making deficiencies);

THE INTELLIGENCE/OPERATIONS INTERFACE

- Analogical reasoning can enhance action plan effectiveness;
- Strategic decision-making quality is dependent upon an understanding of the inference-making/situation assessment process, and vice versa;
- Cognitive feedback can enhance option generation and evaluation in individual and group settings; and
- Communication lies at the heart of shared models and problem-solving.

These and additional findings were leveraged in the design and development of the prototypes. Our intention was to extract a set of relatively uncontroversial findings from the cognitive sciences and apply them to the air defense domain via the creative application of information technology.

5.3 Advanced Information Technology

Section 4.0 presents an analysis of some of the most promising information technology available today. The following general technologies are reviewed:

ADVANCED INFORMATION TECHNOLOGY

- Hypertext;
- Multimedia;

- Animation;
- Simulation;
- Interactive (color) graphics;
- Deductive inferential knowledge bases; and
- Adaptive and direct manipulation interfaces.

These technologies provide opportunities to the systems engineer, but only when judiciously applied. Our filters consist of the air defense requirements and the findings summarized above.

5.4 The Prototyping Process

Andriole (1989a, 1989b, 1990) describes the prototyping process in detail. Prototyping is a euphemism for failure. Designers of analytical computer-based systems realize that it is virtually impossible to capture and validate user requirements the first time through a domain. Iteration is almost always necessary. Failed requirements analyses early in the design process should be expected. Prototyping accepts the inherent recalcitrance of requirements engineering and endorses the development of working models of the system-to-be to validate user and system requirements prior to making large investments in software engineering. Boar's (1984) basic prototyping model appears in Figure 5.1, while Andriole's (1989a, 1989b) prototyping life cycle appears in Figure 5.2.

Andriole's life cycle calls for prototyping as a means to requirements validation. He proposes the use of "storyboards" to

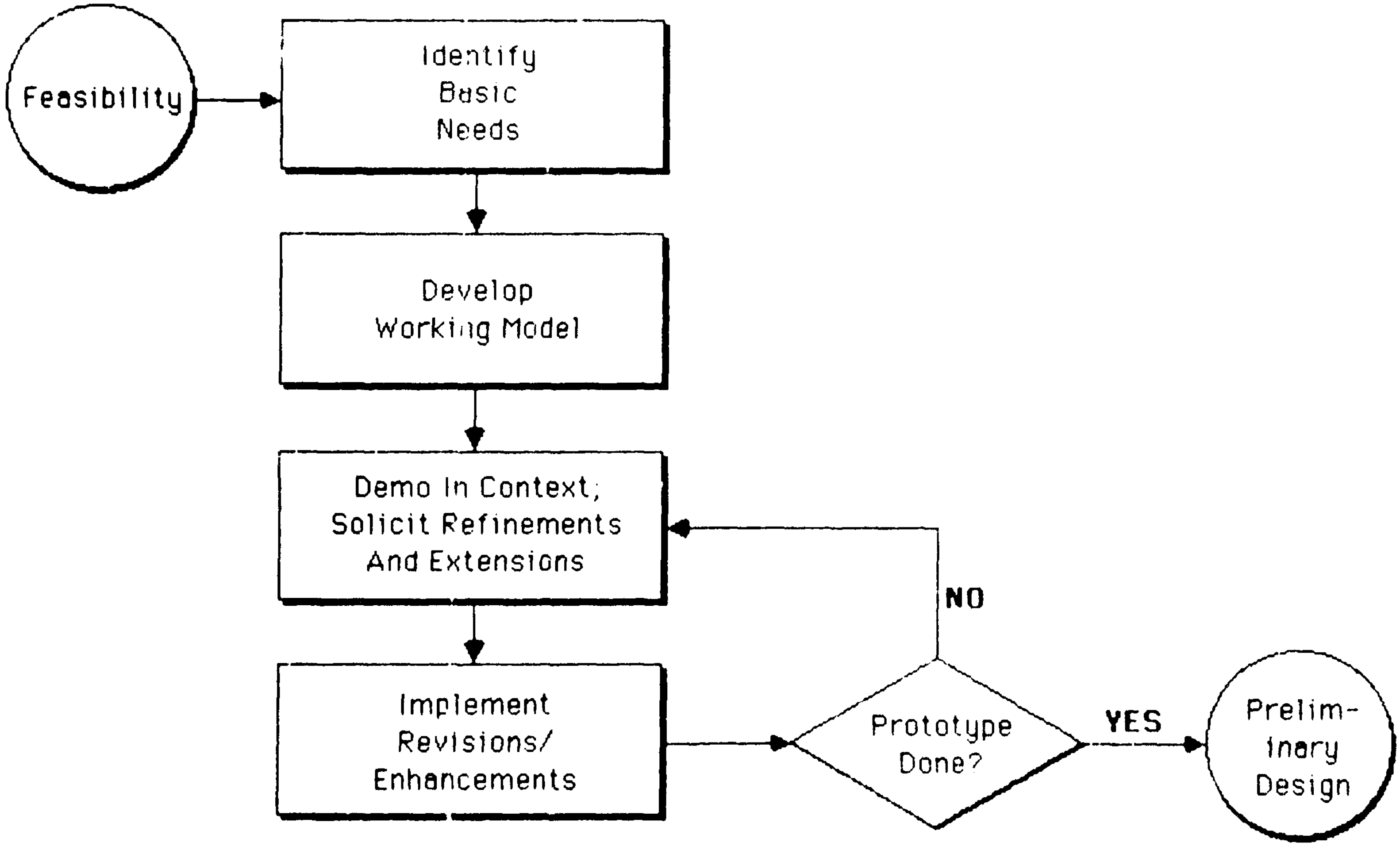


Figure 5.1: Boar's Prototyping Model

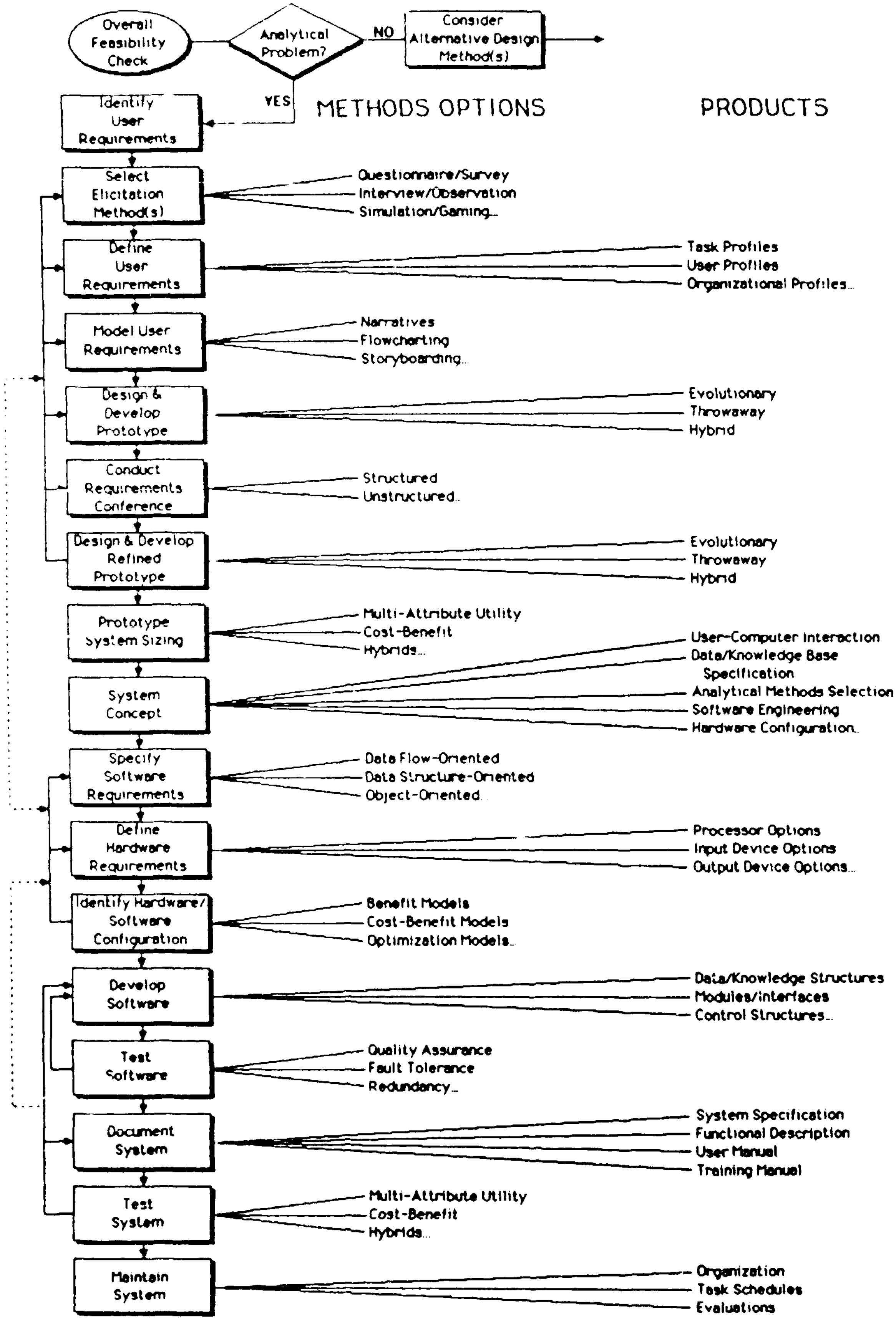


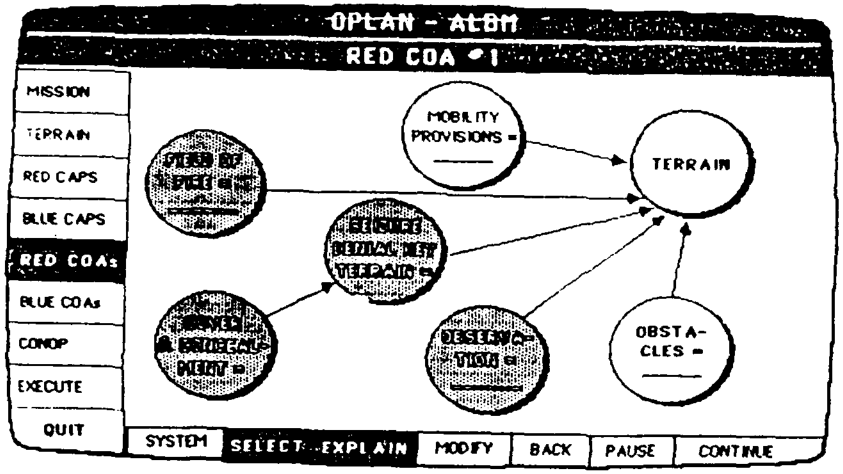
Figure 5.2: Andriole's Prototyping Life Cycle

demonstrate system capabilities (prior to actual programming). Storyboards are linked displays of simulated system functions and capabilities. Figures 5.3, 5.4, and 5.5 present some storyboards extracted from a tactical planning prototype. Storyboards are reviewed by prospective system users, modified, and re-developed for additional review. Storyboarding is fast and inexpensive; it is thus a solid prototyping strategy when requirements are fuzzy or when advanced system concepts comprise the design objective.

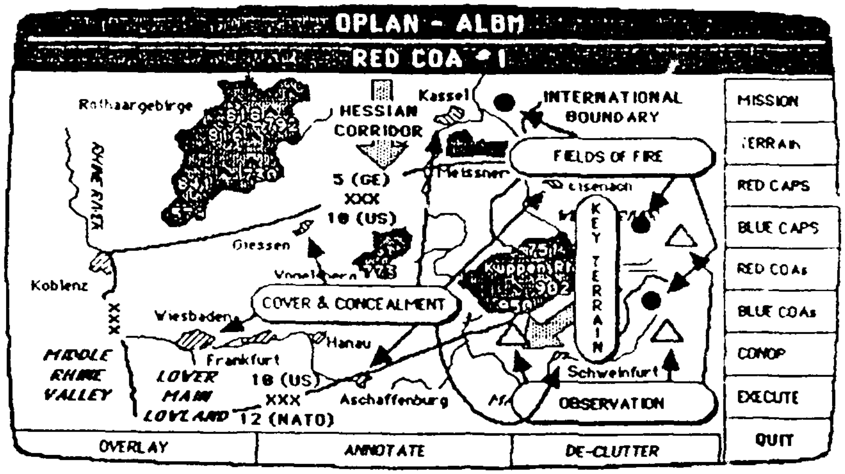
5.5 The Storyboard Prototypes

This section describes the prototypes that were designed to demonstrate how information technology can be cognitively engineered to enhance air defense intelligence, operations, and the intelligence/operations interface. There are three prototypes: one for intelligence, one for operations, and one for the intelligence/warning/operations interface (which has several embedded mini demonstrations).

5.5.1 The Air Defense Intelligence Analysis and Production Prototype - This prototype was conceived after the domain was assessed, after the pertinent findings from cognitive science were studied, and after the rarge of information technologies was surveyed. The domain suggested that the system could in fact conduct a variety of analyses on its own. This is not because our "intelligent systems technology" is so advanced but because many aspects of the intelligence problem are relatively well-

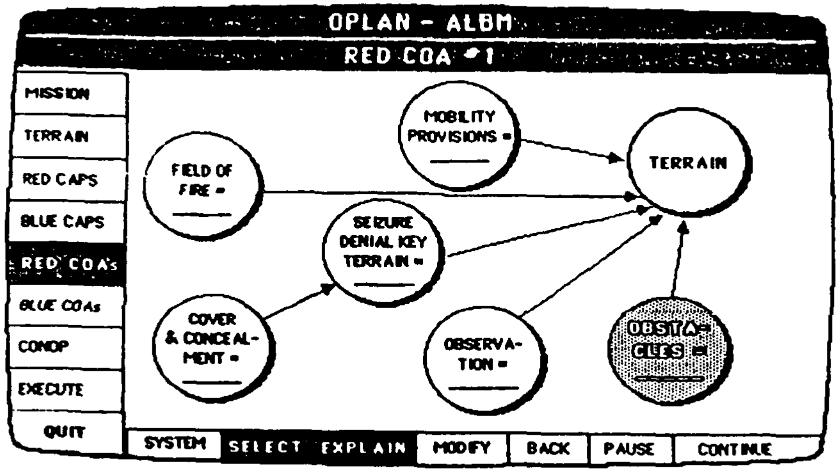


Now the planner wants to see a variety of the terrain components . . . he clicks on four of the six elements . . .

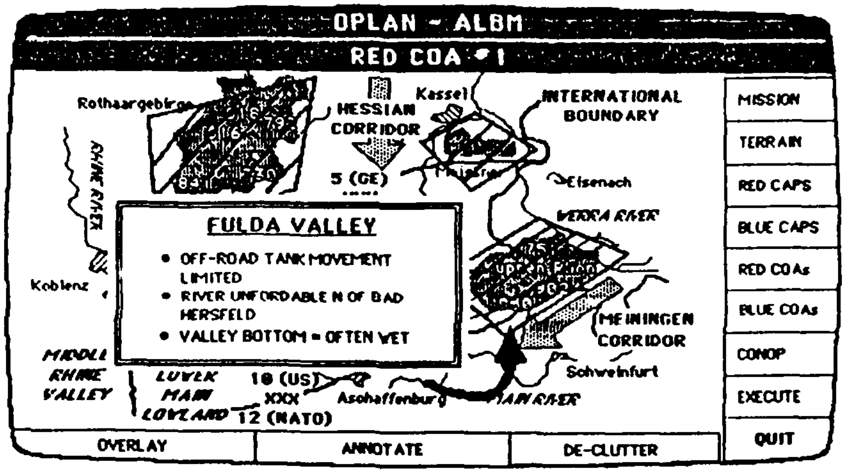


The system displays all of the terrain features . . . note that the planner can now de-clutter the image and see only, for example, "cover and concealment" or "observation points" . . .

Figure 5.3: Planning Storyboard: 1

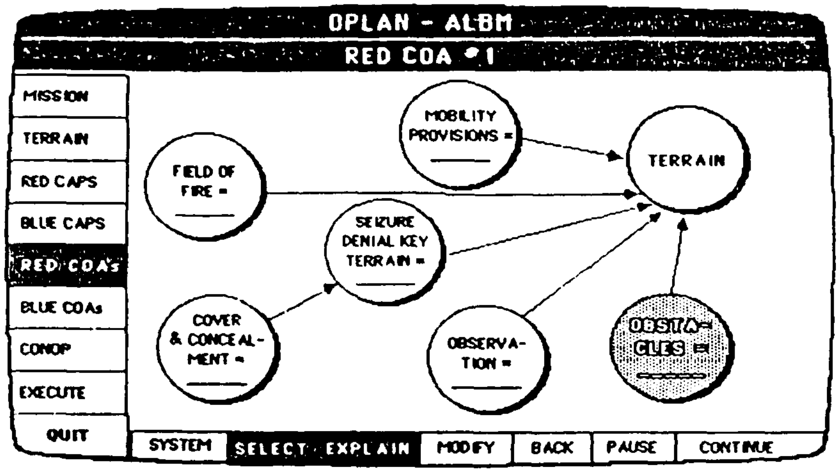


The planner again clicks on explain. Here the hierarchical explanation capability is demonstrated. As long as the user clicks on a function and as long as there is data or a sub-function below it, it will respond . . .

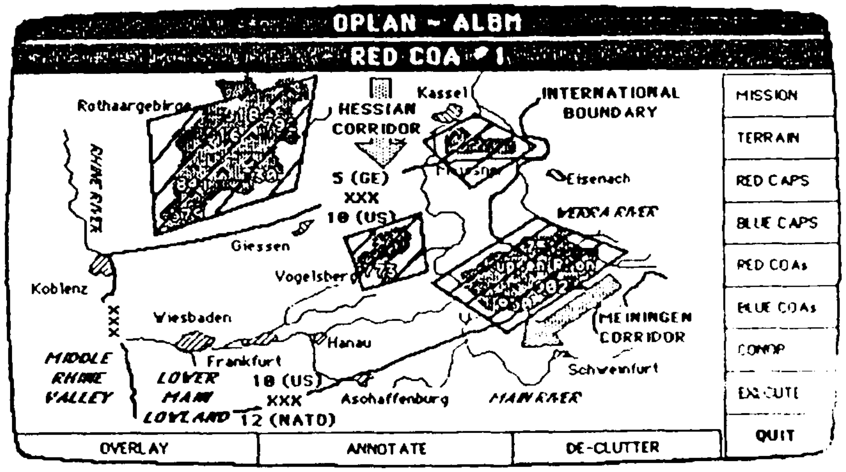


The system responds with a window text explanation on the map display . .

Figure 5.4: Planning Storyboard: 2



Another level of inference-making is displayed to the planner. Now he sees that there are a number of variables that comprise terrain . . .he looks over the variables and decides to find out more about "obstacles" ; note that he is still within the RED COA primary function and is now inquiring about but one of the variables that the system assumes are driving terrain (which in turn is driving capabilities and Blue threat . . .



The map display shows him the obstacles . . .

Figure 5.5: Planning Storyboard: 3

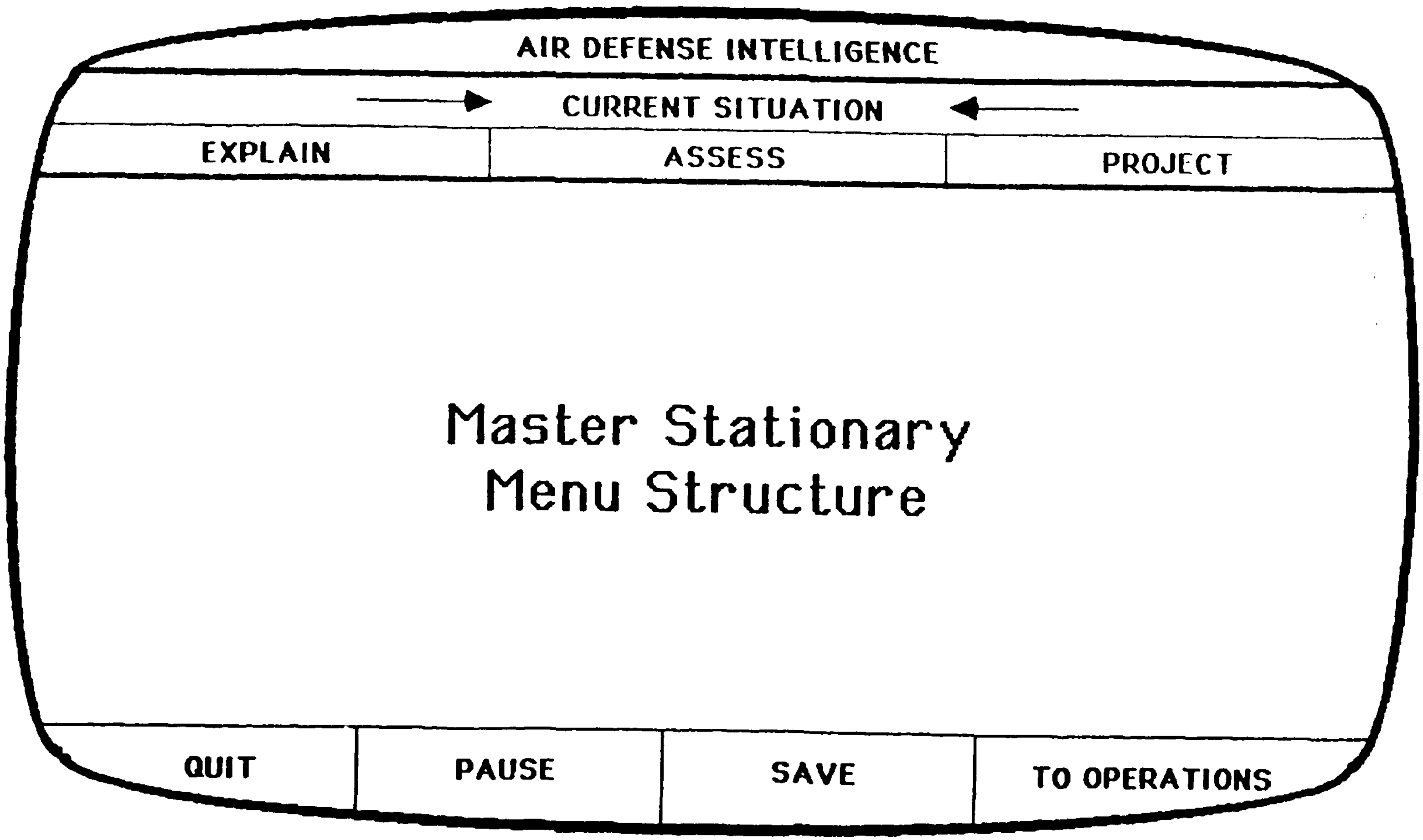
bounded. Cognitive science tells us that analysts are better at critiquing strawmen hypotheses than they are at generating them; the prototype thus generates hypotheses at times for the analyst to accept, modify or reject.

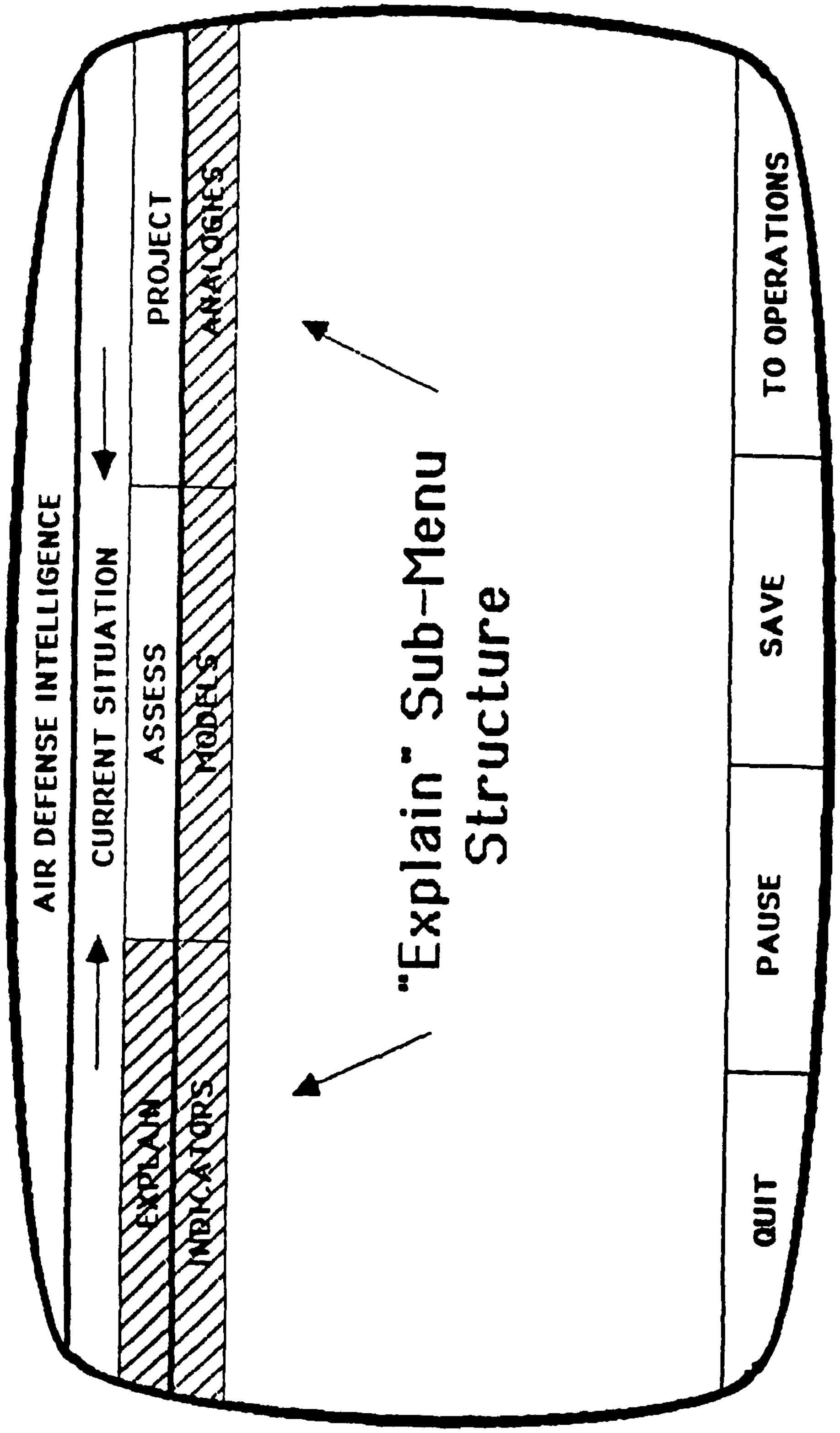
The menu structure reflects simplicity -- and assumes that intelligence analysts are not necessarily experienced computer-based problem-solvers. The notion of "process modeling," that is, communicating to users what the system can (and cannot do) influenced our menu design. Note the relatively small number of commands and our decision to make the commands stationary. The user would not have to learn such a system; its capabilities are obvious. Once options are selected they are highlighted, so users can always know precisely where they are in the general system "flow," and what they are doing at any particular moment. Function and process commands appear along the top of the screen, while system commands along the bottom, all as suggested in the following storyboard display.

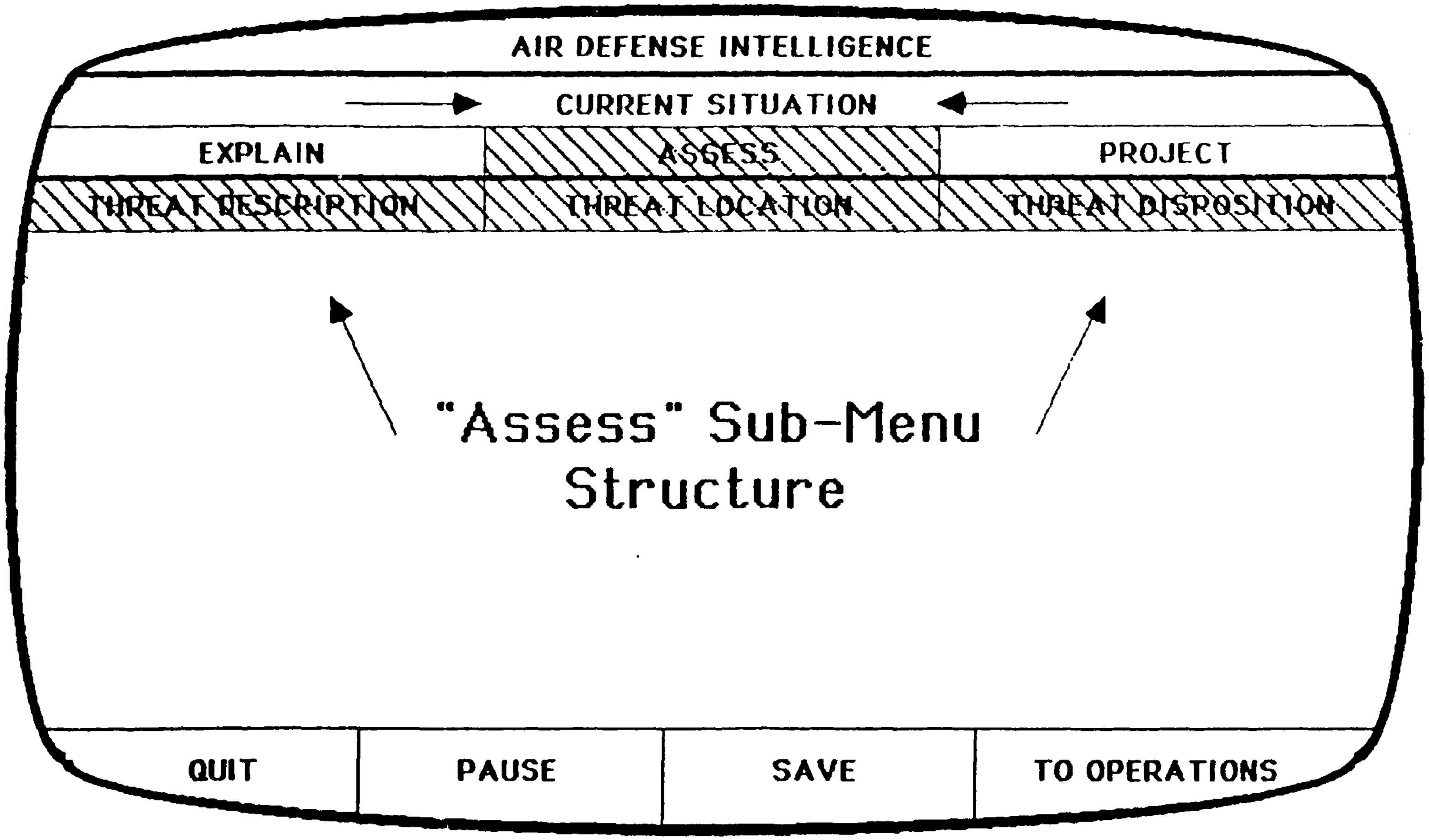
Sub-menus appear when primary menu options are selected, as suggested in the displays. Note also the "portal" to operations. This assumes access to the operations process and all data and knowledge bases that might be used by operational planners.

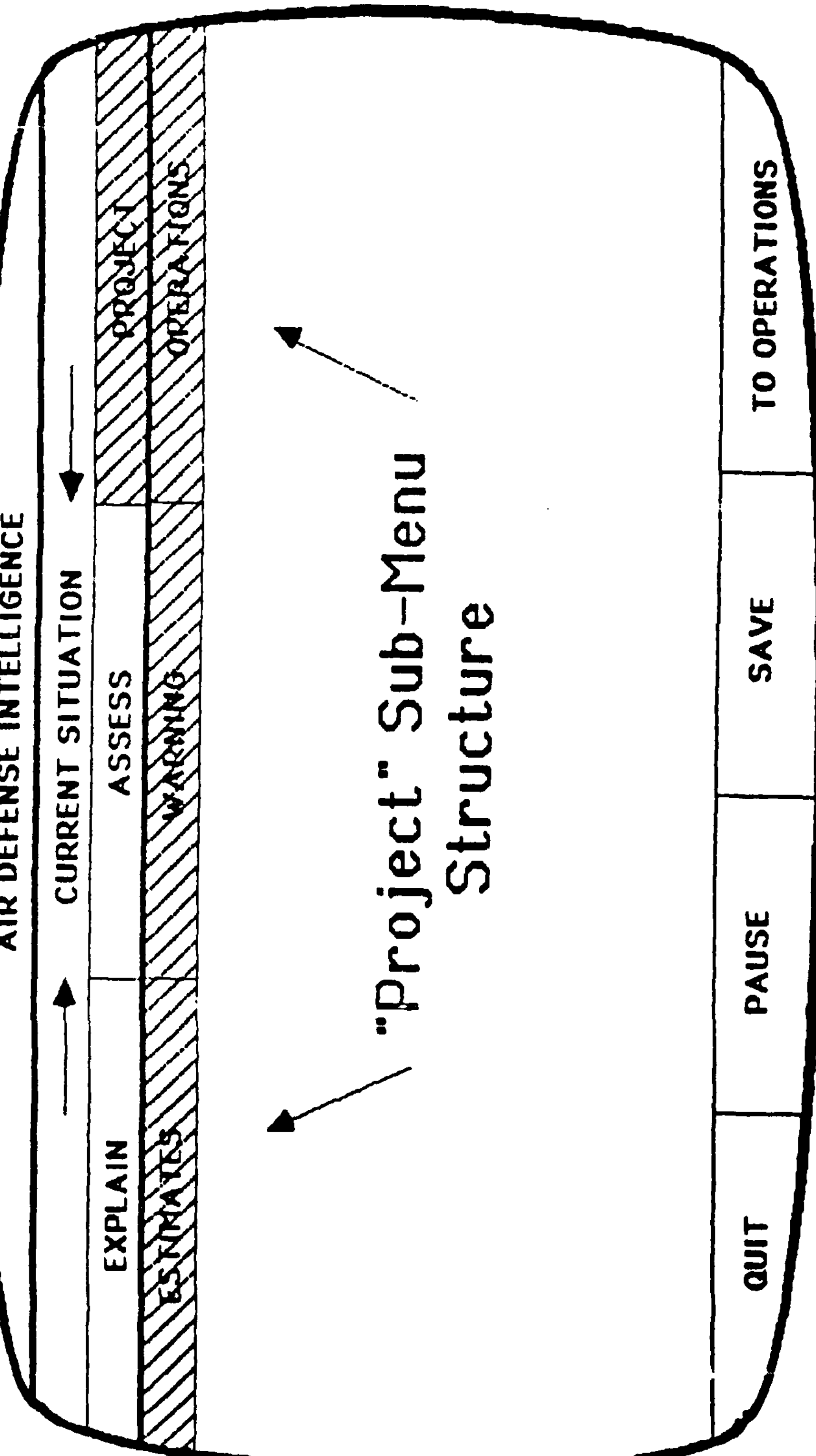
The system concept calls for windows, split screens, and mixed (system/user) initiative.

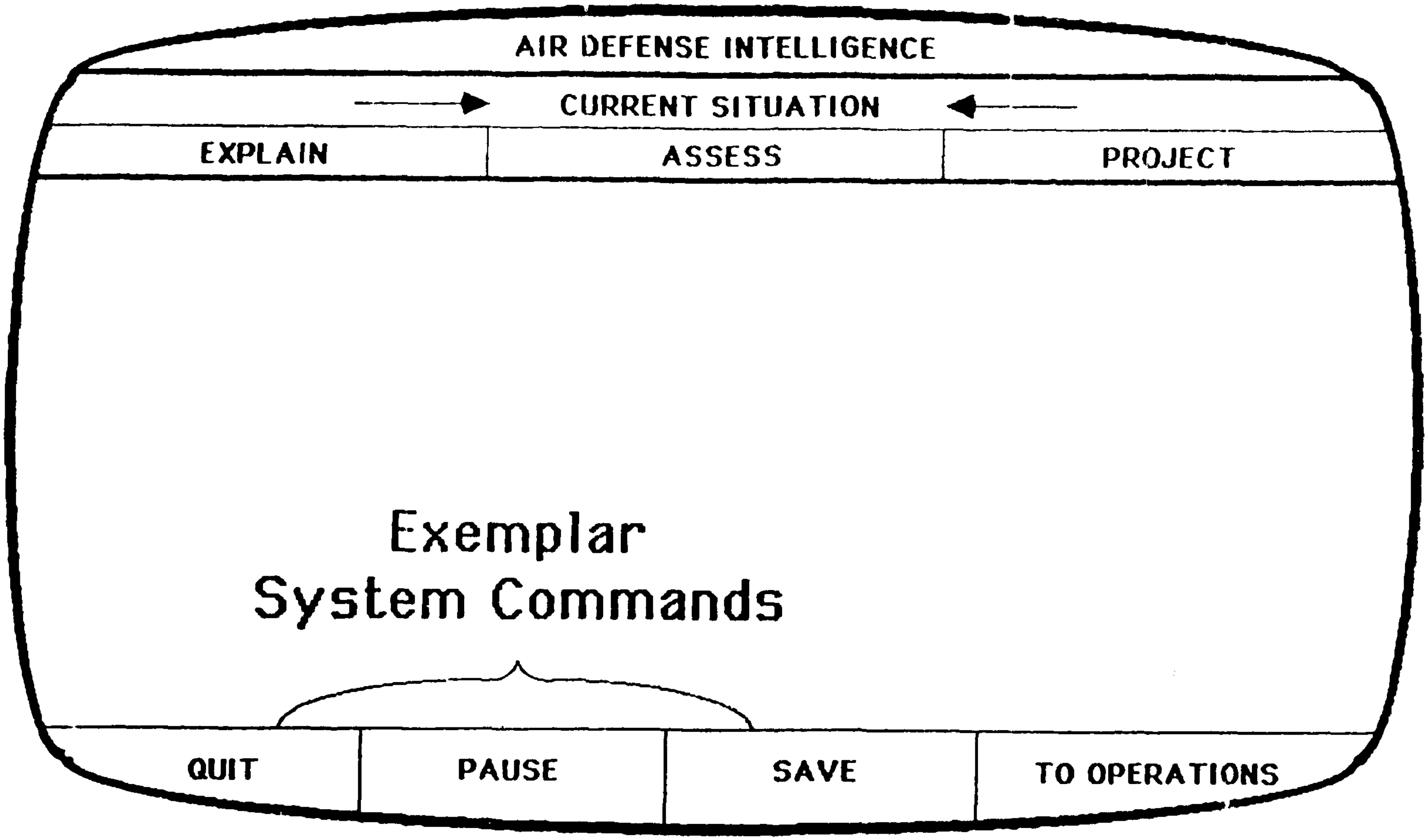
The prototype also makes extensive use of graphics, diagrams, and

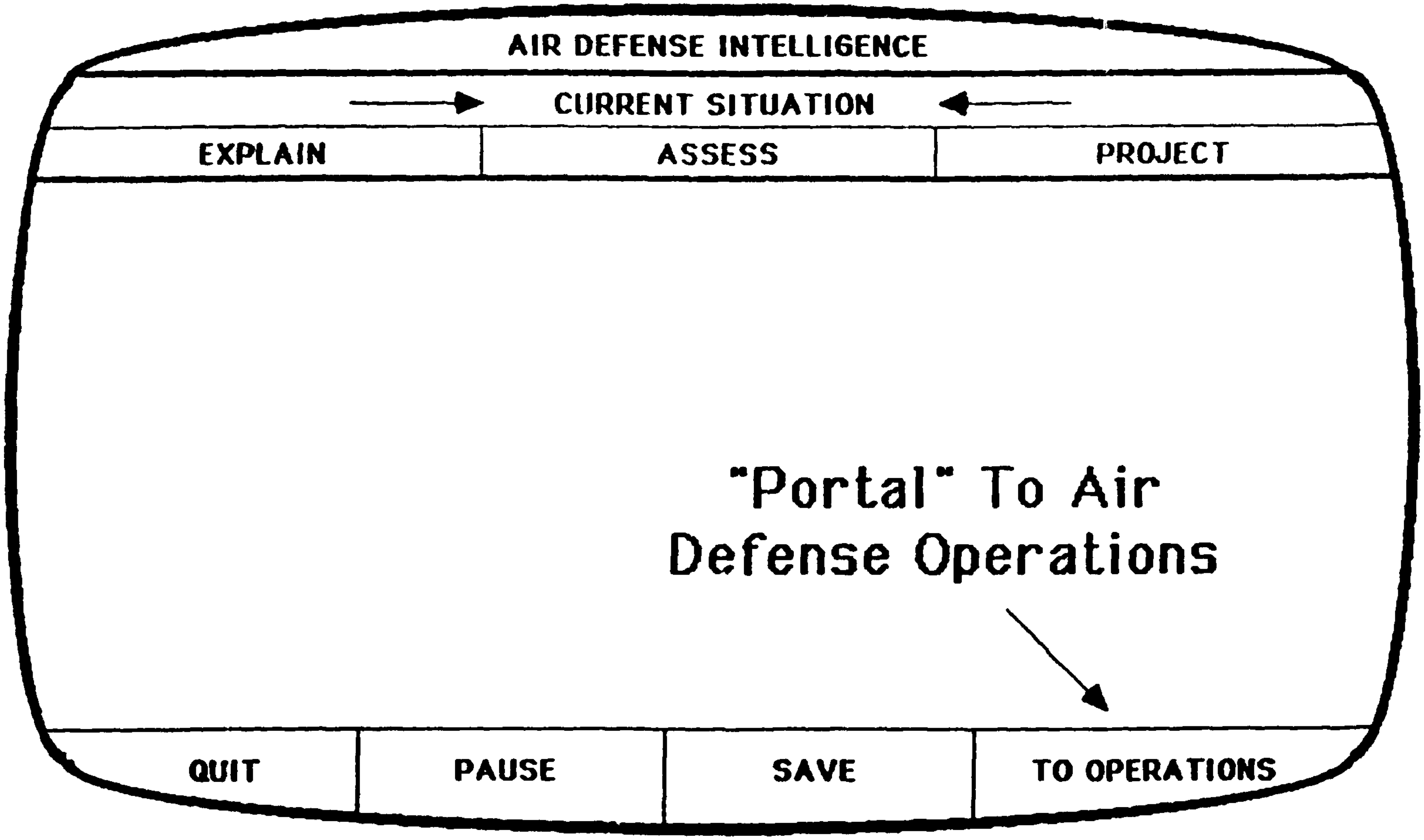

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Master Stationary
Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

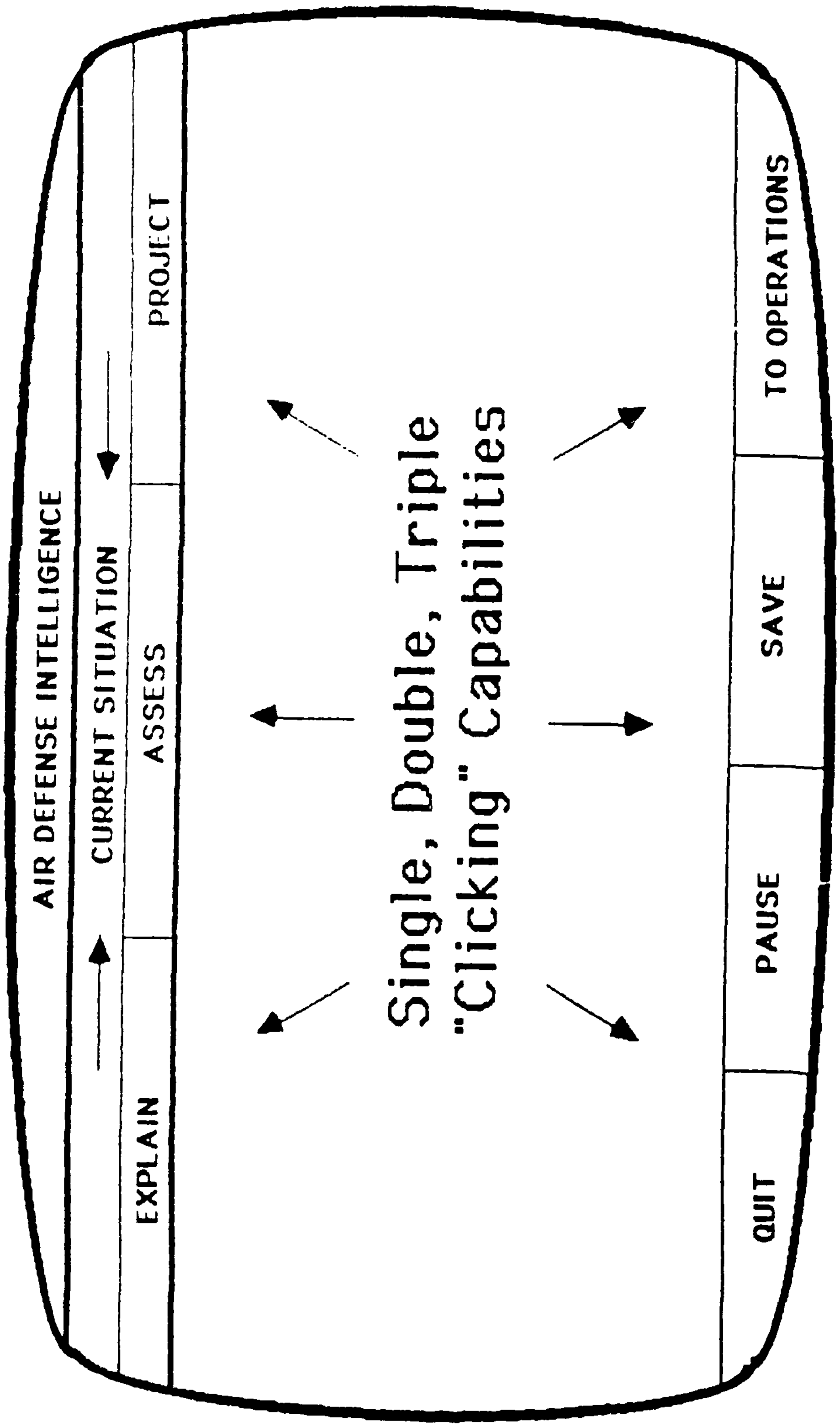

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
INDICATORS
MODELS
ANALOGIES
"Explain" Sub-Menu
Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

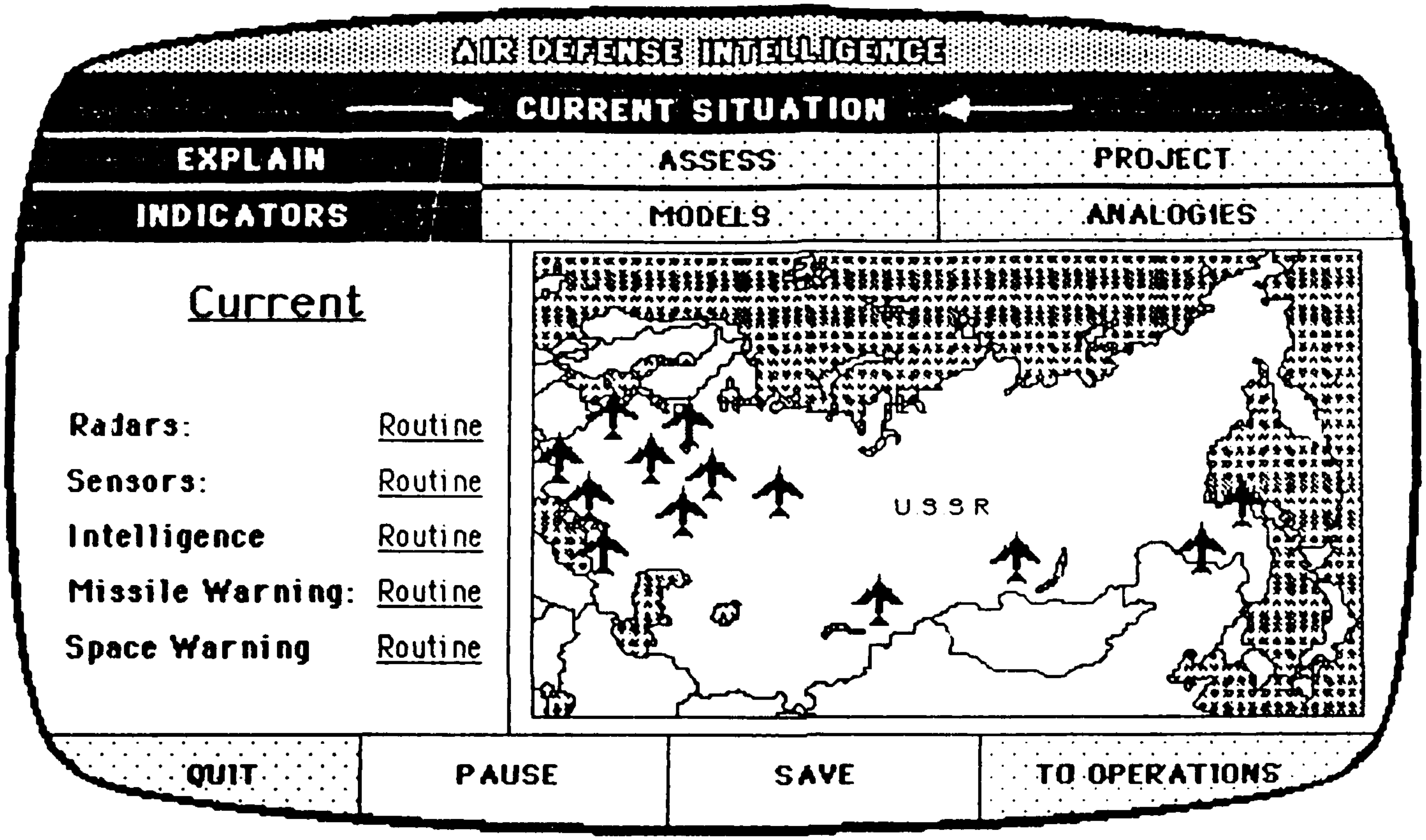

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
THREAT DESCRIPTION
THREAT LOCATION
THREAT DISPOSITION
"Assess" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
"Project" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

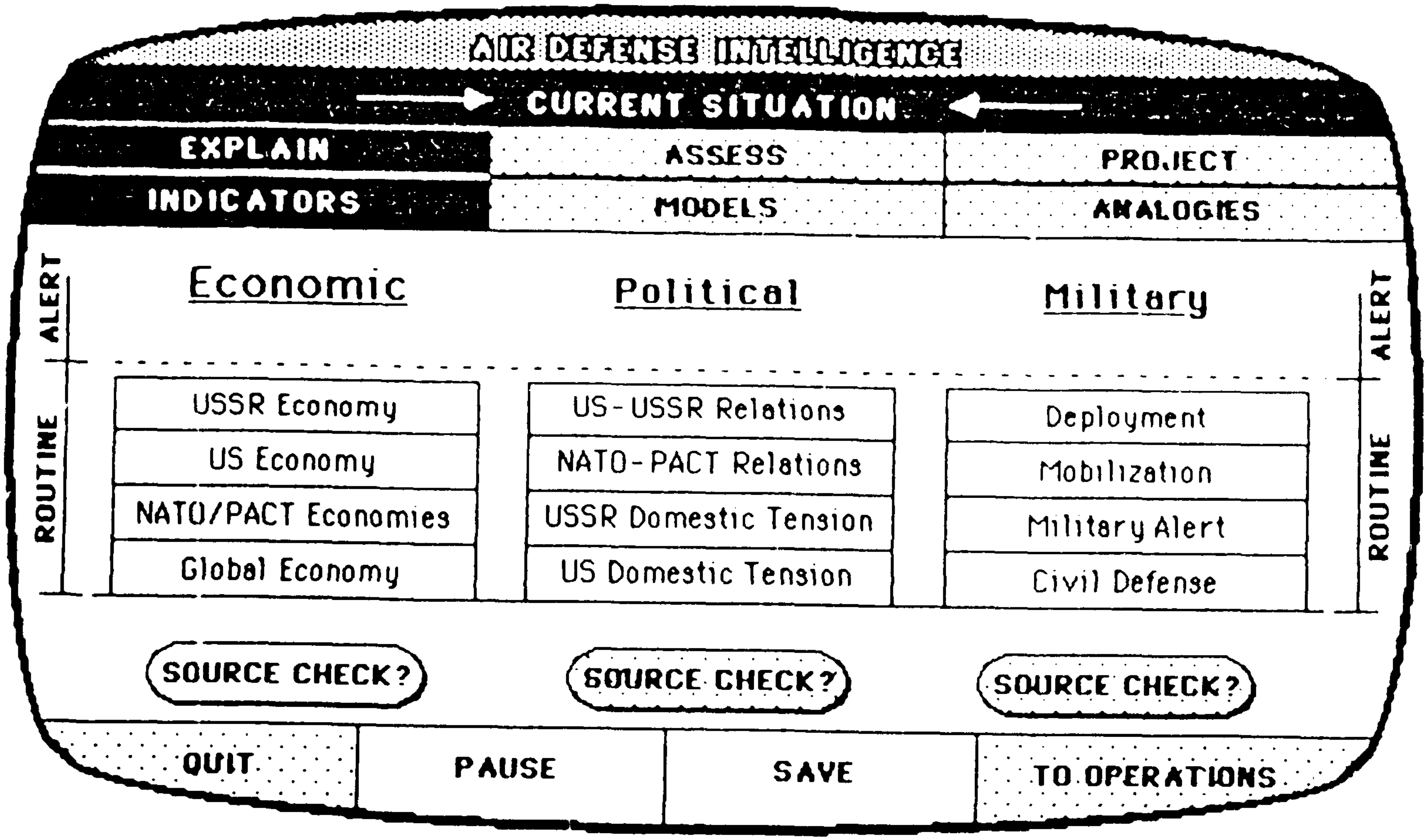

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Exemplar
System Commands
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
"Portal" To Air Defense Operations
QUIT
PAUSE
SAVE
TO OPERATIONS

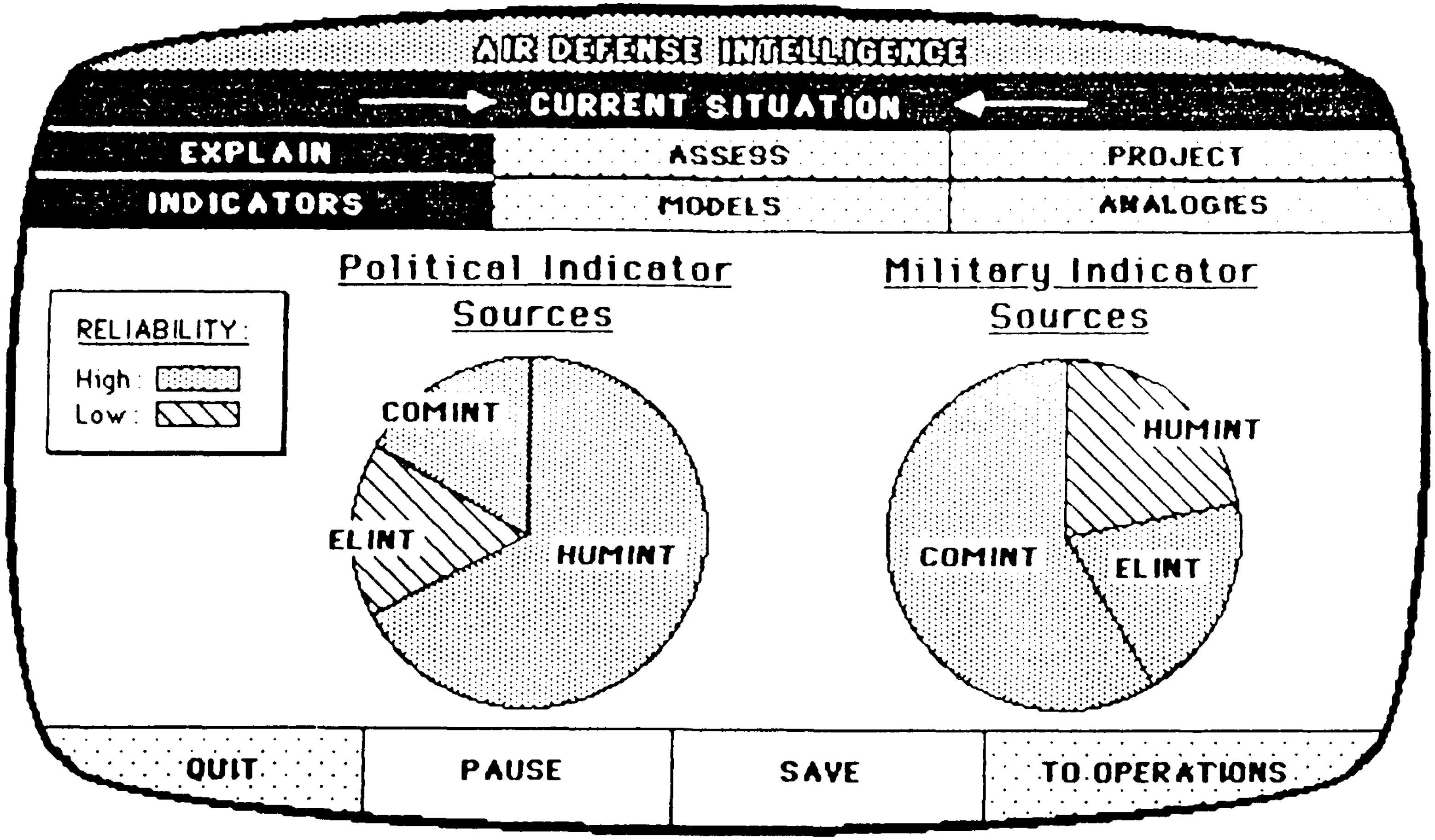

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Single, Double, Triple
"Clicking" Capabilities
QUIT
PAUSE
SAVE
TO OPERATIONS



This display presents a map of the Soviet Union that locates its long range aviation (bomber) capabilities. The system also presents data on the missile and space threat. The user -- having received an overview of the current situation -- decides more information is necessary. He selects the **Explain Indicators** option (with two clicks). Hierarchical data, information and knowledge organization and storage is by design: human information processors store information hierarchically (from general-to-specific and specific-to-general). The system is structured to be compatible with human data, information and knowledge organization and storage.



The system presents a list of indicators to the analyst. The indicators are organized around economic, political and military behavior patterns, patterns that would explain routine, alert and warning situations. The system asks the user if he wants more information about the indicators, especially about their source and reliability. User queries and responses are recorded by the system and correlated with previous user-system interaction. User profiles are developed over time and on-line.



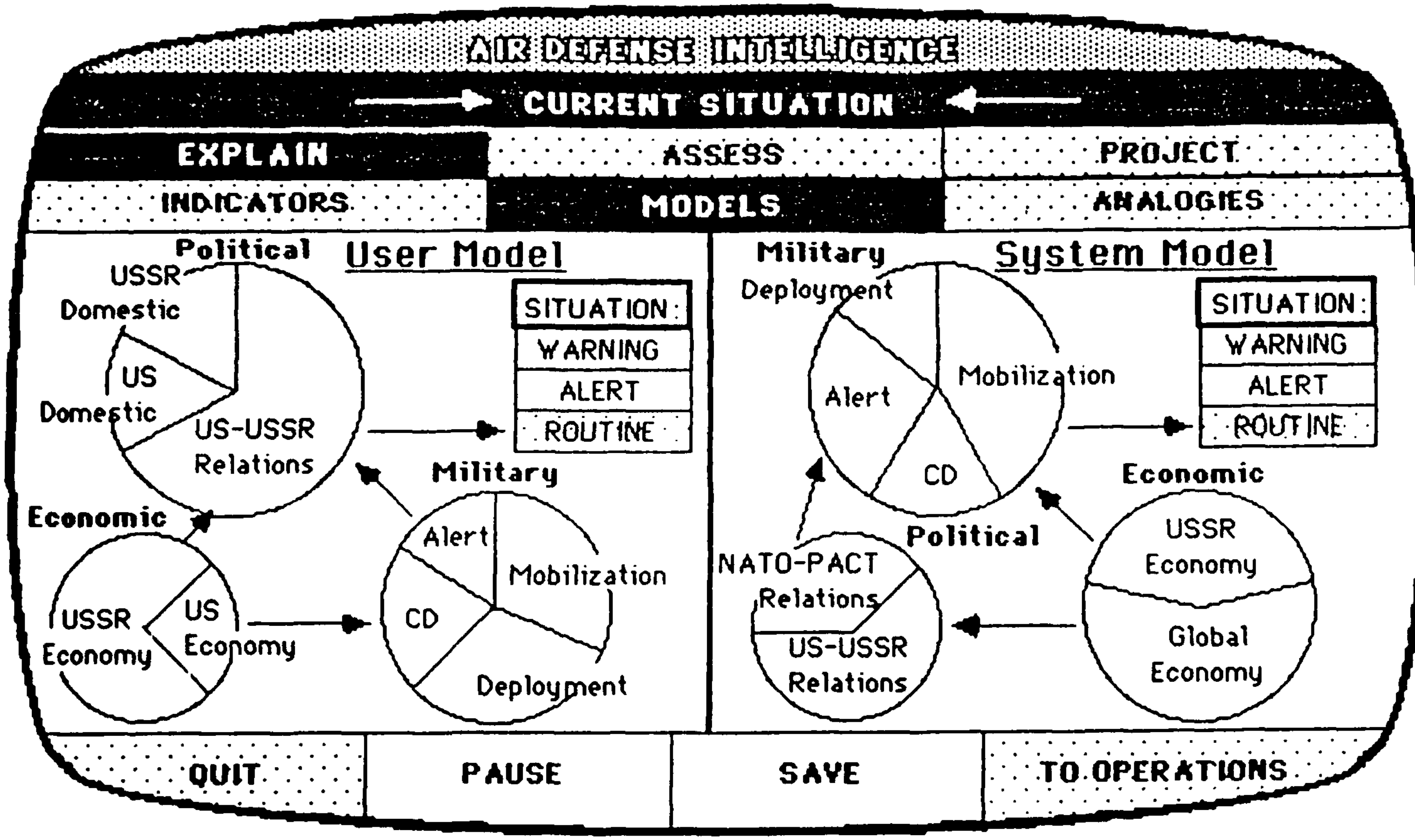
The system displays information about where the political and military indicator information came from, and whether or not it is reliable. The system records the user's interest in the indicators; the user requests information about the models used to generate the intelligence estimate (by clicking on **Models**).

icons. The interaction process is alternately "controlled" by the system and the user. As the next several displays suggest, the system is capable of monitoring the analytical behavior of the user and feeding it back to him for inspection. This capability is consistent with findings from cognitive science that suggest that performance is enhanced via feedback. The modeling process is presented in rough causal form because human information processors tend to organize problem-solving (and especially inference-making) by applying causal schema. Analogical reasoning is supported by the system's matching relevant cases to the current analysis.

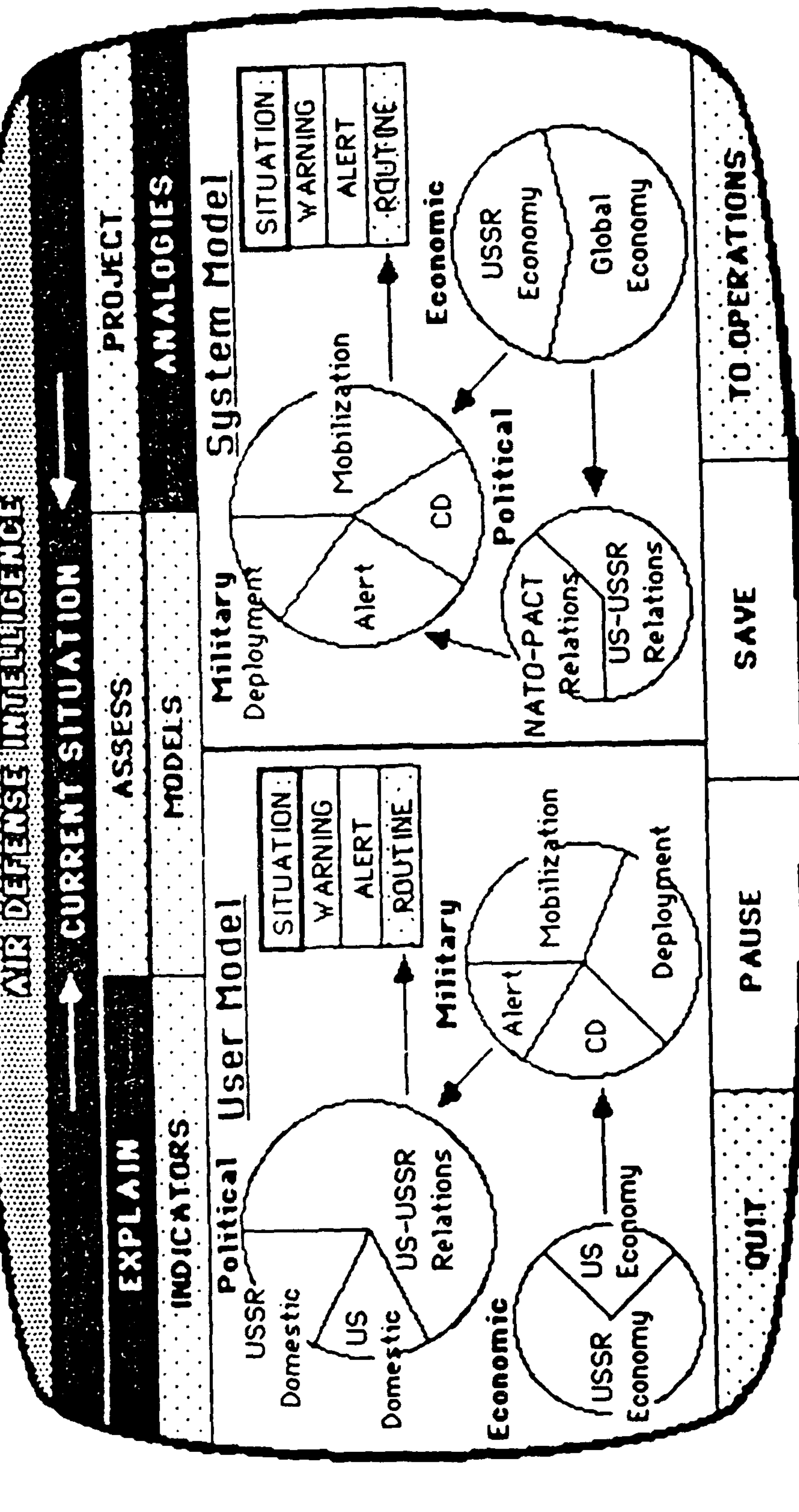
The system also provides analysts with the capability to conduct "if - then" analyses by querying the system about indicator values if, for example, a warning was imminent.

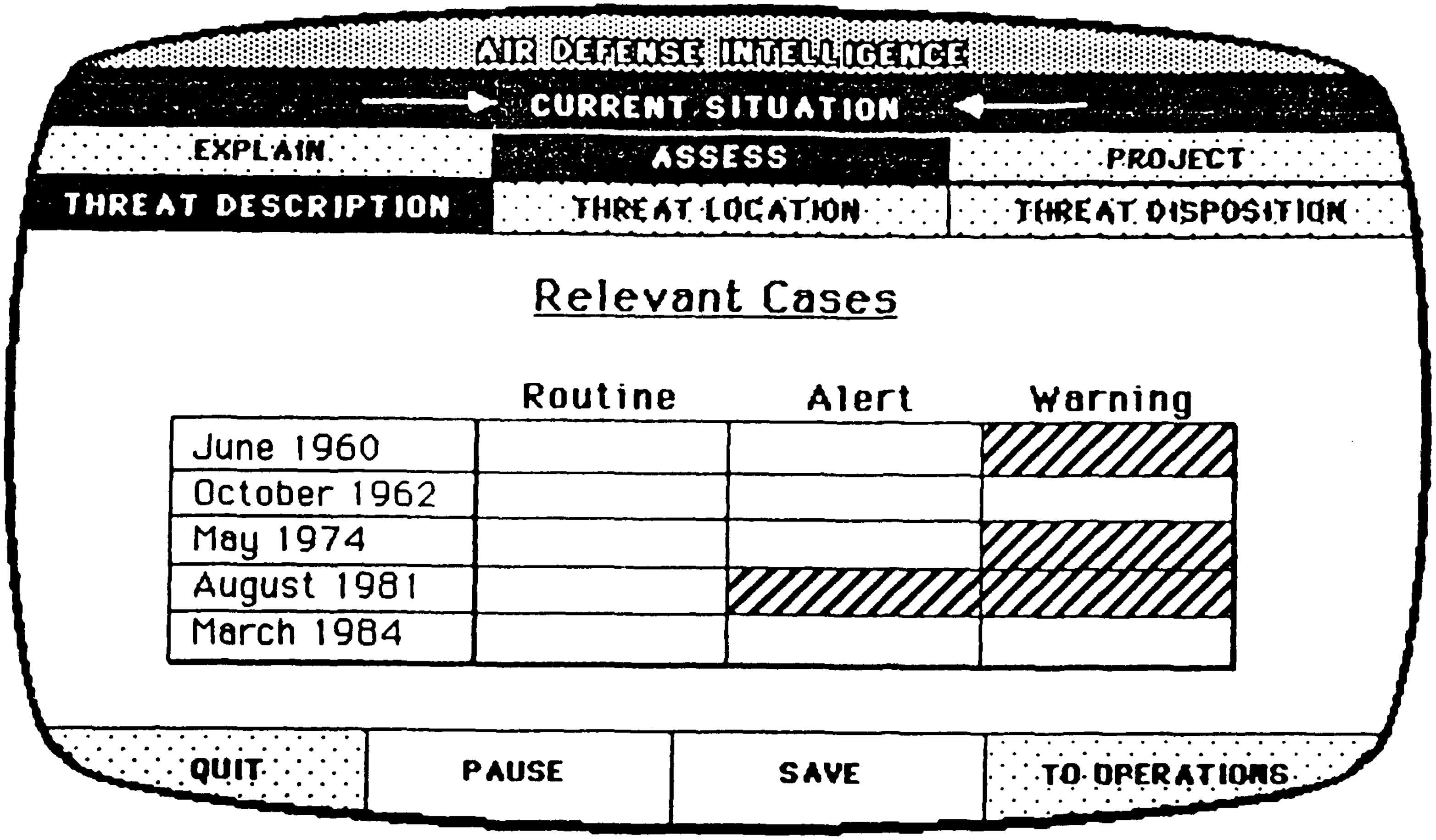
All of these and other capabilities are demonstrated in the intelligence prototype. The full prototype appears in Appendix B. Textual descriptions of each display are also provided. These descriptions suggest precisely where findings from cognitive science and advanced information technologies have been leveraged.

5.5.2 The Air Defense Operations Prototype - This prototype is anchored in a specific scenario that might well occur any time at the "Top ROCC" (NORAD's Region Operations Control Center at Elmendorf AFB near Anchorage, Alaska). The scenario in the

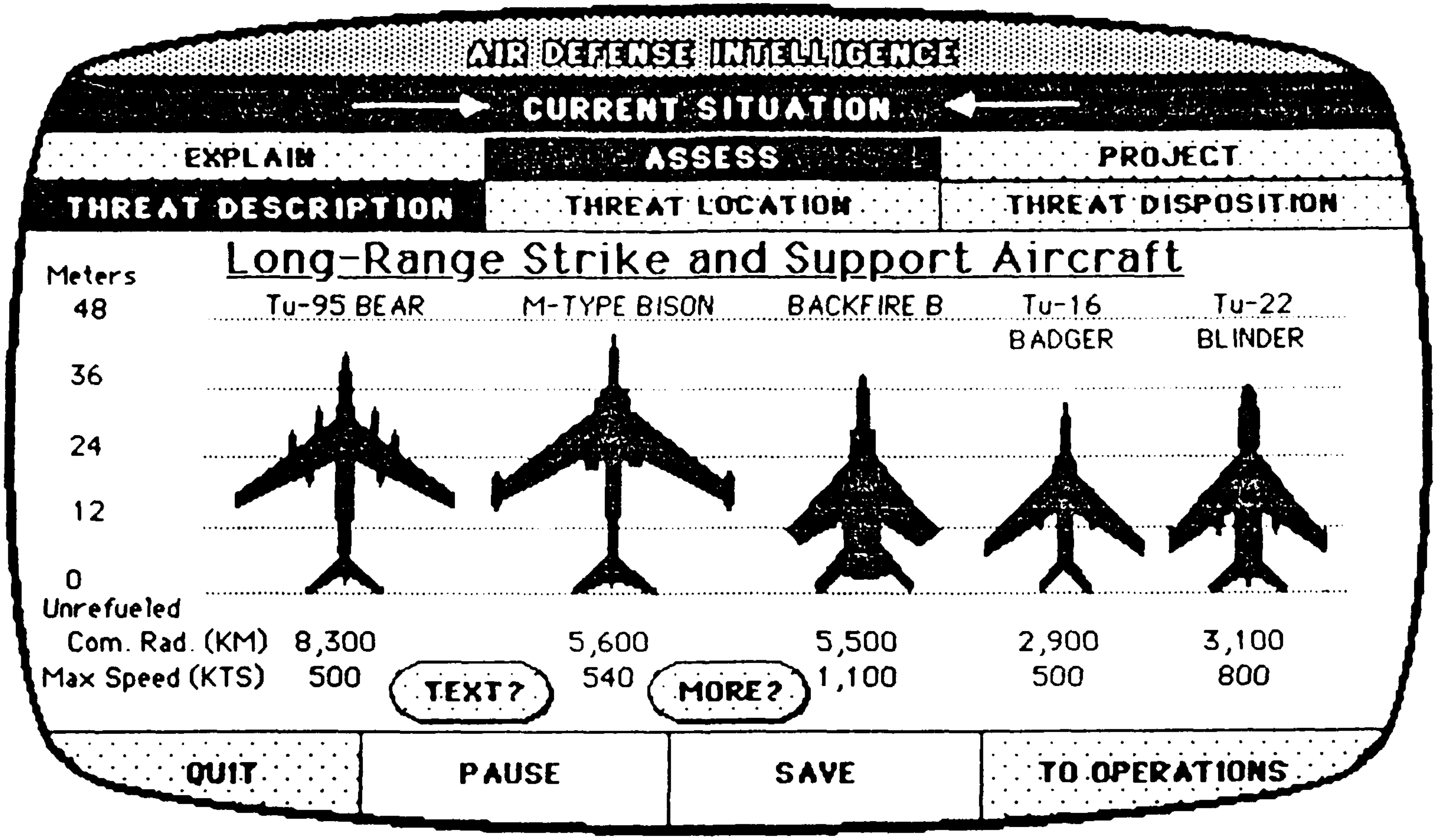


The system displays two models to the user -- that differ in some important ways. The "user model" was constructed by the system from previous user-system interaction and from the queries and responses by the user during the session at hand. The system is providing feedback to the user on his cognitive modeling of the current situation. The "system model" was developed from the system's embedded models. They are presented side-by-side to call attention to the differences and stimulate additional user analysis. The models are presented as "causal"/"influence" diagrams of the situation assessment process, since analysts tend to diagnose problems causally. The user then selects **Analogies**.

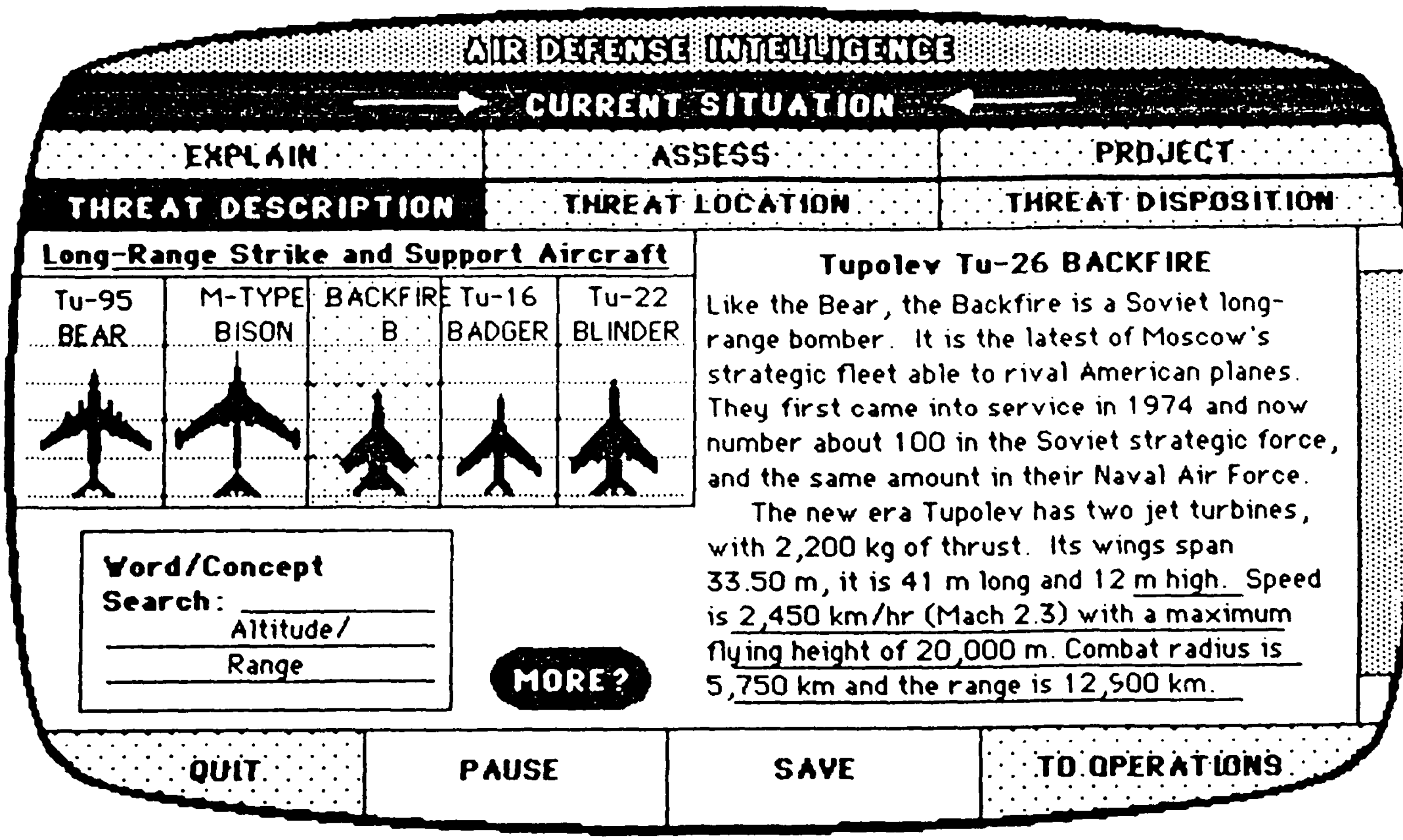

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
INDICATORS
MODELS
ANALOGIES
User Model
SITUATION
WARNING
ALERT
ROUTINE
Political
USSR Domestic
US Domestic
US-USSR Relations
Military
Alert
CD
Mobilization
Deployment
Economic
USSR Economy
US Economy
System Model
SITUATION
WARNING
ALERT
ROUTINE
Military
Deployment
Alert
CD
Mobilization
Political
NATO-PACT Relations
US-USSR Relations
Economic
USSR Economy
Global Economy
QUIT
PAUSE
SAVE
TO OPERATIONS



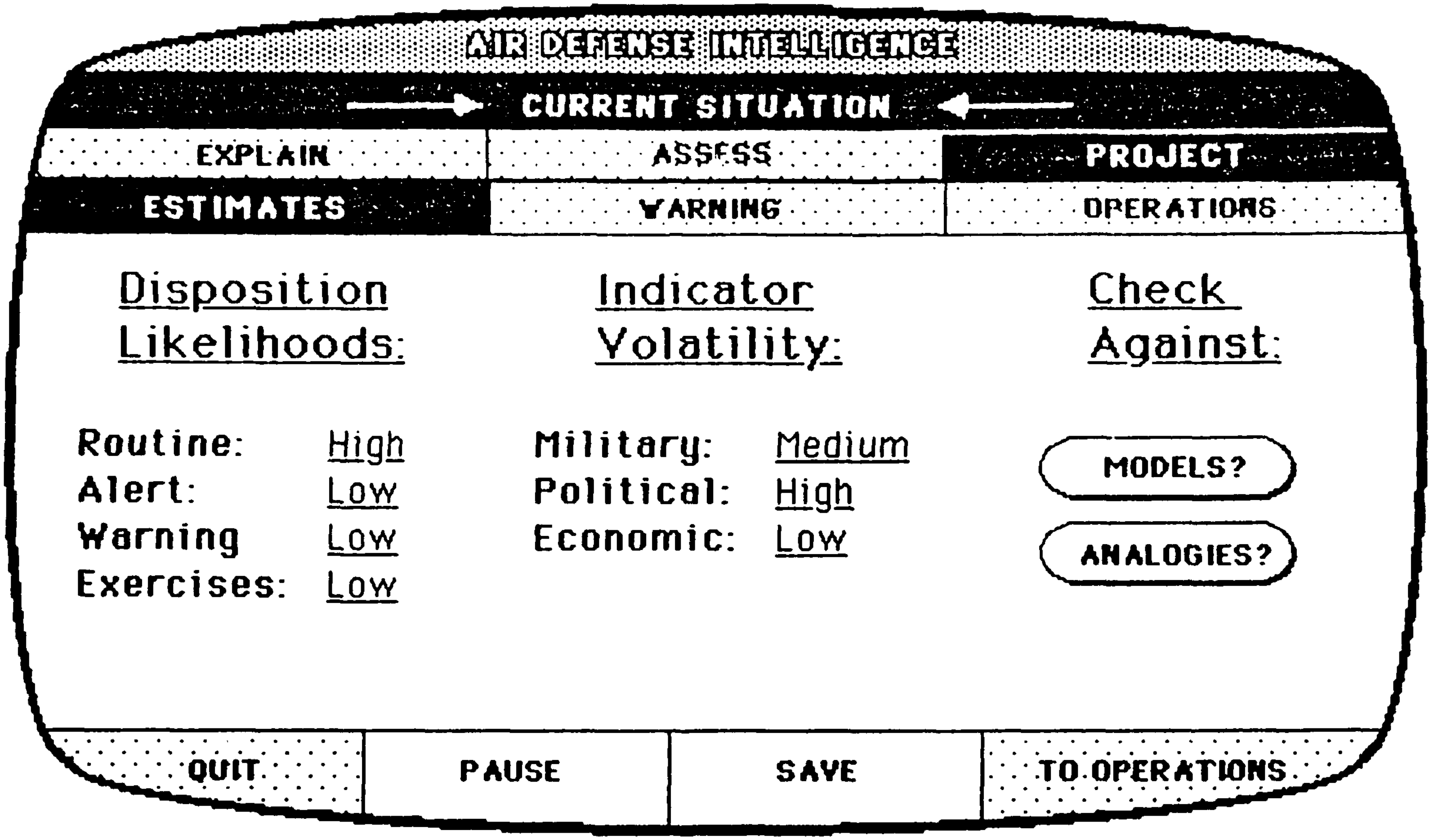
The system identifies the "cases" that are relevant to the current situation. It identifies -- via a simple pattern recognition process -- a set of dates and situations for inspection by the analyst. While the storyboard does not illustrate the process, the analyst would be capable of calling up "causal/influence" diagrams of the past and overlaying them onto the current situation for comparison. The user then clicks on **Assess Threat** for additional information.



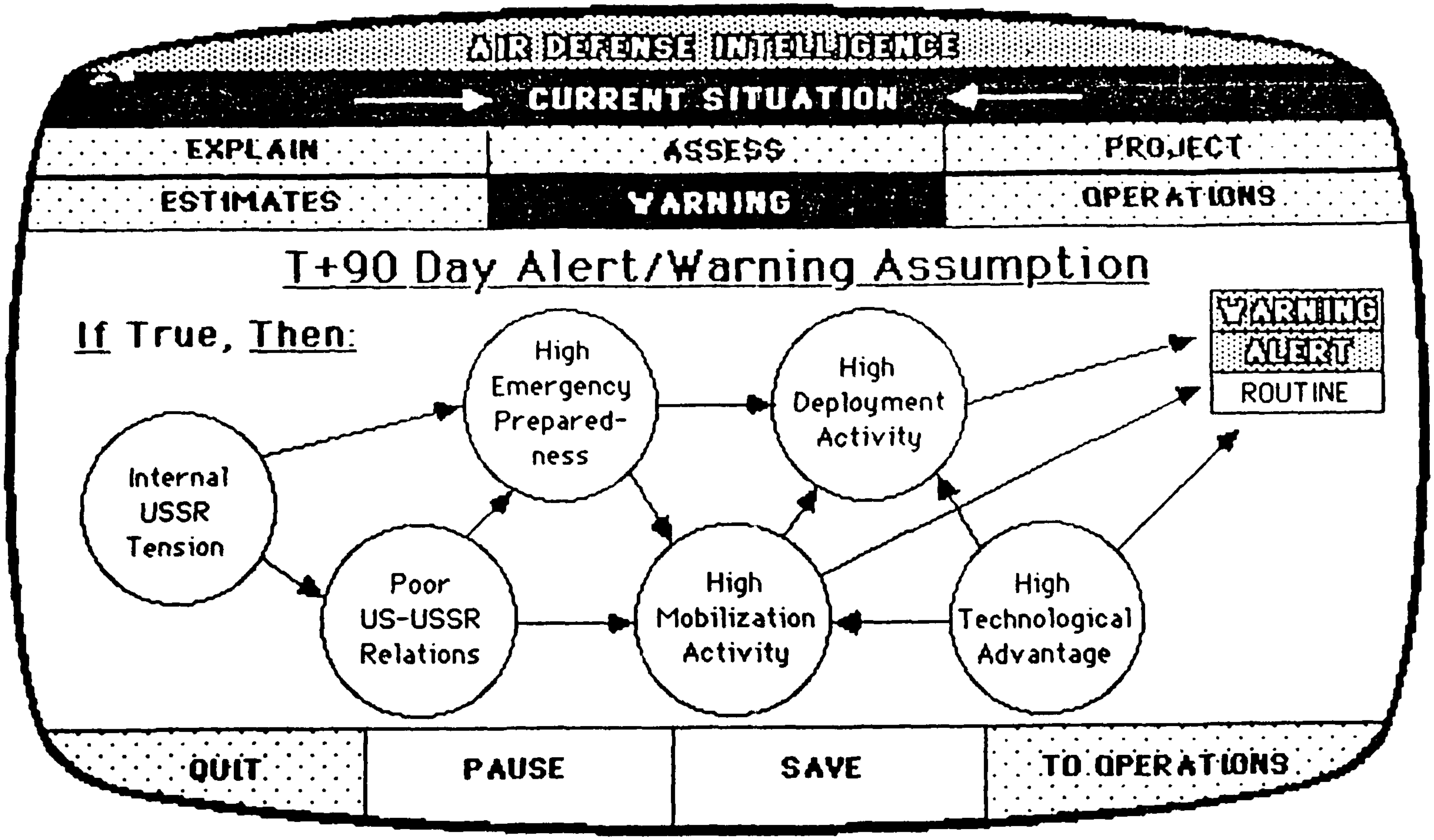
The system presents information on the long range bomber (and support aircraft) that comprise a large segment of the Soviet threat. The system provides options for **Text** and **More?** data. The analyst clicks on **Text**.



The system provides a scrolling textual data base on the bombers as well as a hypertext search capability. In the example, the user inputs two key words ("altitude" and "range") and the system highlights the places in the text where references to the words/concepts appear. Icons are used to search through the data base; the user then clicks on **More?**.



The system presents disposition likelihoods to the analyst and provides the analyst with the opportunity to check the likelihoods against inference **models** and pertinent analogies. The analyst then clicks on **Project Estimates**.



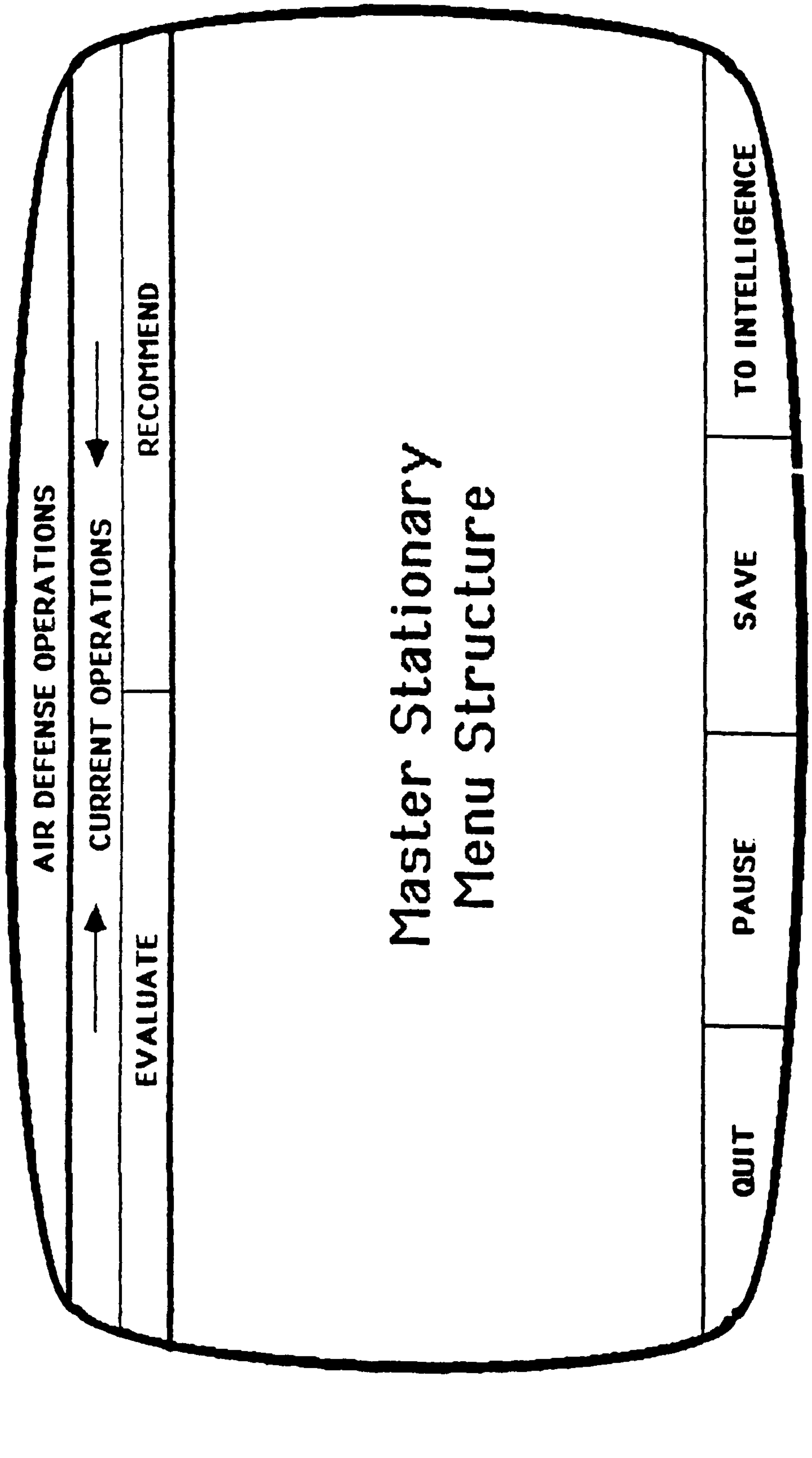
The system suggests that "if warning is true, then . . . " the following inferential relationships will also be true. This capability permits analysts to play "what - if" games with the system, and call the system's knowledge base into question, when appropriate. The capability also helps suggest how intelligence collection assets should be tasked, if the analyst is "looking" for something in the threat environment. The user then clicks on **Operations**.

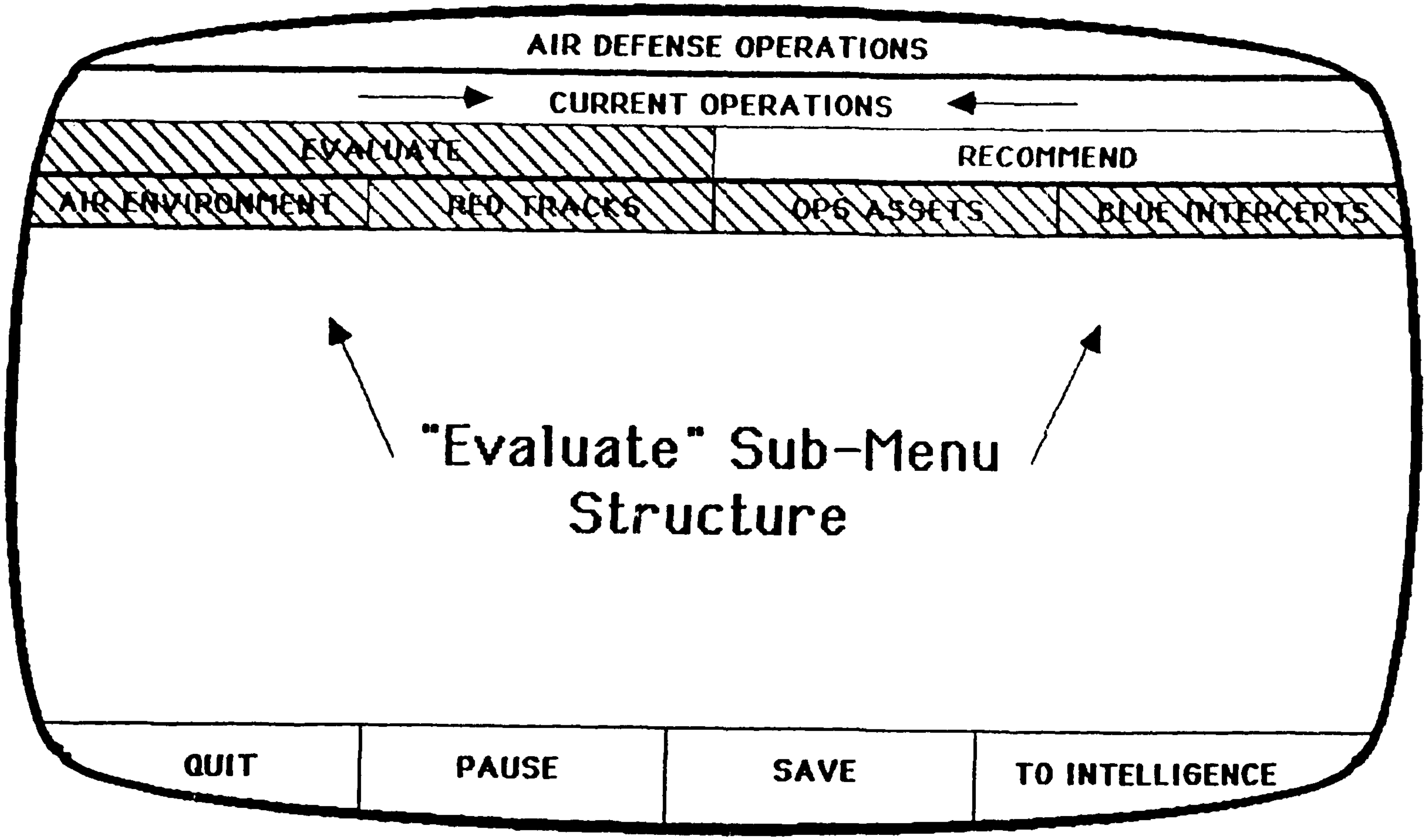
storyboard begins with a radar identification of unknown aircraft in the region.

The menu structure for the operations prototype appears below. Like the intelligence prototype, the menu structure is simple and stationary. It is also designed to be operable by either the intelligence or operations analyst. Like the intelligence prototype which provides a portal to operations, the operations prototype permits access to the intelligence analysis and production system. Windows, graphics and icons are also used to communicate with users.

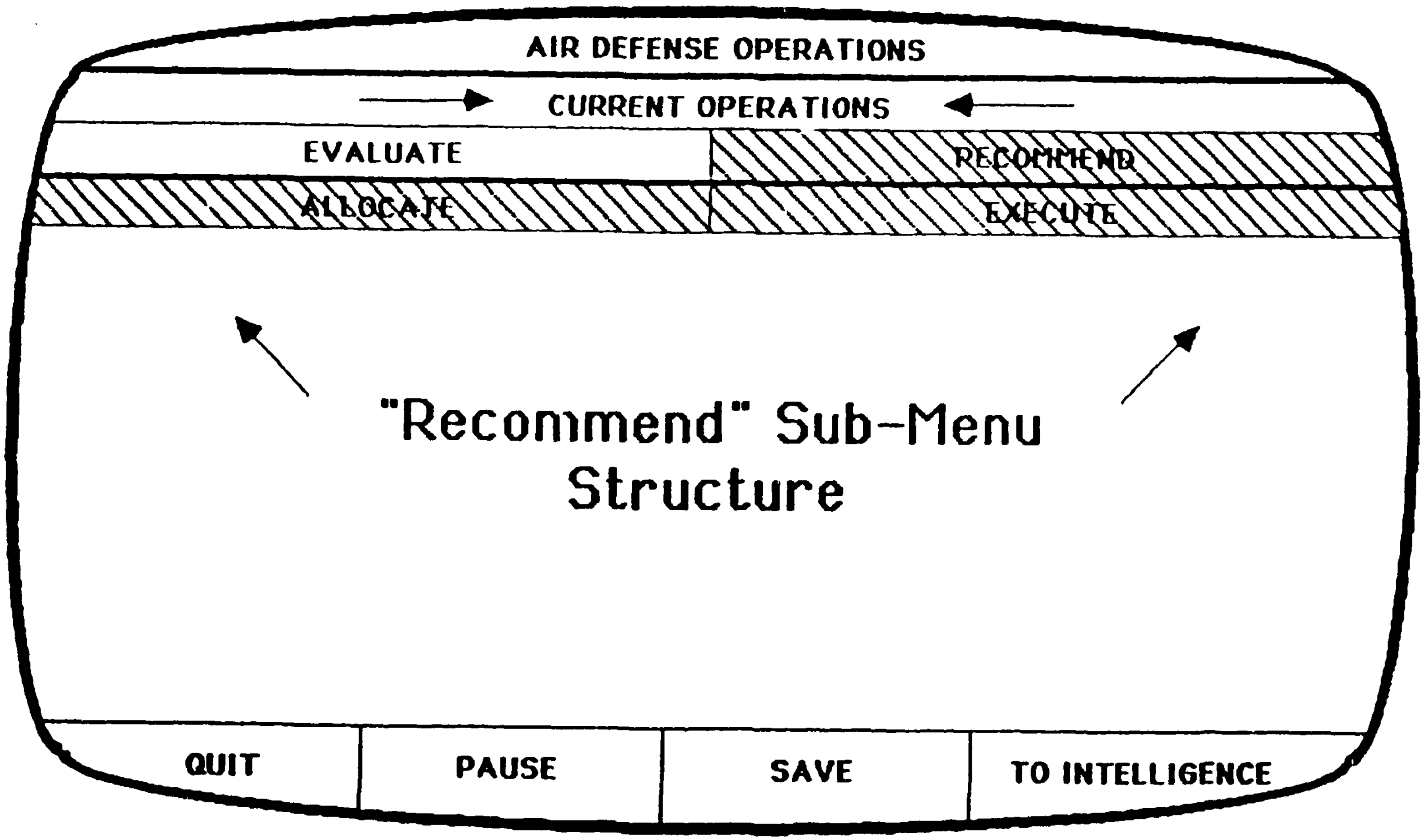
The prototype suggests that operations tasks can be templated, and that a healthy percentage of activity can be system controlled. Intercept tracks, for example, can be calculated given projected Soviet tracks. Criteria for selecting among competing plans can also be presented to the user for examination. As the following displays suggest, the system presents the user with its planning assumptions and the user is free to change the assumptions. The decision-making process is made explicit through this iterative process, and the user will learn about the assumptions and processes embedded in the system as well as his own. The system also permits the testing of plans and the means by which competing plans can be compared.

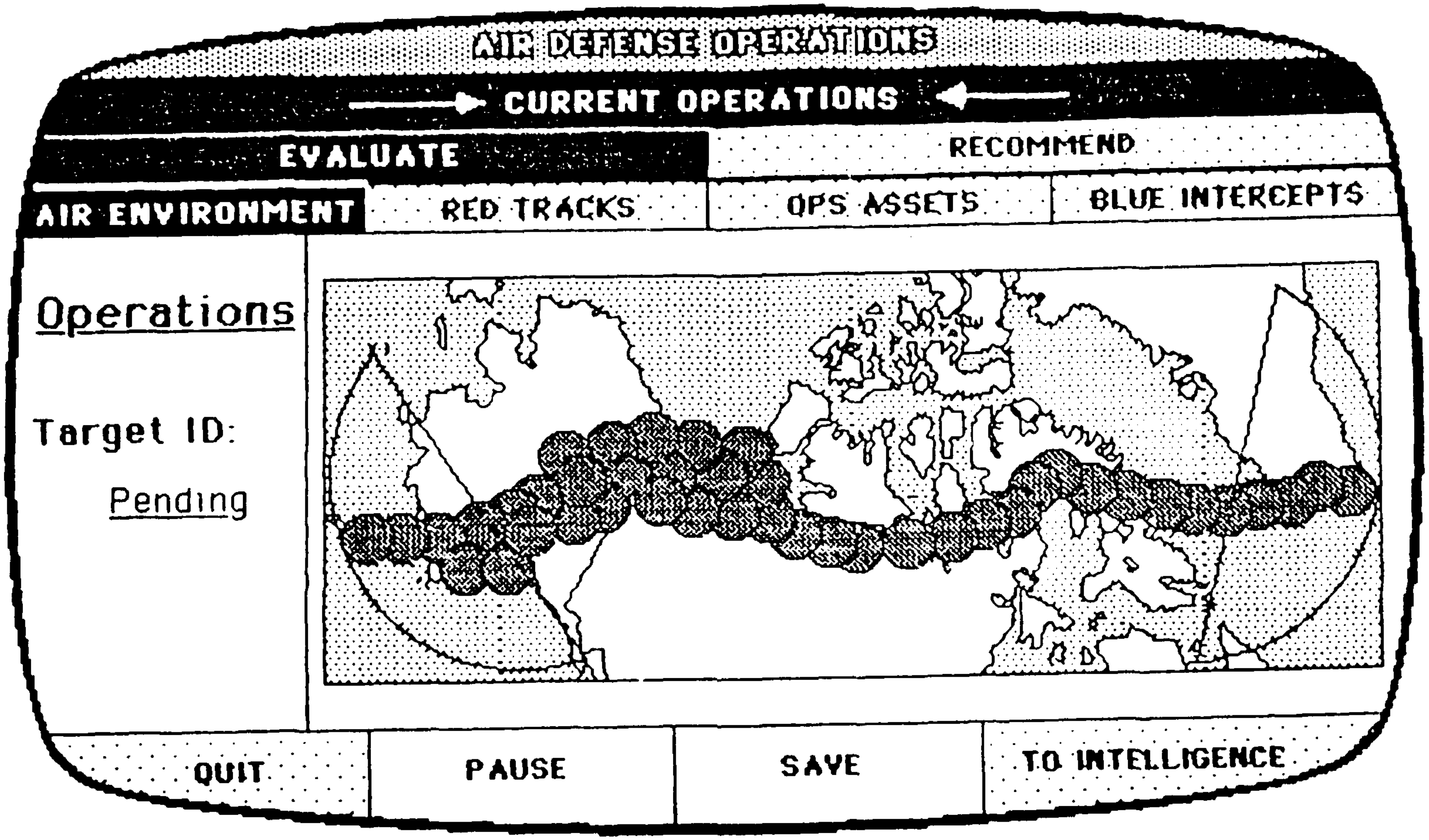
The complete operations storyboard prototype appears in Appendix B. Textual descriptions of each of the displays appear below each storyboard.


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Master Stationary
Menu Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE

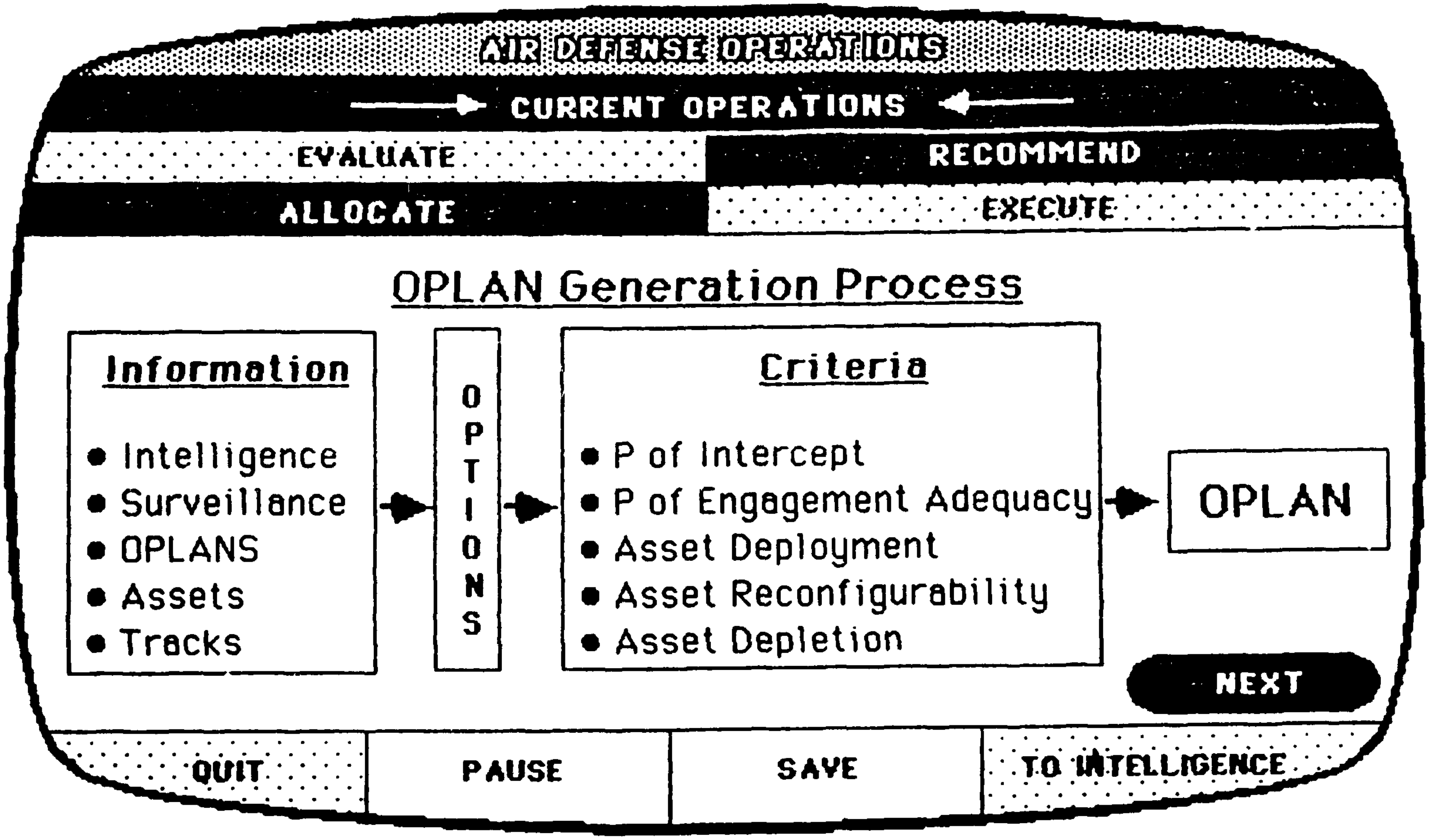


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
"Evaluate" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE

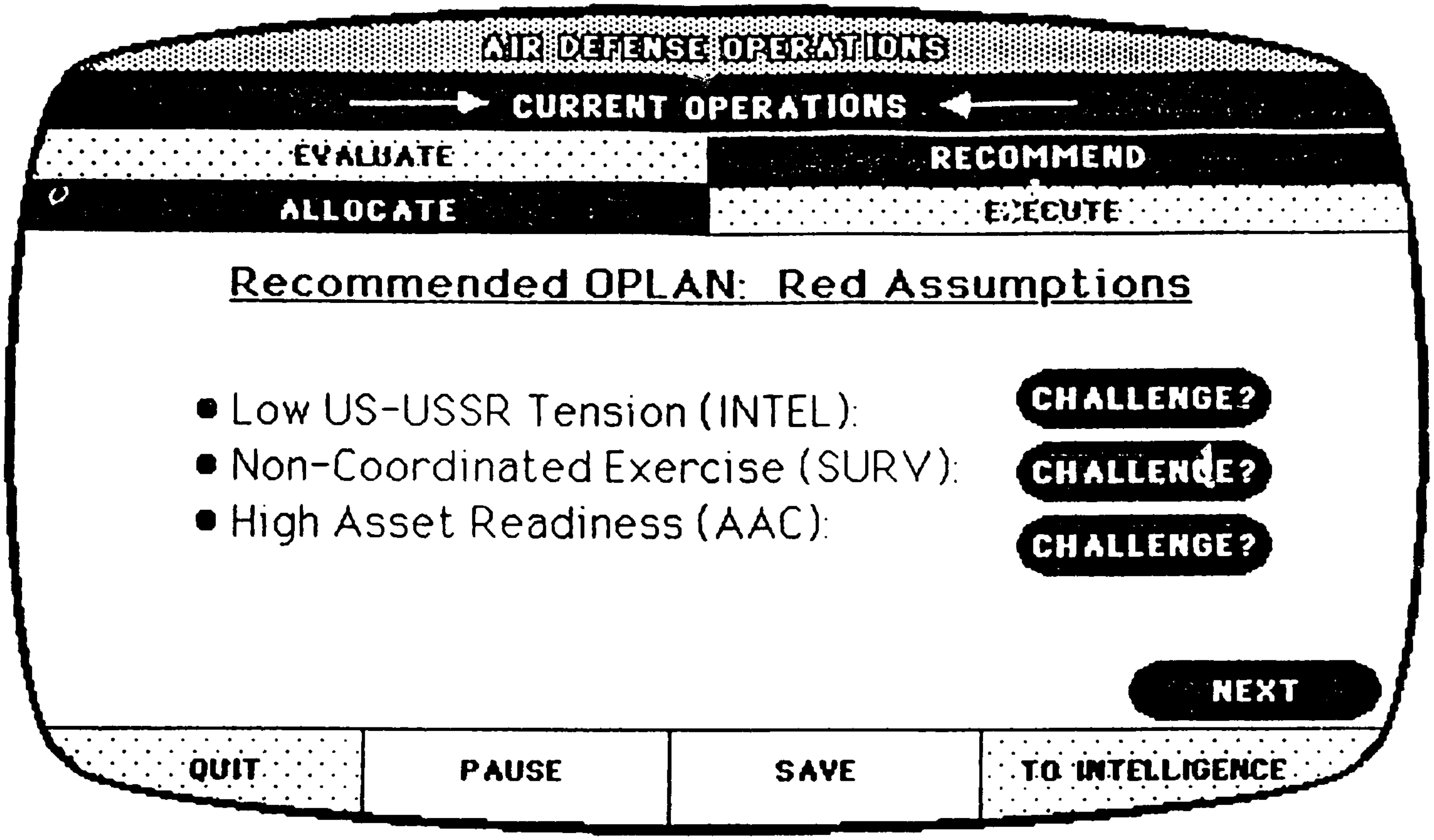

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
"Recommend" Sub-Menu
Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE



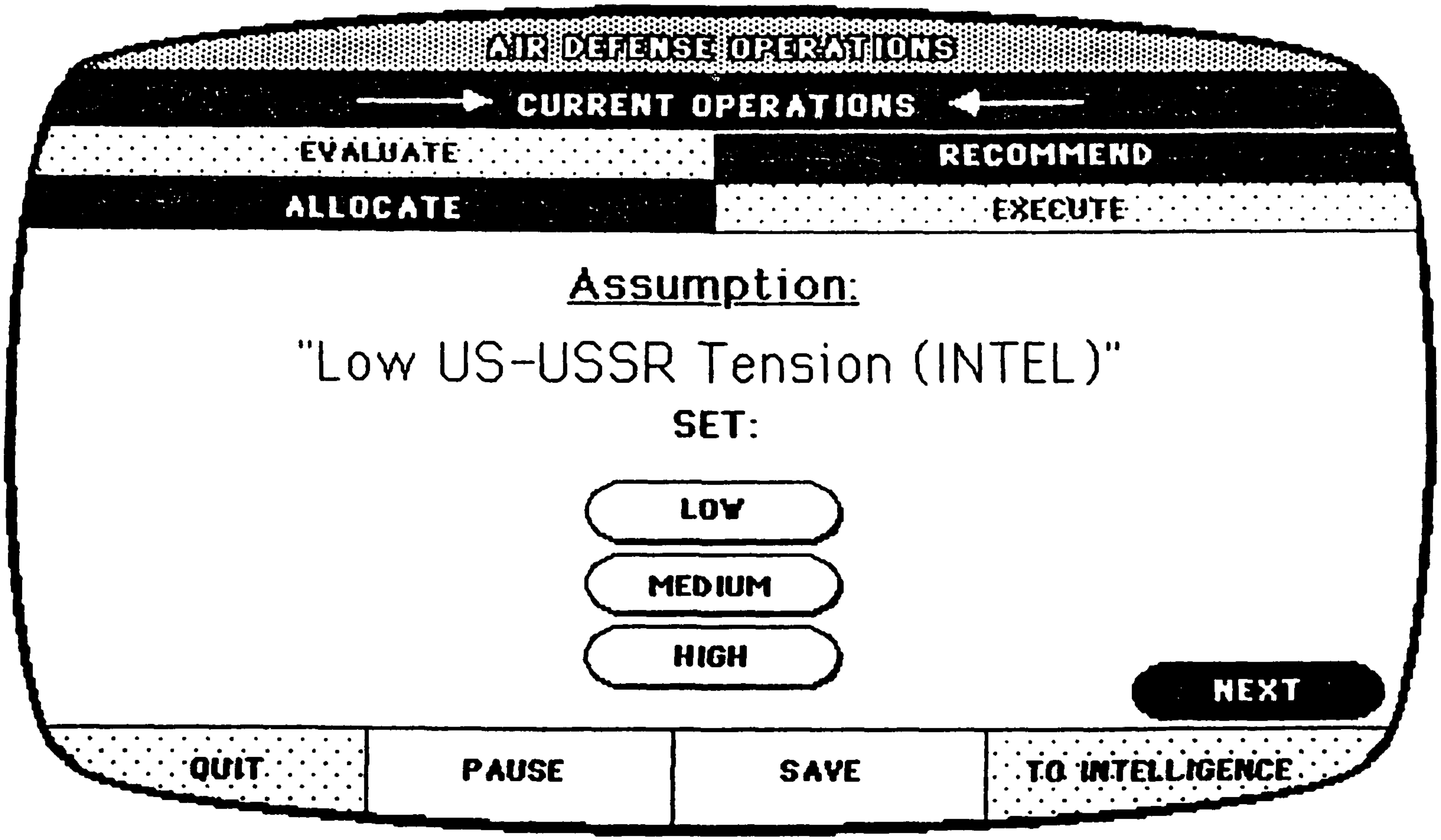
This display presents the current situation at the "Top ROCC," NORAD's Region Operations Control Center at Elmendorf AFB near Anchorage, Alaska. Surveillance has detected several aircraft in the zones of coverage that surround North America. The target ID is designated as "pending," consistent with ROCC operations. The user clicks on **Evaluate Air Environment** to get more information about the situation.



After the user challenges the system, the system presents its "internal (decision-making)logic" to the user. Here the system is actually displaying its option generation/selection process to the user. Users are better able to understand system output if they understand the model from which it came. The system suggests that it processes information, then looks to a set of correlated candidate OPLANS, and then scrutinizes them vis-a-vis a set of normative criteria. The user clicks on **Next**.



The system then displays the key assumptions it made during the OPLAN calculation. The user can override the system's assumptions by **Challenging** them. In effect, this capability permits users to alter the facts (conditions; stimuli) that trigger the system's knowledge base about optimal OPLANS given certain (pre-specified) sets of conditions. This additional insight into the system's decision-making process provides users with a deep understanding of the option generation/selection process and, therefore, into their own decision-making processes (via their agreement or disagreement with the system). He clicks on **Next**.

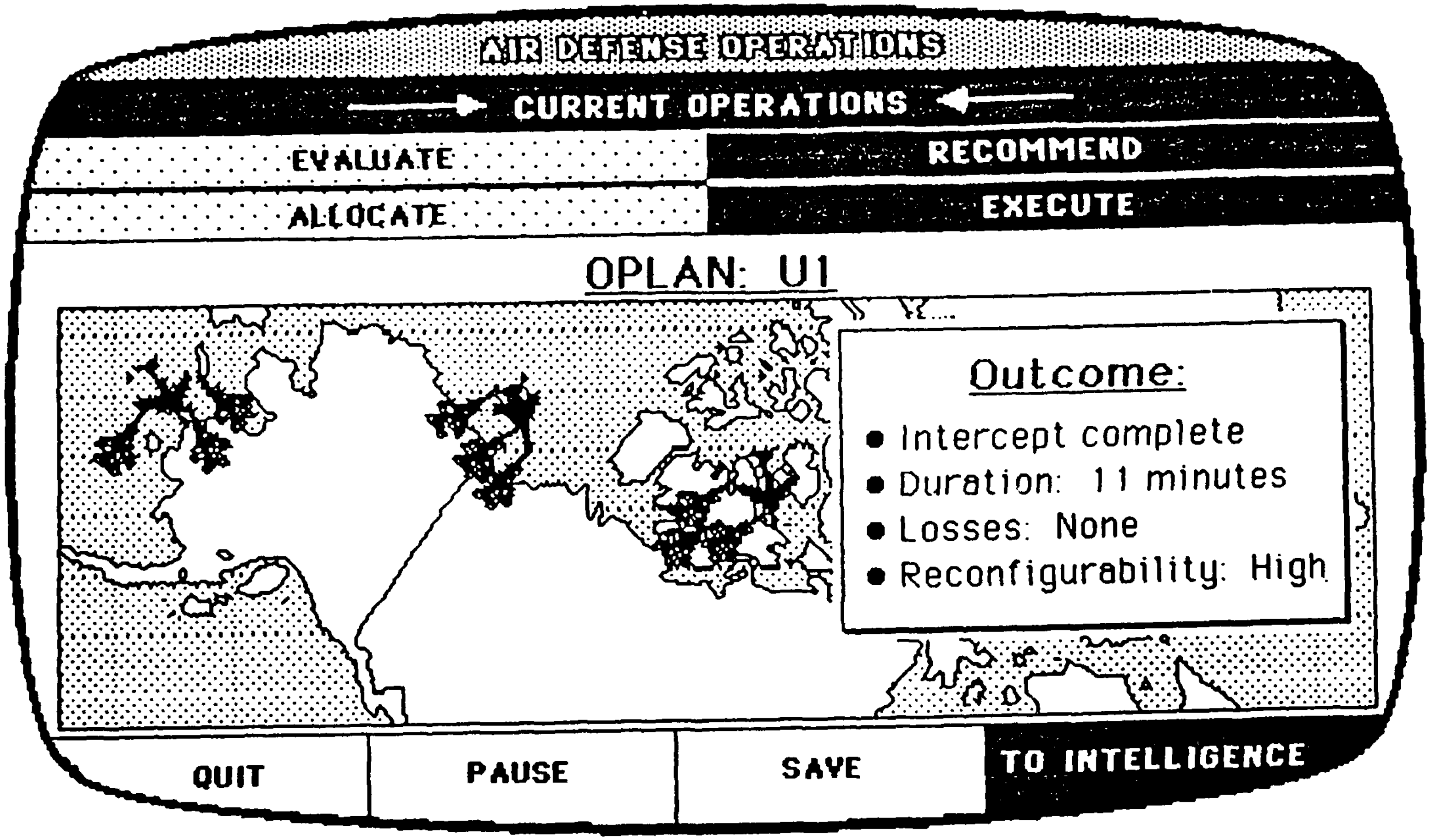


The system permits the user to change the planning assumption. He clicks on **Next**.

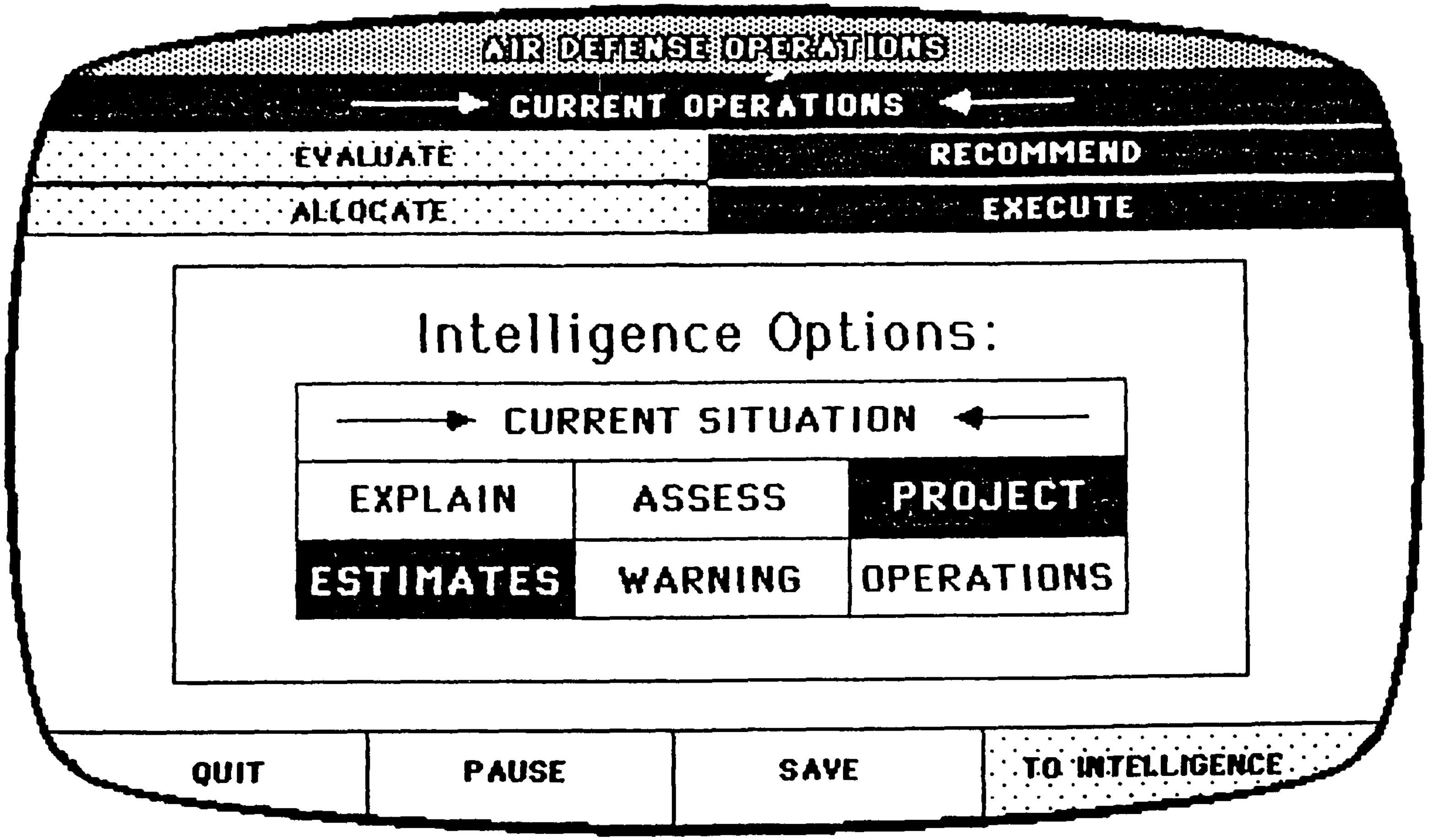
5.5.3 The Air Defense Intelligence/Warning/Operations Interface Prototypes - There are several mini demonstrations of how advanced information technology and cognitive science can combine to connect the intelligence and operations processes. The portals in the air defense intelligence and operations storyboards are used to suggest how the intelligence/operations interface can be supported via unconventional systems design.

In the first demonstration the operations planner has two plans to consider. One will yield a faster intercept of unknown aircraft than the other, but the "longer" one will leave the commander with greater flexibility to reconfigure his forces, if necessary. The decision to go with the shorter, but less reconfigurable, plan hinges on the need to reconfigure. But the need to reconfigure is part of the larger intelligence and warning process. In the demonstration the operations planner leaves the OPLAN generation process and enters the intelligence analysis process to determine what the short and longer term futures hold for his region. What are the estimates about Soviet strategic behavior? What is the likelihood that the current situation is part of a larger Soviet operation? Such questions should guide the option selection process. The answers will determine which plan should be selected.

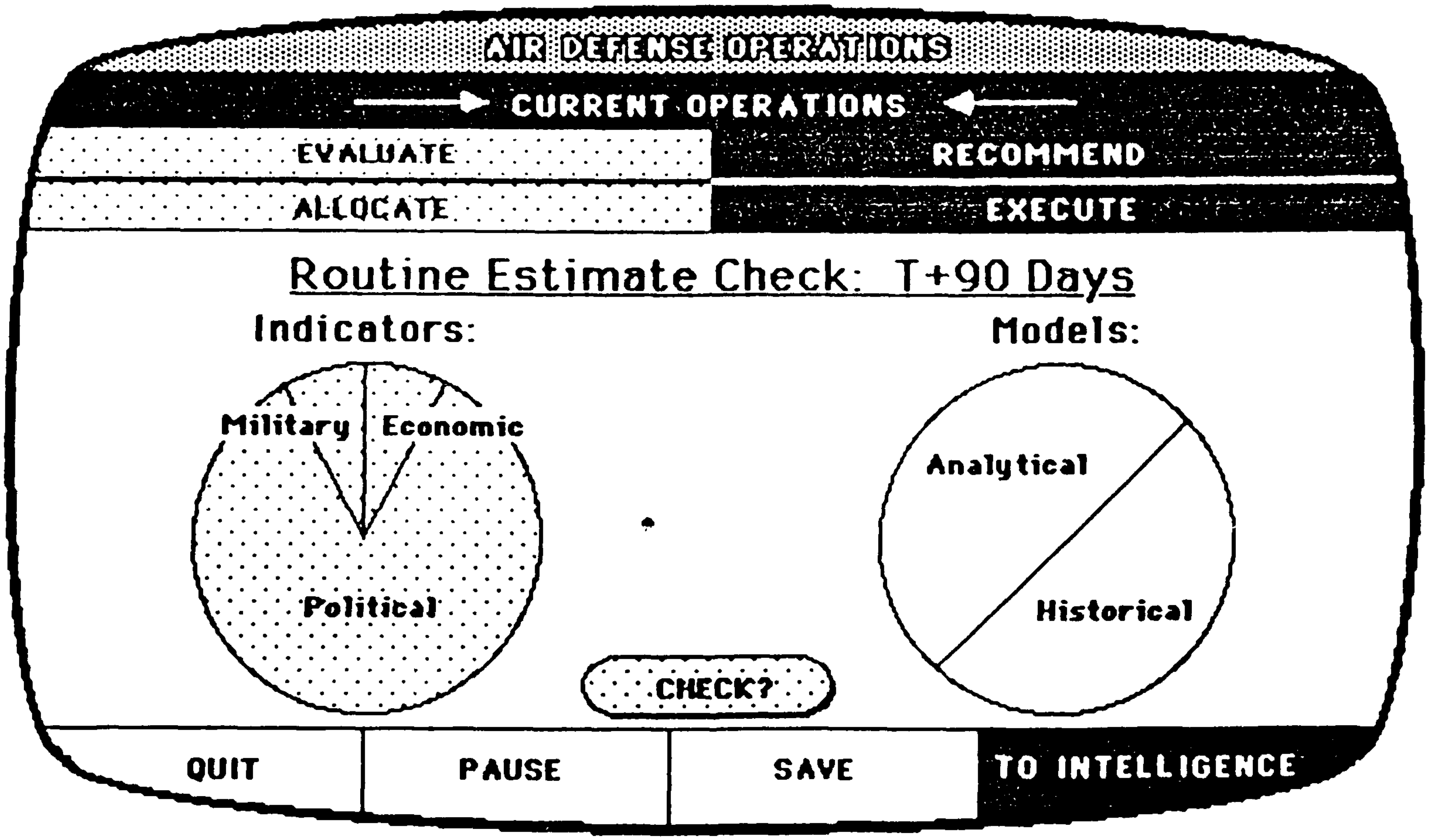
The figures below suggest how the portal can be accessed and how operational planners can access the intelligence analysis and production process. The complete mini-storyboard appears in



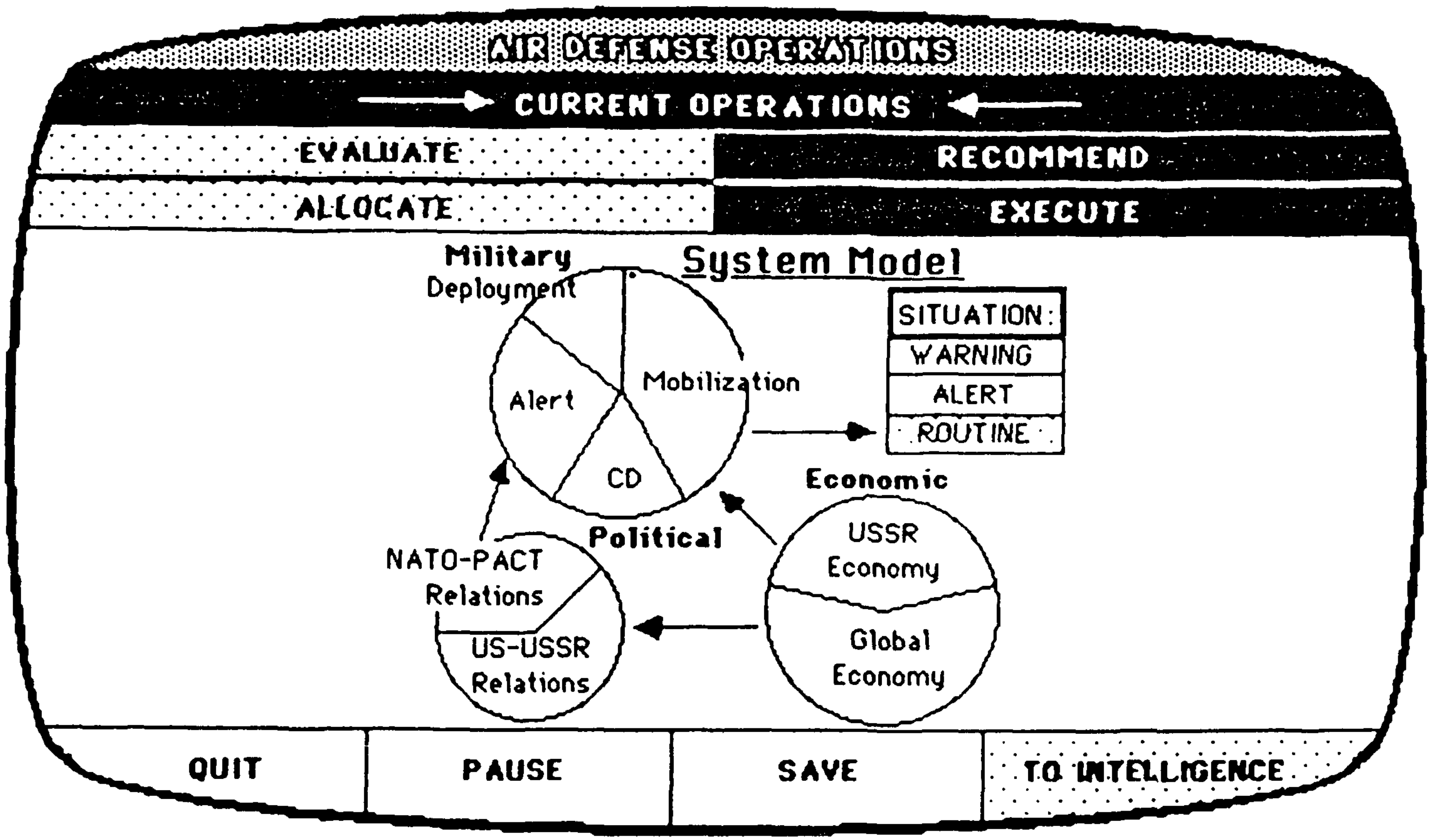
This display presents the results of a second plan. The trade-off is simple: time versus reconfigurability. If the likelihood of a sustained threat -- a war -- is great, or the likelihood of repeated air space violations is high, then there may be good reason to favor the reconfigurable plan over the "faster" one. But without information about the likelihood of these two events, the planner cannot make a good decision about which plan to select. He clicks on **To Intelligence** for real-time insight into the overall threat situation.



The planner is now in a different world -- the intelligence world. He has, in fact, entered the intelligence analysis and production system via his workstation. This linkage presumes electronic access to intelligence data and the intelligence process. The planner is presented a menu of intelligence analysis options. He decides to look first at the projections of US/USSR hostility likelihoods. He clicks on **Project/Estimates**.



The intelligence system shows the planner the reason why increased tension is expected . . . he clicks on **Check?**.



The system presents its inference model to the planner. Note that the planner is seeking information about the likelihood of increased tension between the superpowers to determine if he should favor reconfigurability over timeliness. The operations planning system provided direct access to the intelligence analysis and production system, as well as the capability to browse through the inference models embedded in the system. Specific queries can be made quickly and resolved much faster than if OPS tasked INTEL to conduct additional analyses.

Appendix B.

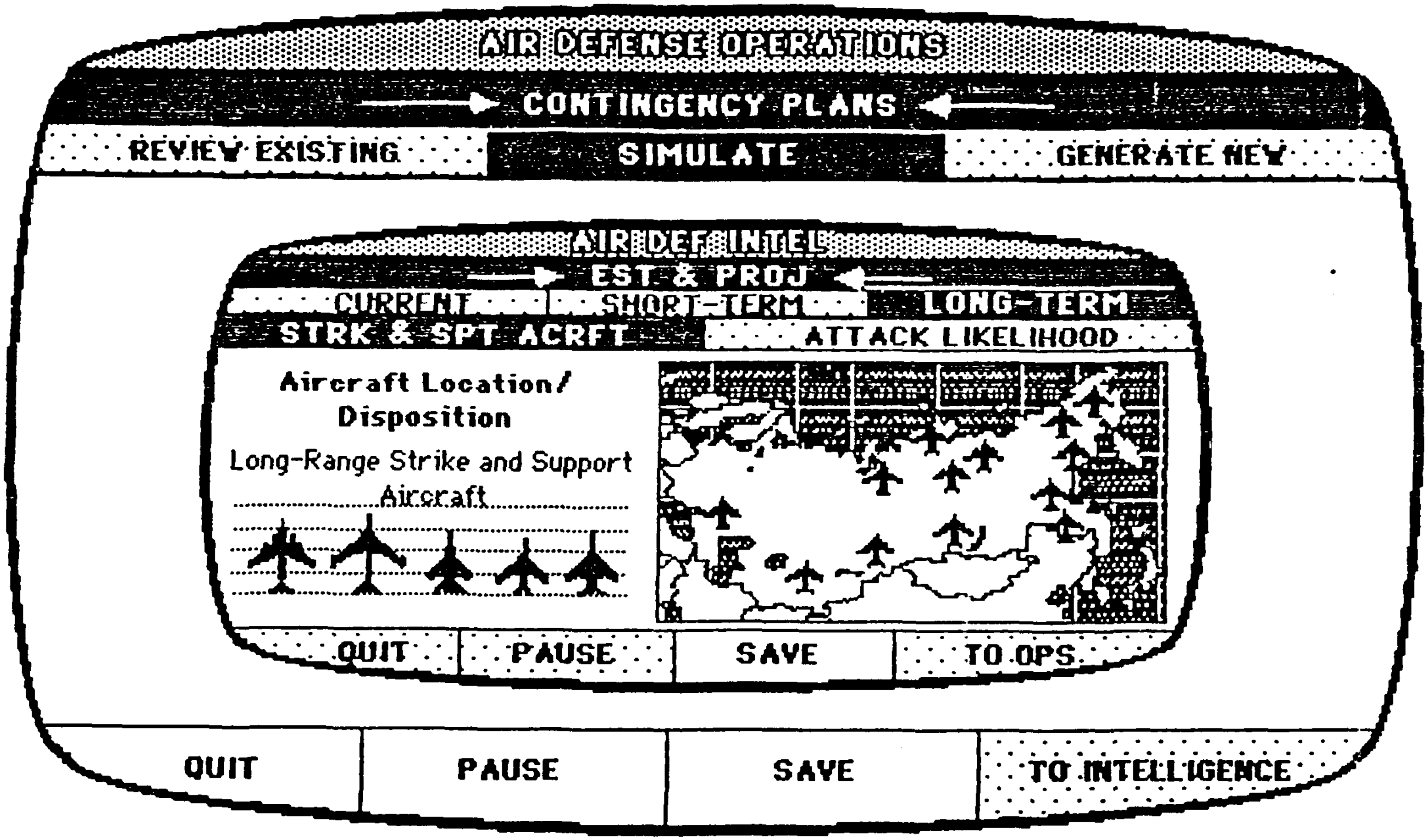
Another demonstration of how interactive systems can support the intelligence/operations interface suggests how operations personnel can review old and generate new contingency plans. The system simulates how analysts can query the system about old plans and generate new ones; it also suggests how the old or new plans can be simulated to determine how well or badly they might do. In the example the simulated outcome is poor so the analyst decides to probe the intelligence aspect of the problem. This demonstration represents how operations personnel can access intelligence data and inferential processes directly from his workstation.

Some figures from the storyboard appear below.

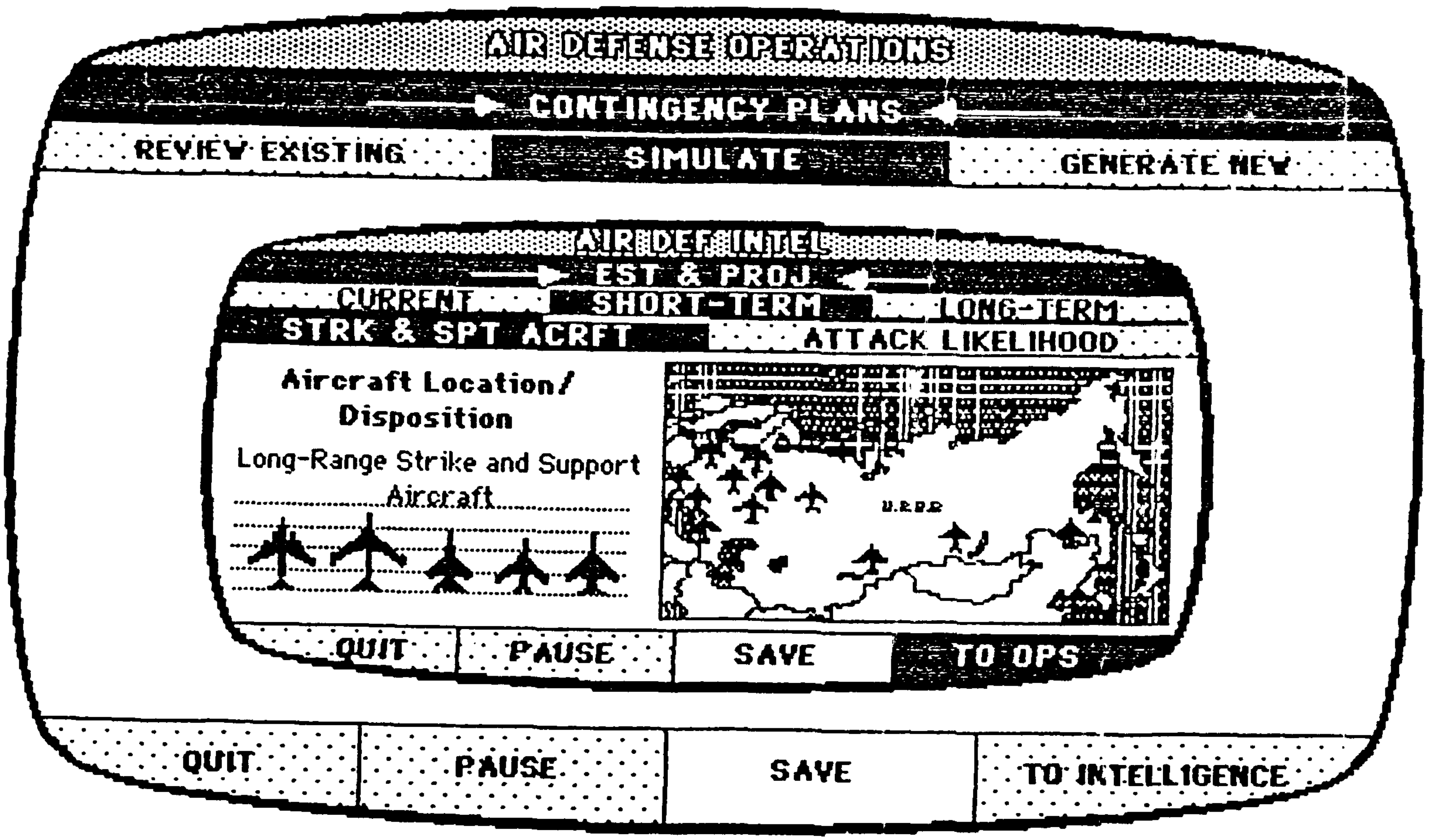
In the third example, the problem is reversed. The intelligence analyst is estimating short- and long-term threat and decides to check into the contingency planning of the operations personnel to determine if it is adequate. This represents an extension of the role of the air defense intelligence analyst, an extension that may or may not be welcomed by operations personnel.

Several figures from this third interface storyboard appear below.

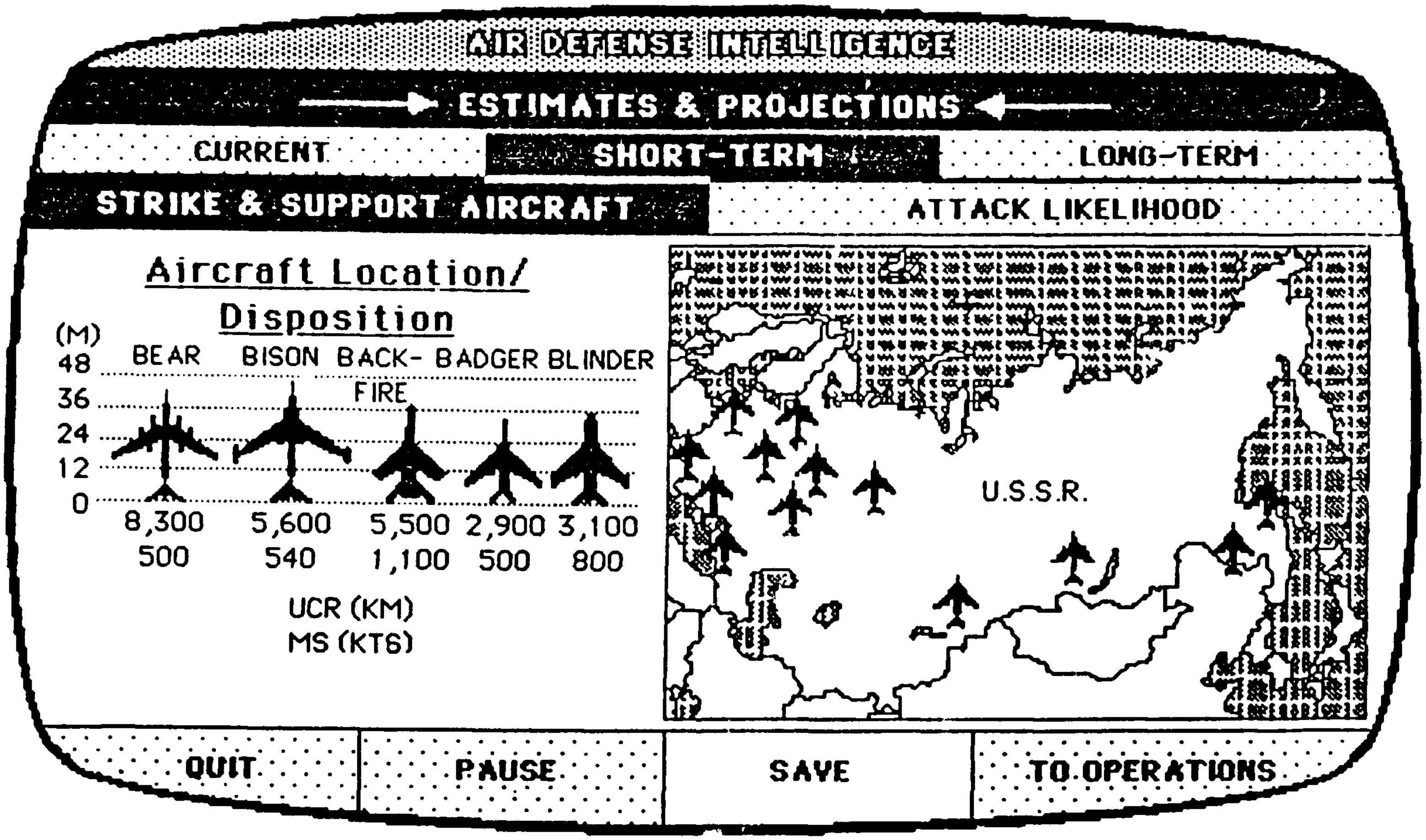
The important aspect of these interface prototypes is linkage. They assume that linkage among functions and personnel is feasible and desirable. The linkage also challenges conventional



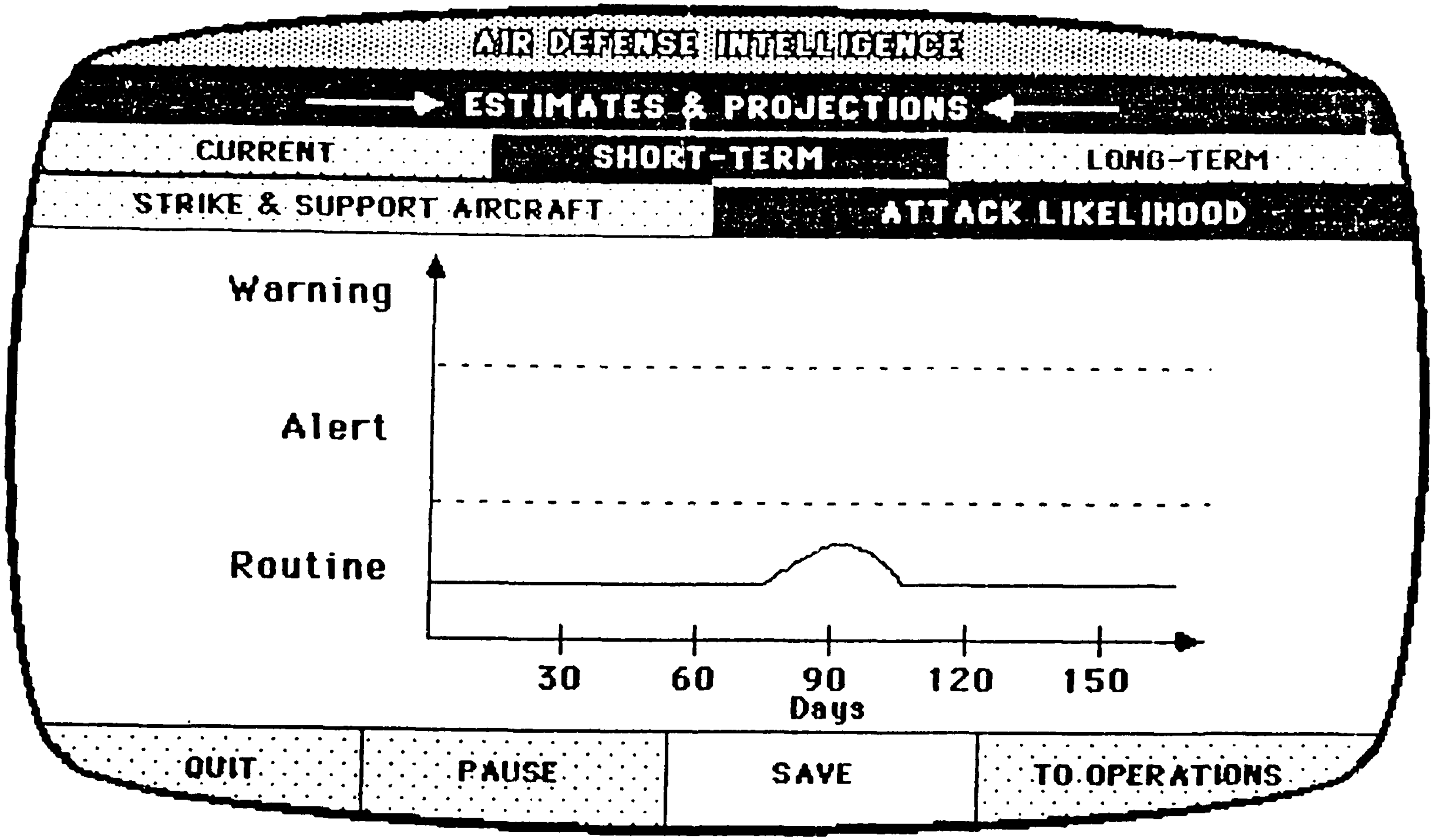
The system displays a window into the intelligence system. The menu structure and interaction process is identical to "his" system. He clicks on **Long-Term Strike & Support Aircraft** to look at what intelligence believes is likely. The system presents him with its best estimate. He then clicks on **Short-Term Strike & Support Aircraft**. A variety of "what-if" activities would be possible via such interaction.



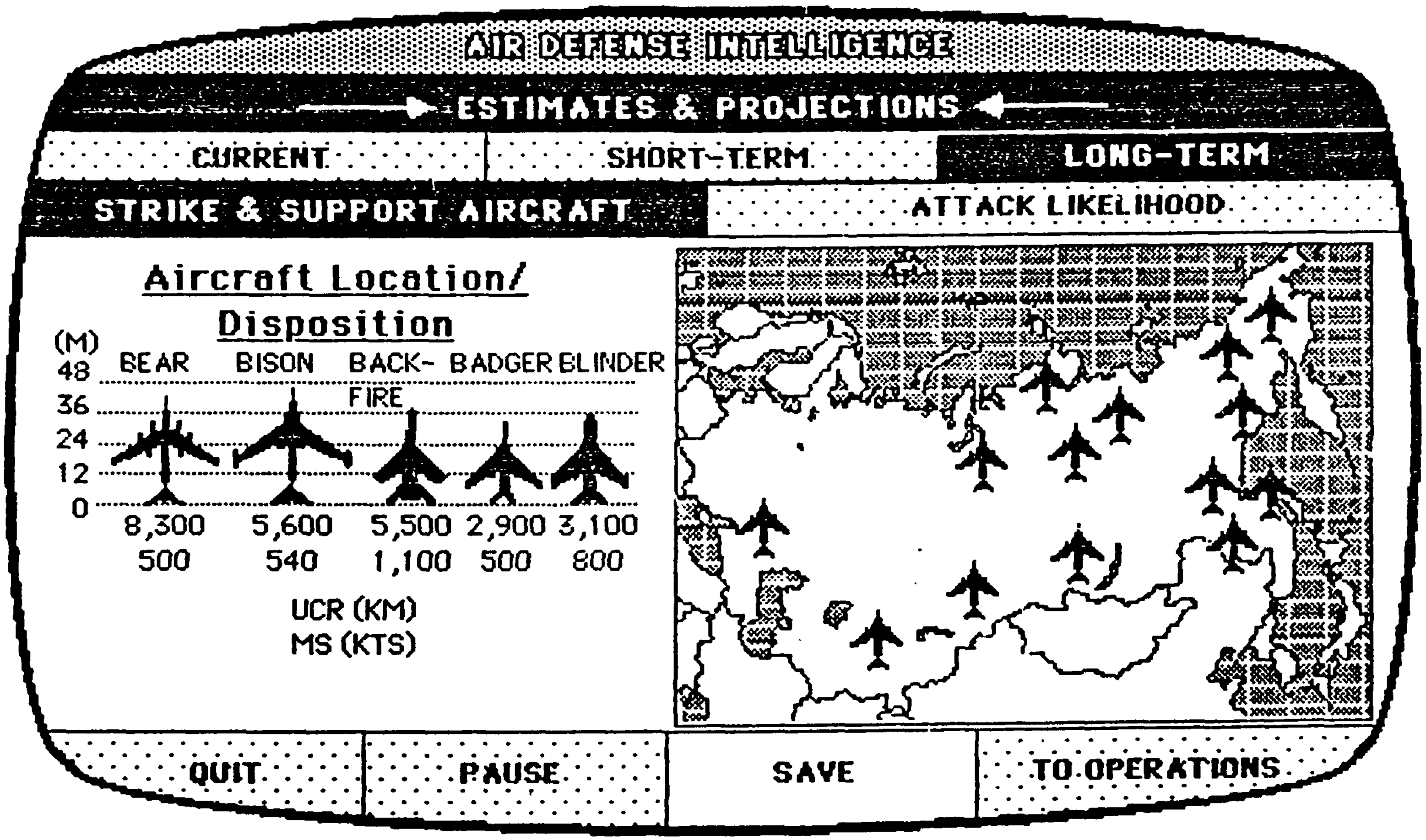
The system displays its most recent intelligence. The planner returns to Air Defense Operations Contingency Planning.



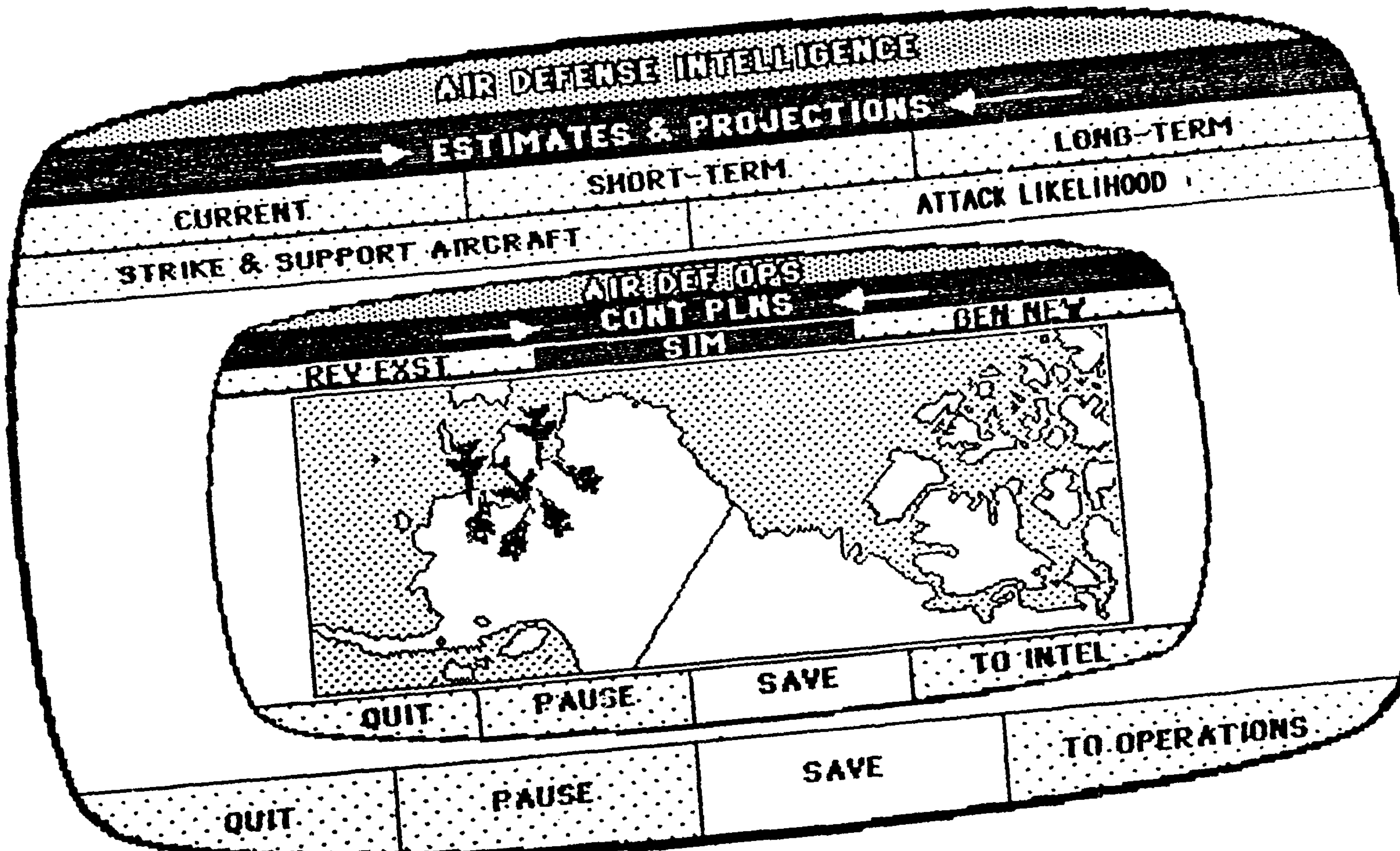
The intelligence analyst clicks on **Short-Term Strike & Support Aircraft** to detemine the current intelligence situation.



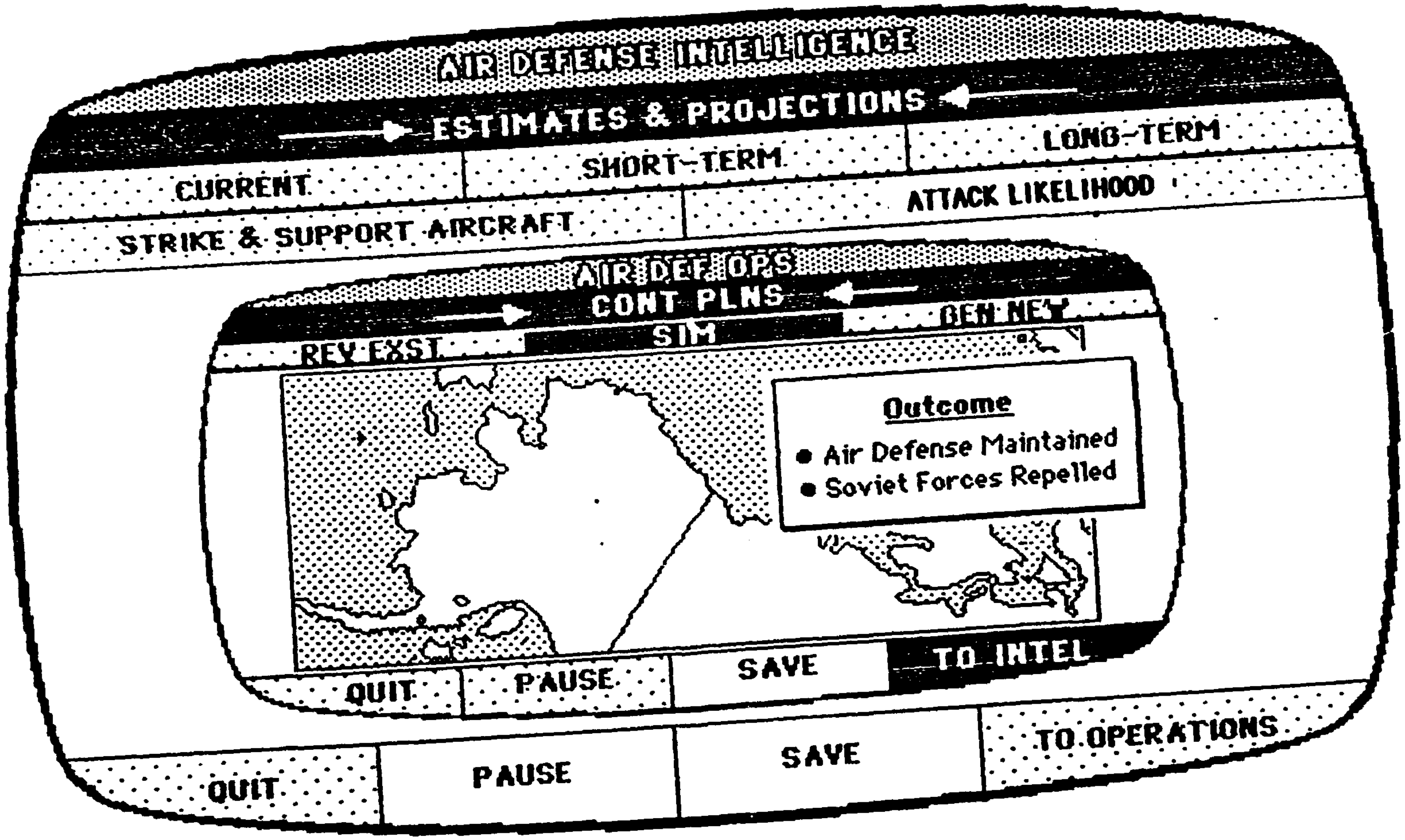
The analyst then looks at the **Short-Term Attack Likelihood**.



Long-Term Strike & Support Aircraft is selected and displayed.



The analyst then enters the Air Defense Operations system via **To Operations**. Here the intelligence analyst decides to simulate some plans based on "his" intelligence estimates.



The system suggests that the plans are adequate, given current intelligence estimates. Had the plans been inadequate the intelligence analyst would inform Operations of potential problems.

doctrinal wisdom and suggests that our systems should be designed in some radically new ways.

All three interface prototypes appear in Appendix B.

6.0 EVALUATION AND SIZING

The prototypes demonstrate what is feasible. Their capabilities are anchored in assumptions about available information technology and how findings from the cognitive sciences can be translated into user-computer interaction and overall system capabilities. We did not, however, formally evaluate the prototypes to determine if they would indeed enhance or degrade human performance, though we did undertake a "sizing" exercise to determine if the "throwaway" prototypes could cost-effectively evolve into "evolutionary" ones (Andriole 1989a, 1989b, Boar, 1984).

6.1 Contributions to Human Performance

The research reported here was designed to test several assumptions. The prototypes suggest that it is possible to leverage findings from the cognitive sciences via the application of selected information technologies. There is every reason to believe that if the findings and technologies have been applied carefully then human performance -- in the air defense intelligence and operations domain -- will be enhanced. However, without empirical results it is impossible to determine the nature or strength of the contribution.

Any systematic evaluation must proceed according to some established guidelines (Adelman, 1990). Experiments must be designed, measures (or criteria) of effectiveness must be developed and validated, and data collection strategies must be developed and tested. There are a variety of interrelated hypotheses that must be identified and organized. The experiments must control for the use and non-use of certain displays and interaction processes, and assess how well the findings/technology marriage contributes to "better" and more "accurate" inference- and decision-making, and intelligence/operations communication.

One approach to evaluation is anchored in multi-attribute utility assessment (MAUA) methodology. As Adelman suggests (1990), MAUA is a powerful and versatile systems evaluation methodology. But it is also important to think in terms of multi-method, multi-faceted evaluation, where several approaches are used to measure a range of behavioral phenomena. Figure 6.1 presents a generic MAUA evaluation structure comprised of criteria for systems evaluation (Adelman, 1990). Such a structure -- along with whatever additional methods, tools and criteria deemed appropriate -- would comprise an overall evaluation strategy. Before the existing prototypes are converted into working evolutionary prototypes, a set of experiments should be conducted to determine the high and low payoff areas.

6.2 Implementing the Prototypes

Given that any additional investment in the prototypes should be

1.0 DSS/User Interface
- 1.1 Match with Personnel
  - 1.1.1 Training & technical background
  - 1.1.2 Work style, workload & interest
  - 1.1.3 Operational needs
- 1.2 DSS' characteristics
  - 1.2.1 General
    - 1.2.1.1 Ease of use
    - 1.2.1.2 Understanding DSS processes
    - 1.2.1.3 Ease of training
    - 1.2.1.4 Response time
  - 1.2.2 Specific
    - 1.2.2.1 User interface
    - 1.2.2.2 Completeness of data files
    - 1.2.2.3 Accuracy of *expert judgements*
    - 1.2.2.4 Ability to modify judgements
    - 1.2.2.5 Understanding of DSS algorithms
    - 1.2.2.6 Utility of graphs
    - 1.2.2.7 Utility of print-outs
    - 1.2.2.8 Understanding of text

2.0 User-DSS/Organization
- 2.1 Efficiency factors
  - 2.1.1 Acceptability of time for
    - 2.1.1.1 Task accomplishment
    - 2.1.1.2 Data management
    - 2.1.1.3 Set-up requirements
  - 2.1.2 Perceived *reliability* under average battle conditions
    - 2.1.2.1 Skill availability
    - 2.1.2.2 Hardware availability
- 2.2 Match with organizational factors
  - 2.2.1 Effect on organizational procedures and structure
  - 2.2.2 Effect on other people's position in the organization
    - 2.2.2.1 Political acceptability
    - 2.2.2.2 Other people's workload
  - 2.2.3 Effect on onformation
  - 2.2.4 Side effects
    - 2.2.4.1 Value in performing other tasks
    - 2.2.4.2 Value to related organizations
    - 2.2.4.3 Training value

3.0 Organization/Environment
- 3.1 Decision accuracy
- 3.2 Match between DSS' technical approach and problem's requirements
- 3.3 Decision process quality
  - 3.3.1 Quality of framework for incorporating judgement
  - 3.3.2 Range of alternatives
  - 3.3.3 Range of objectives
  - 3.3.4 Weighting of consequences of alternatives
  - 3.3.5 Assessment of consequences of alternatives
  - 3.3.6 Re-examination of decision making process
  - 3.3.7 Use of information
  - 3.3.8 Consideration of implementation and contingency
  - 3.3.9 Effects on *group discussions* plans
  - 3.3.10 Effects of decision makers' confidence

Figure 6.1: Adelman's MAUA Evaluation Model

informed by experimental results, it is important to note that the throwaway prototypes have in fact been "sized." Sizing is a complicated process that requires assessments about the costs connected with scaling up the prototypes (Andriole, 1989a, 1989b, 1990). Typically five general areas define the sizing process:

- Data/knowledge base specification;
- User-computer interface specification;
- Specification of analytical methods;
- Software engineering specification; and
- Specification of the hardware configuration.

These areas are used to challenge the prototype's conversion or evolutionary robustness. Is it possible to really build this thing? Can it be done cost-effectively? Does the necessary technology exist? Can we program it in the designated language? Can the data and/or knowledge bases be developed? These are the kinds of questions the sizing process seeks to answer.

6.2.1 Data/Knowledge Base Specification - The prototypes call for deep data and knowledge bases. Much of the necessary data exists; knowledge bases for inference- and decision-making would have to be developed. The prototypes call primarily for deductive inferential processing and, therefore, reasonably well-bounded deductive knowledge bases. It would be possible to develop evolutionary prototypes that accessed real data and deductive knowledge bases cost-effectively. The prototypes do not call for inductive or abductive reasoning, though additional requirements analyses might very well require such reasoning.

6.2.2 User-Computer Interaction Specification - In spite of the detail and flexibility represented in the prototypes, all of the interaction routines can be cost-effectively developed and implemented. We did not select interaction routines, or presume interaction devices, that are beyond the reach of emerging technology or realistic budgets. This is especially true if the target platform remains the Apple Macintosh SE, II or IIx. Apple Computer, Inc. and its vendors have placed advanced interface technology high on their list of priorities -- and at the top of that list is multimedia. Other manufacturers and vendors are following suit, but they are lagging well behind Apple.

6.2.3 Specification of Analytical Methods - Figure 6.2 from Hopple (1986) suggests the range of methods, tools and techniques available to the modern systems engineer; Figure 6.3 suggests the ones that would support the operation of the next generation prototype.

None of the methods are beyond the reach of today's capabilities; as always, the real leverage lies in how the methods are matched to system functions and integrated.

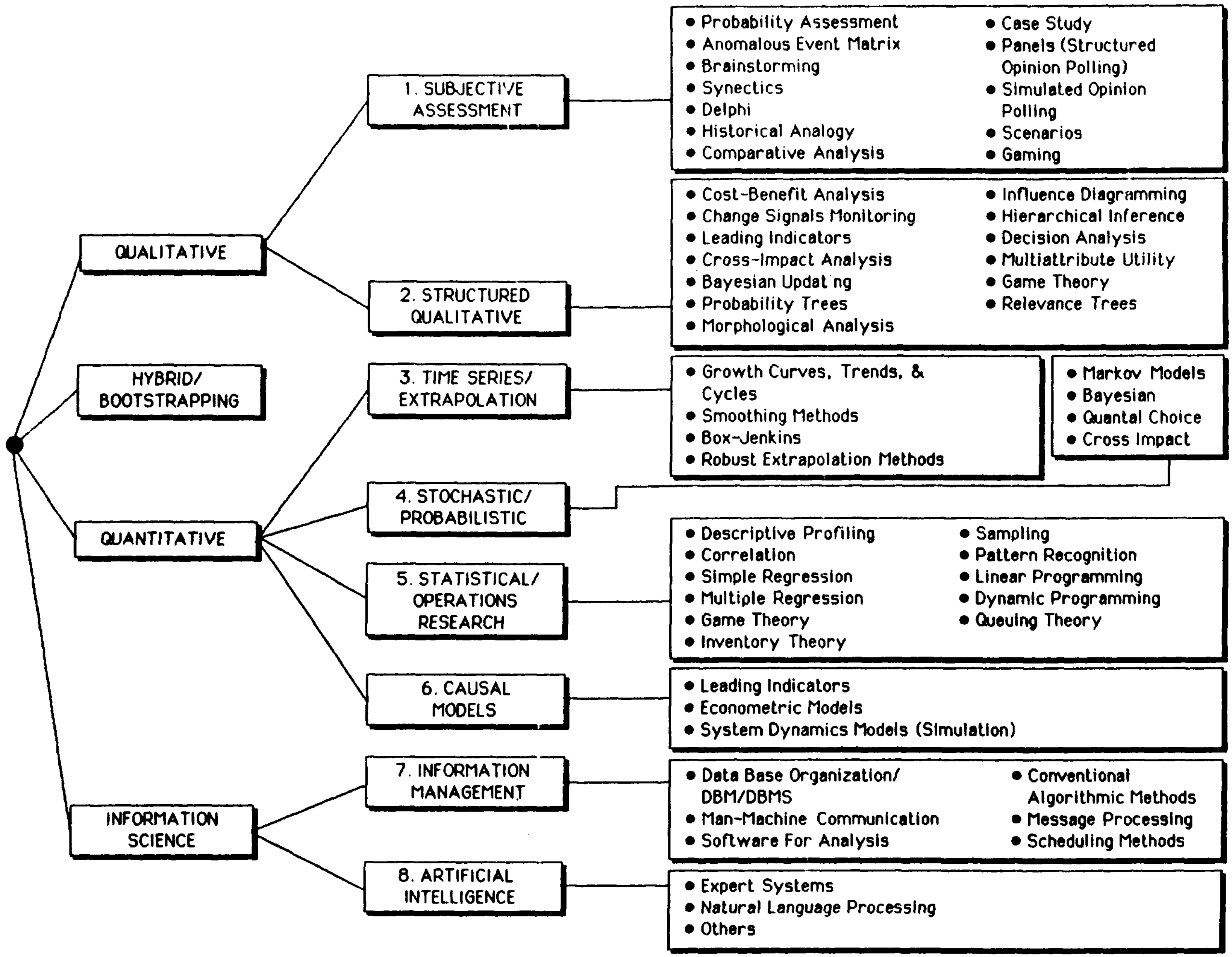


Figure 6.2: Hopple's Analytical Methods Taxonomy

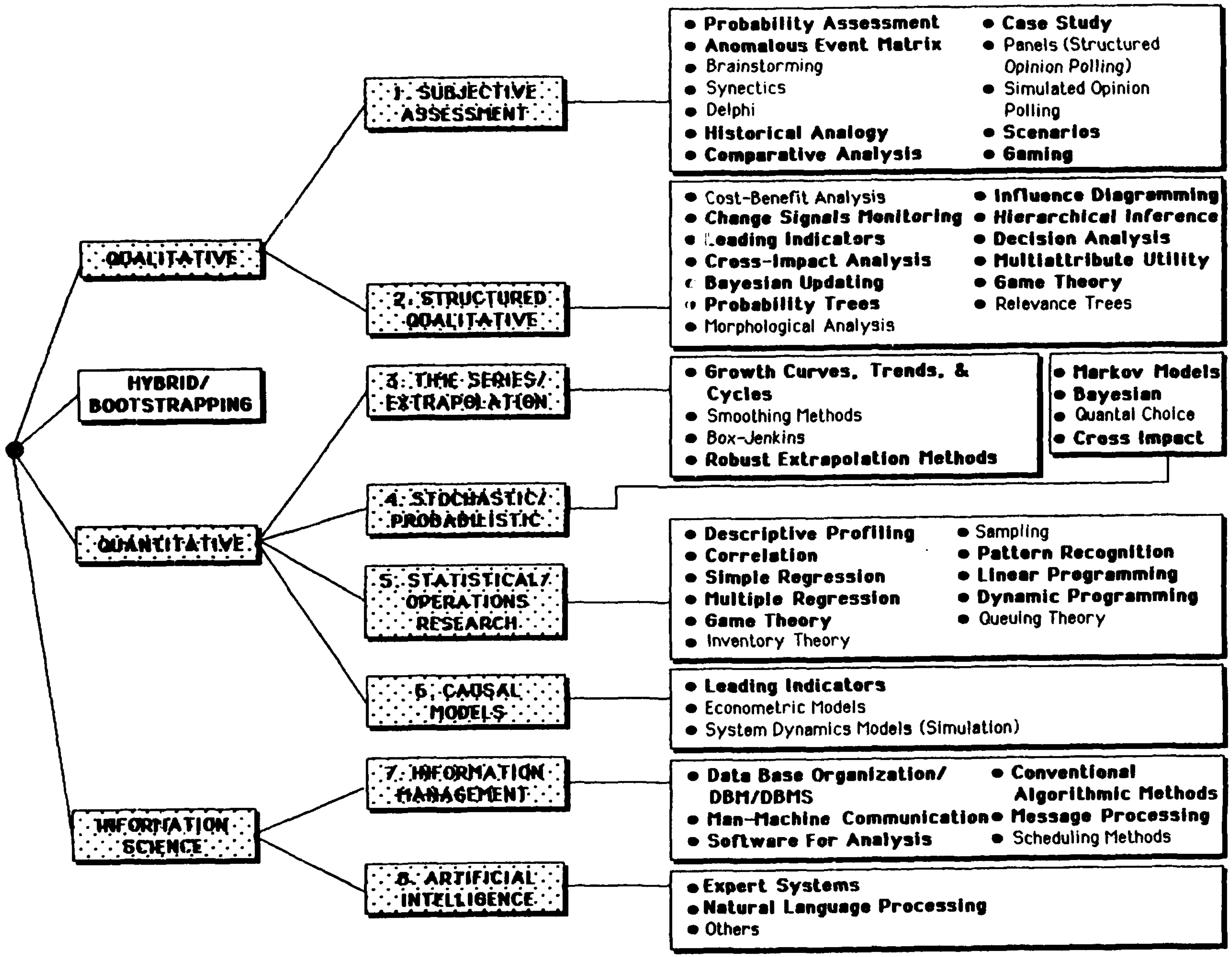


Figure 6.3: Methods For Strategic Air Defense Intelligence, Operations and Intelligence/Operations

6.2.4 Software Engineering Specification - The system concepts embedded in the prototypes are certainly programmable. Our analysis of the effort it would take to convert the prototypes into several languages (C, Ada, or via fourth generation programming) did not reveal any special problems. There are, however, several assumptions about the hardware configuration (see below) that influenced our judgments about engineering the software.

6.2.5 Specification of the Hardware Configuration - If the platform remains an Apple Macintosh SE, II or IIx, then the above analyses hold. We did not size the prototypes beyond the Macintosh environment. At the same time, the Macintosh environment would have to be customized to accommodate the kinds of interaction processes and displays suggested in the prototypes. Video boards, video input and output devices, large memory and storage capabilities, CD-ROM players, and the like, would all become part of the evolutionary prototyping environment. It is estimated that the necessary configuration would cost approximately $15K (or approximately $20K if color output was considered necessary). It is important to note that a very large part of the hardware and software architecture would be off-the-shelf.

7.0 SUMMARY AND CONCLUSIONS

Our research has attempted to merge several distinct fields of inquiry. We began with assumptions about how findings from cognitive science could be leveraged in systems design and development and how the findings could be amplified via the application of selected information technology. We demonstrated the leverage in several working prototypes designed to illustrate how strategic air defense intelligence, operations, and the intelligence/operations interface could be supported by some advanced system concepts. The research has led to several conclusions -- and recommendations for further research.

7.1 Phase I Findings

This report describes the steps we took to design and develop several demonstration prototypes. We began with a requirements analysis of air defense intelligence, operations, and intelligence/warning/operations. We followed this analysis with a review, assessment and distillation of the cognitive science literature, a process that yielded a set of findings particularly relevant to air defense processes. The distilled findings represent a contribution unto themselves. We then undertook a review and assessment of advanced information technology, especially as it represented opportunities for enhanced user-computer interaction. This review examined a variety of technologies -- multimedia, graphics, animation, among others --

to determine if they were now cost-effective enough to apply. We concluded that they are and that when married to the distilled findings from cognitive science represent a powerful new solution to some perennial man-machine systems problems.

We converted the marriage into several working demonstration prototypes. These prototypes suggest that it is possible to design systems in some unique multidisciplinary ways, that it is possible to widen the communications bandwidth between analysts and machines -- and among analysts using machines.

We also sized the prototypes to determine if they could be scaled up to evolutionary status. Our analysis of data/ knowledge, user-computer interaction, analytical methods, software engineering, and hardware configuration requirements suggested that the prototypes could indeed be enhanced.

Our Phase I research has thus yielded a number of findings, feasibility assessments, and suggestions for further research and development.

7.2 Phase II Research Options

At the top of the list is evaluation. The system concepts embedded in the prototypes -- while anchored in the cognitive and information sciences -- have not been empirically tested. We thus know virtually nothing about the extent to which they might contribute to -- or degrade -- human performance in air defense.

A series of experiments should thus be conducted to determine the nature and strength of the relationships among system capabilities, specific air defense tasks, and human inference- and decision-making, and intelligence/warning/operations performance.

The results of these experiments should inform the design and development of a set of evolutionary prototypes which would demonstrate what the new system concepts could do in quasi- and fully-operational environments.

The working prototypes could be developed on an Apple Macintosh II.

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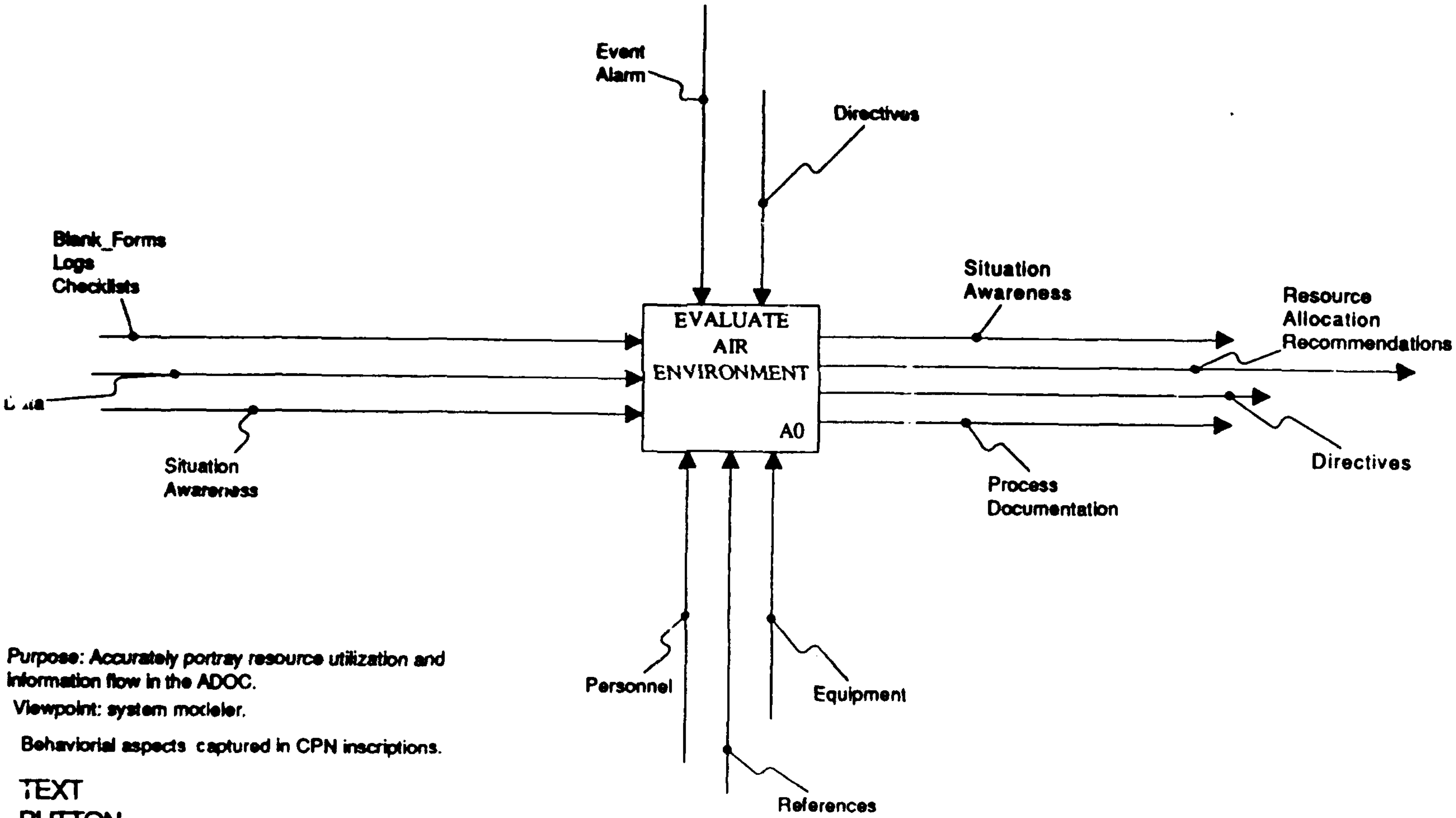
APPENDIX A

AIR DEFENSE OPERATIONS IDEF MODEL

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/13/88 REV: 1/27/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



Purpose: Accurately portray resource utilization and information flow in the ADOC.
Viewpoint: system modeler.
Behaviorial aspects captured in CPN inscriptions.

TEXT
BUTTON

NODE: A-0	TITLE: NORAD ADOC OPERATIONS (CONTEXT)	NUMBER: RES1

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 11/17/88 REV: 12/20/88	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

A-0 TEXT

Data

Blank Forms/Logs/Checklists

Process Documentation - Filled out Logs, Slides, Forms & Maps.

Command Post Directives - Orders, Queries

Situation Awareness - Communication of the situation.
Includes: Friends, foes, specials surveillance network status.

Event Alarm - Periodic & aperiodic

Resource Allocation Recommendations -

Directives - For maintaining surveillance network

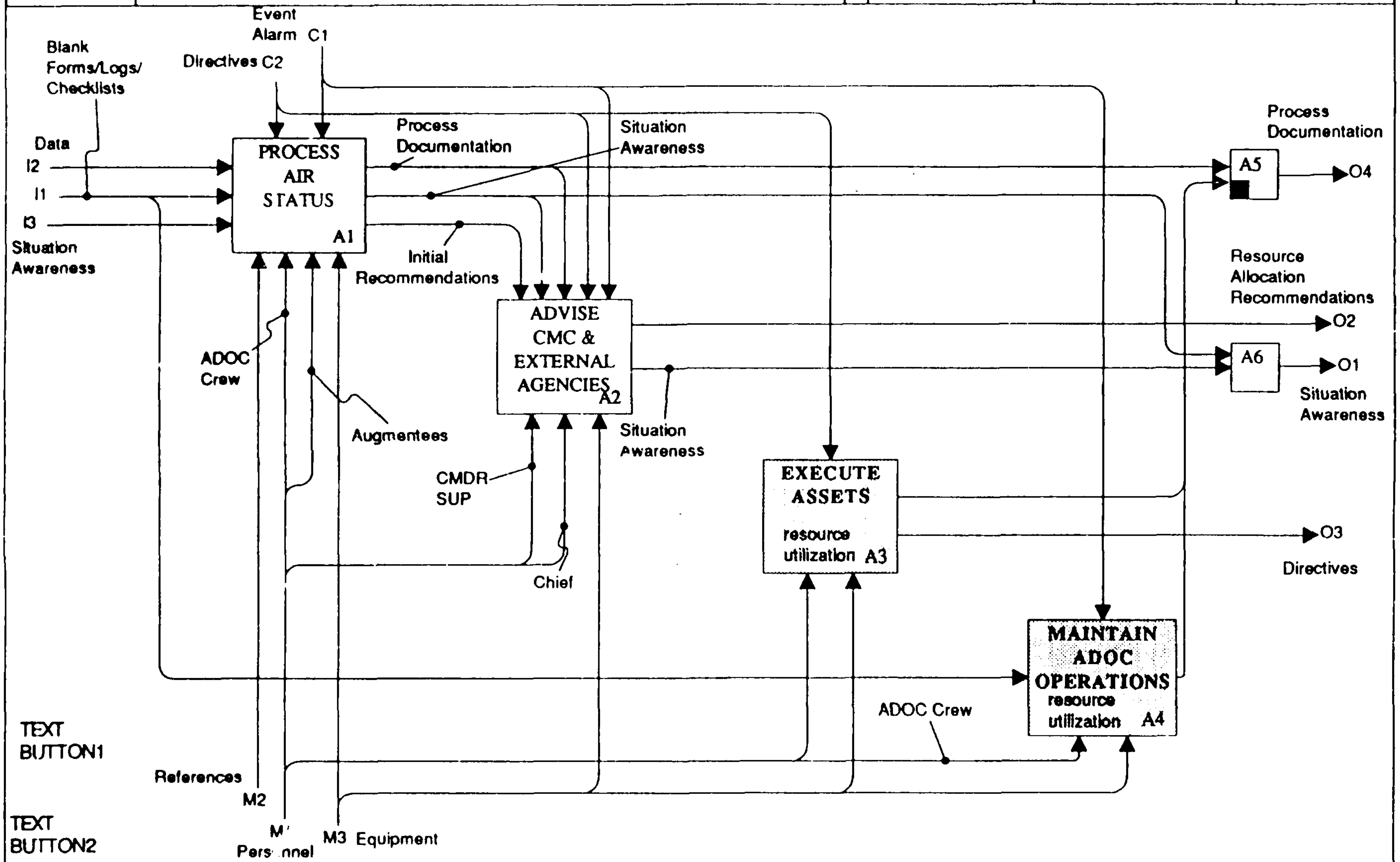
Functions that are not further decomposed are shaded like this: ☐

RETURN

This text page associated with diagram A-0.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/13/88 REV: 1/31/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



NODE: A0	TITLE: EVALUATE AIR ENVIRONMENT	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:00:14 PM	DATE: 12/28/88 REV: 1/9/89 3/30/89	x	WORKING	READER DATE	CONTEXT:
				DRAFT		
				RECOMMENDED		
				PUBLICATION		

Tasks that are part of maintain ADOC(A4):

These tasks generally are performed periodically:

Perform on-coming crew changeover - task 1.
Perform off-going crew changeover - task 2.
Conduct COMSEC inventory - task 3.
Checkout graphic display console - task 4.
Perform communications line checks - task 5.
Operate SURTAC - task 6. This one can occur aperiodically.
Prepare CINC briefing - task 7.
Prepare and conduct CD, Crew Changeover Briefing - task 8.
Perform ADOC power outage procedures - task 10.
Prepare CALLSIGN card - task 13 .
Use AFKAI-1 - task 14.
Verify random alert schedule(RAS) - task 15.
Maintain Airbase Facilities Status - task 16. This task can also occur aperiodically.
Perform ADOC physical security procedures - task 25.
Receive Region/DEWLINE/SURTAC outages - task 30.
Perform fire & emergency evaluation procedures - task 31.
Operate TSEC/KY-58 - task 38.
Perform daily destruction of COMSEC material - task 48.
Perform supersession/destruction of COMSEC material - task 49.
In Perform End of Zulu Day funtions form 57, Daily Unknown Track Disposition(55-312), is completed. Each Form 57 original is filed in the ADOC Unknown Track Book a second copy goes to NCOA(55-312).

These tasks generally are performed aperiodically, but for now are part of maintain ADOC:

Perform region command & control identifiers - task 41.
Perform region simplex/noplex procedures - task 42.
Perform transfer of control to/from SPACC - task 44.
Perform bomb scare/threat procedure - task 45.
Safeguarding COMSEC material during emergency evacuation - task 50.
Perform ADOC recall - task 51.
Safeguard the ADOC restricted area - task 53.

RETURN

This text page associated with A0.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 11/4/88 REV: 11/4/88	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: A

ADOC Crew member and Augmentee Abbreviations

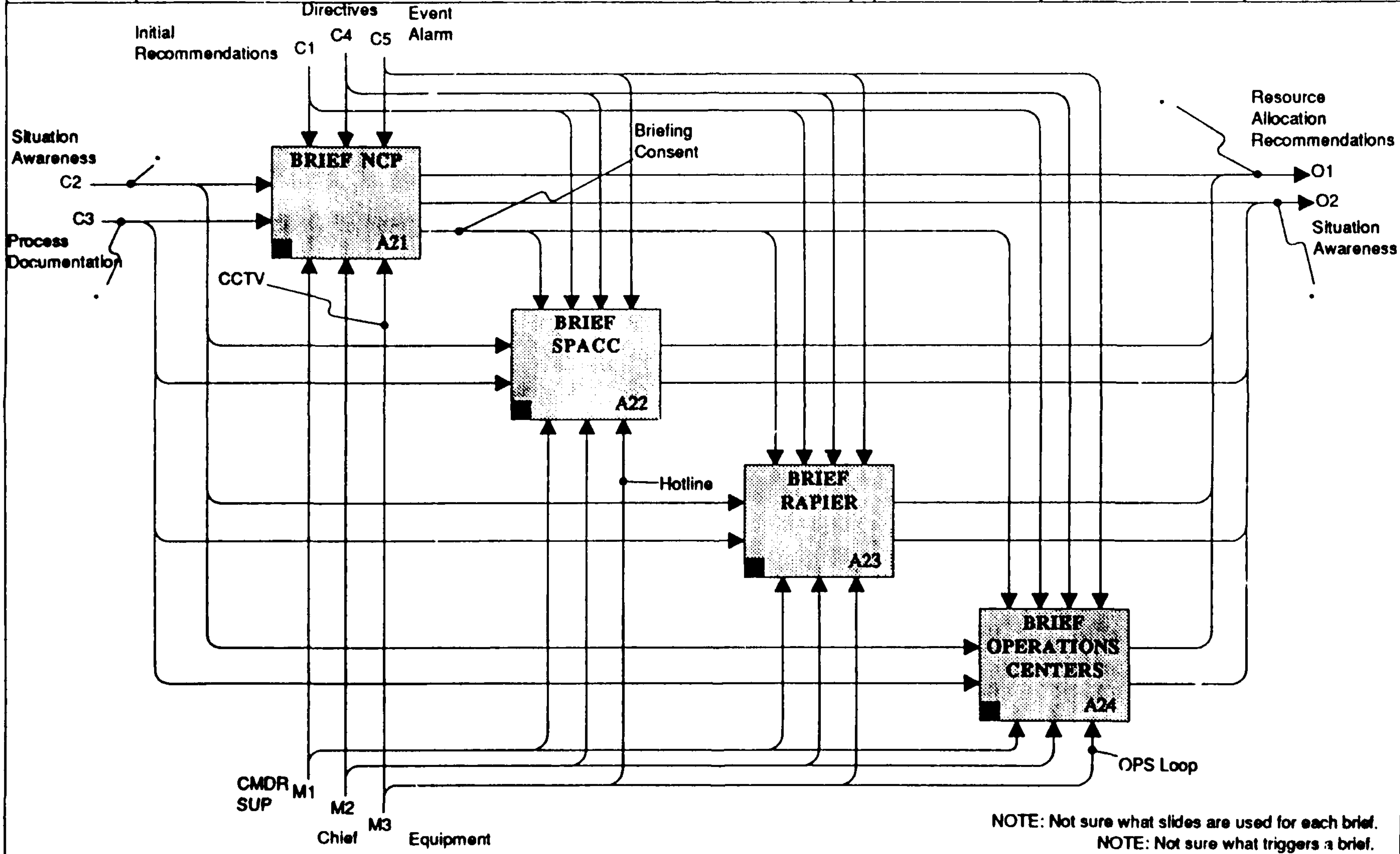
ADOC Crew	IDEF Abbreviation
Crew Commander	CMDR
Crew Supervisor	SUP
E-3 TECH	E-3 TECH
ADOC TECH's	CCO
AUGMENTEES	
ADOC Chief	CHIEF
AWACS	E-3 AUG
Ground Enviornment	GEO
Fighter	Fighter

RETURN

This text page associated with A0.

NODE:	TITLE:	NUMBER:

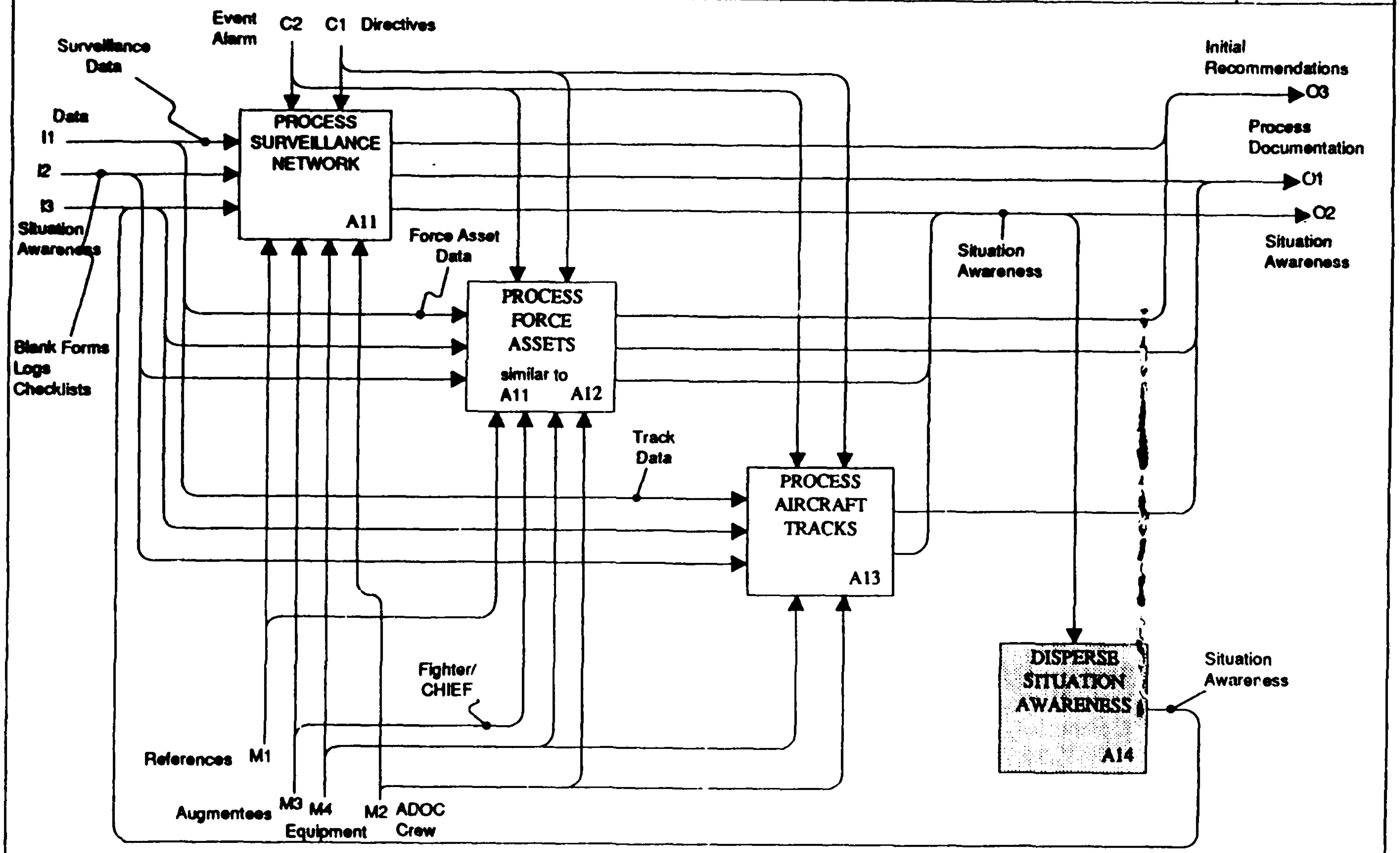
USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 12:23:12 PM	DATE: 1/27/89 REV: 1/27/89 3/30/89	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			



NOTE: Not sure what slides are used for each brief.
NOTE: Not sure what triggers a brief.

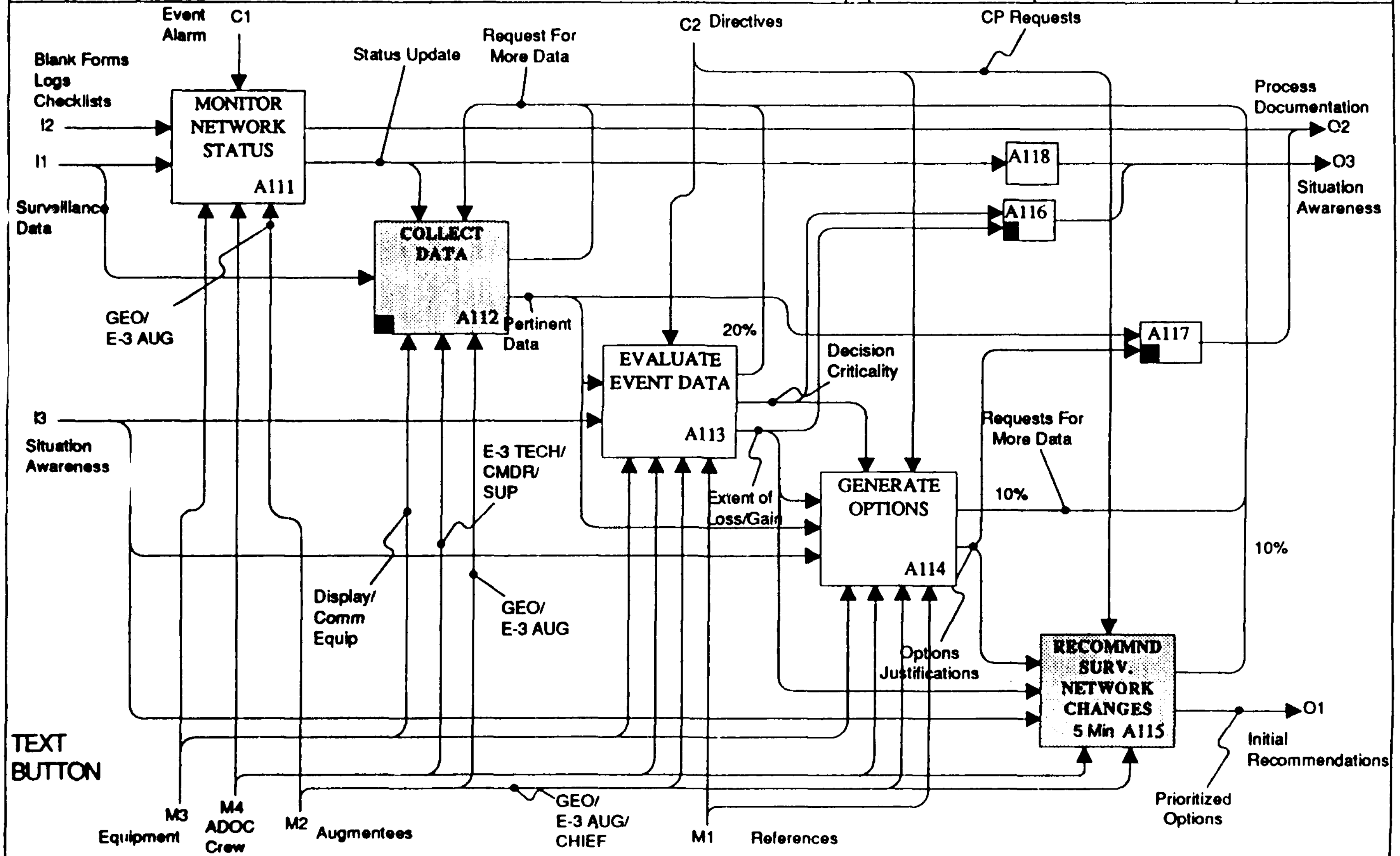
NODE: A2	TITLE: ADVISE CMC & EXTERNAL AGENCIES	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/13/88 REV: 1/31/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



NODE: A1	TITLE: PROCESS AIR STATUS	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/13/88 REV: 1/31/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



NODE: A11	TITLE: PROCESS SURVEILLANCE NETWORK	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:00:47 PM	DATE: 12/9/88 REV: 12/20/88 3/30/89	x	WORKING	READER DATE	CONTEXT:
				DRAFT		
				RECOMMENDED		
				PUBLICATION		

CP Request changed to control of "Make Recommendations" from control of "Collect Data." "Make Recommendations" has a way to get data(4O1), the CP is likely to ask questions about the recommendations, and talk to the augmentees or the E-3 tech(RES).

Changes made 12/20/88:
Make Recommendations changed to Prioritize Options.

Fixed branch-join-branch.

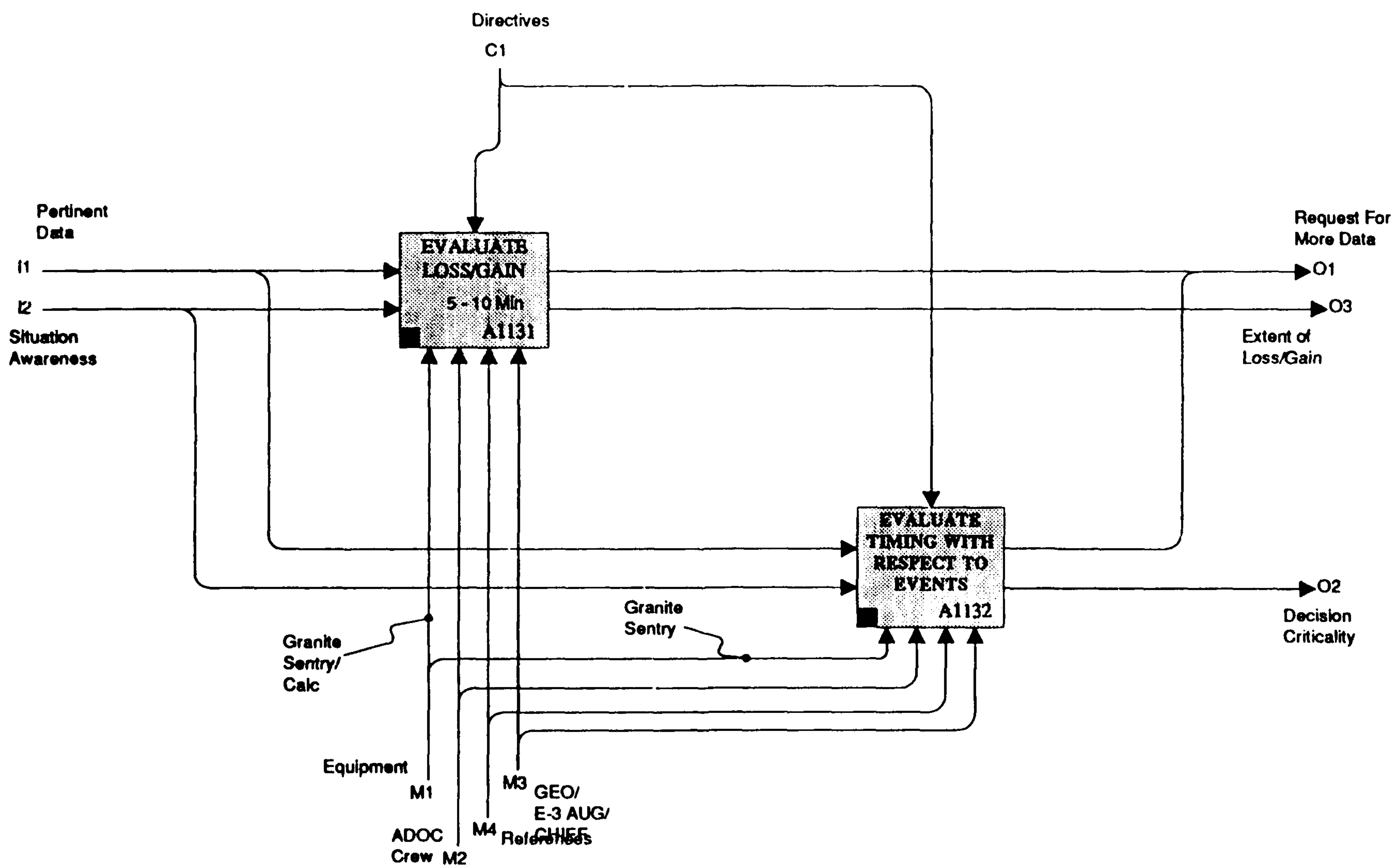
Options & Justifications may not feed into Process Documentation, but have been drawn that way.

RETURN

This text page associated with diagram A11.

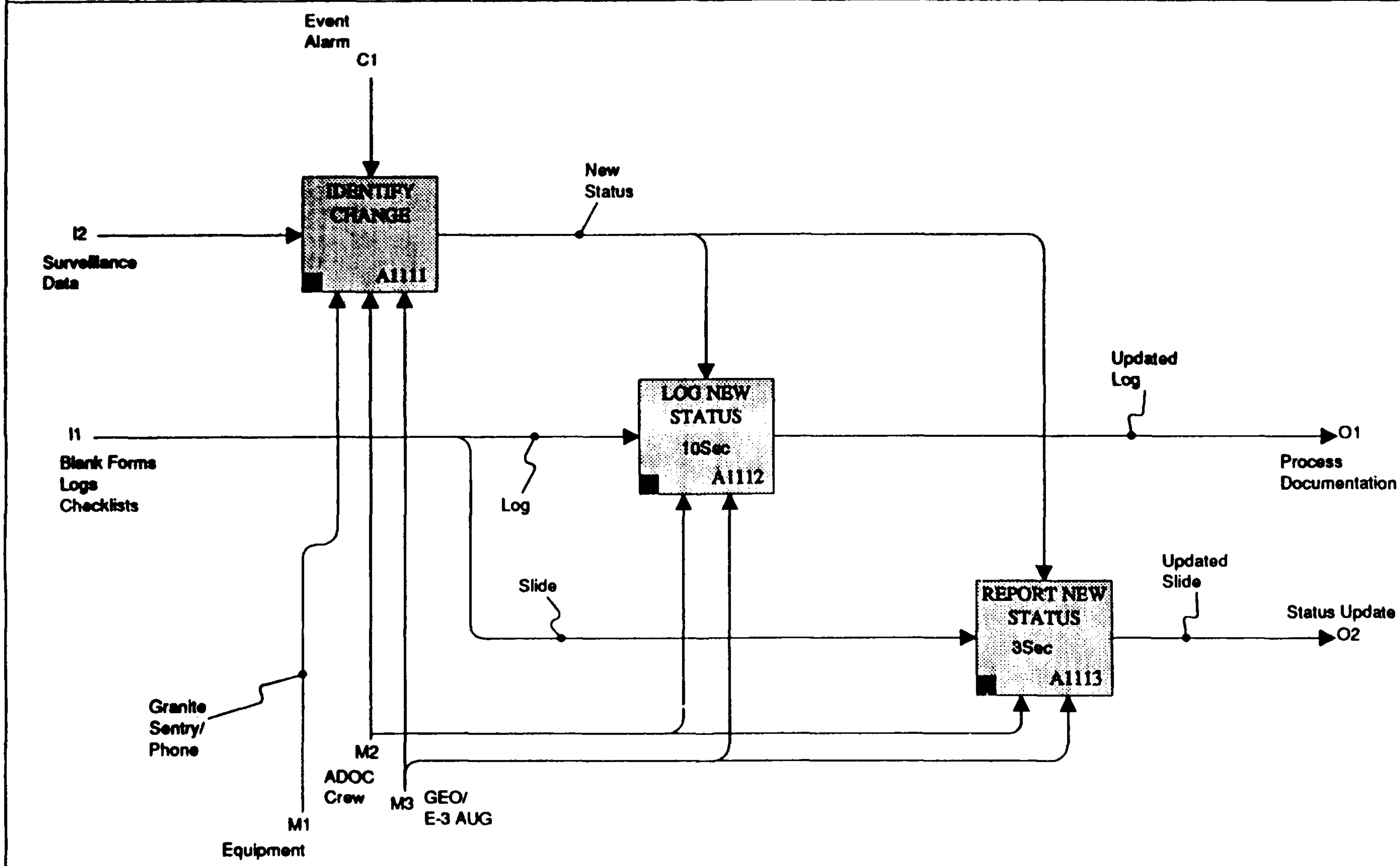
NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 12:57:25 PM 3/30/89	DATE: 1/31/89 REV: 1/31/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A113	TITLE: EVALUATE EVENT DATA	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 12:59:44 PM	DATE: 10/13/88 REV: 1/27/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A111	TITLE: MONITOR NETWORK STATUS	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/13/88 REV: 1/31/89		WORKING	READER	DATE	CONTEXT:
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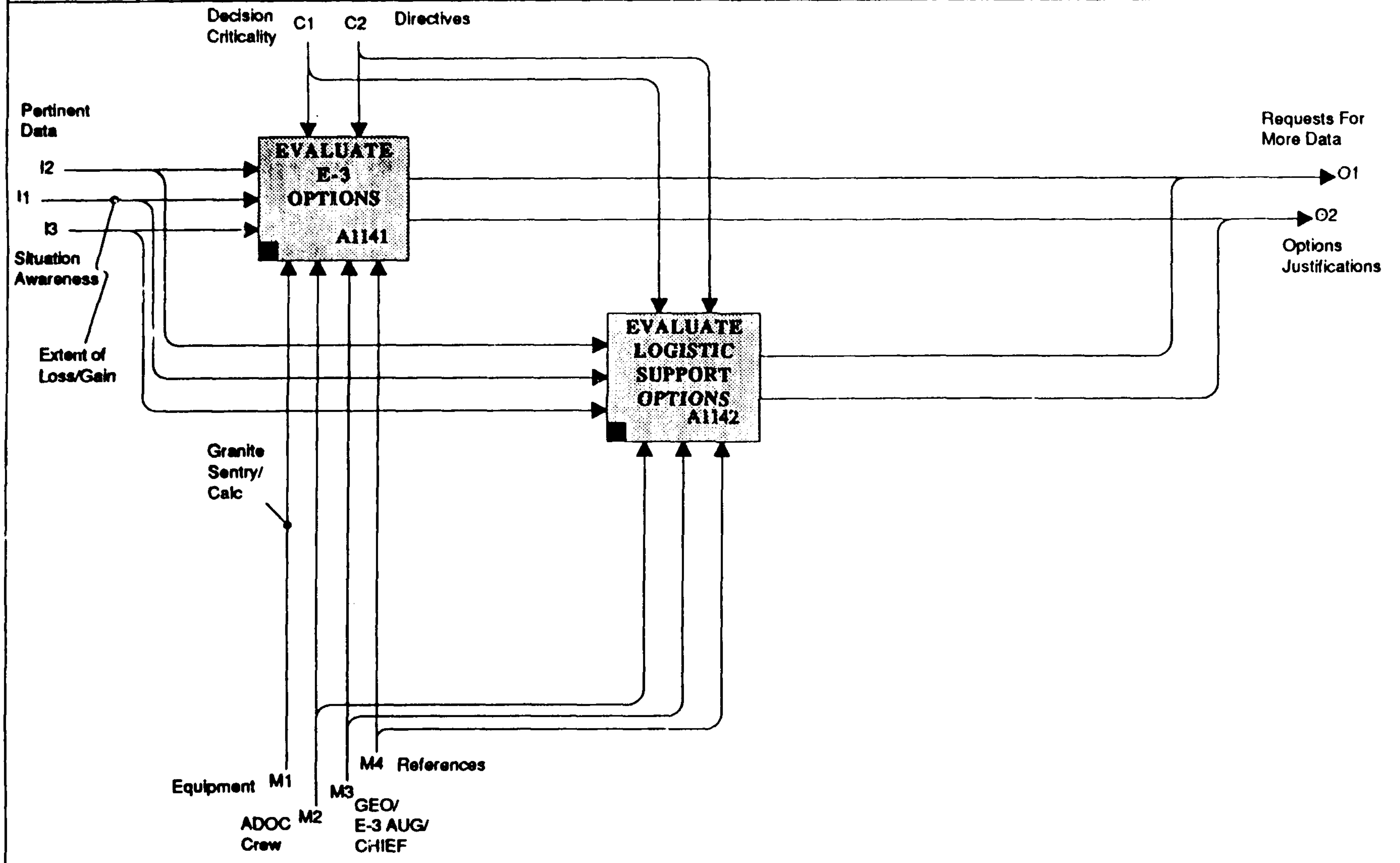
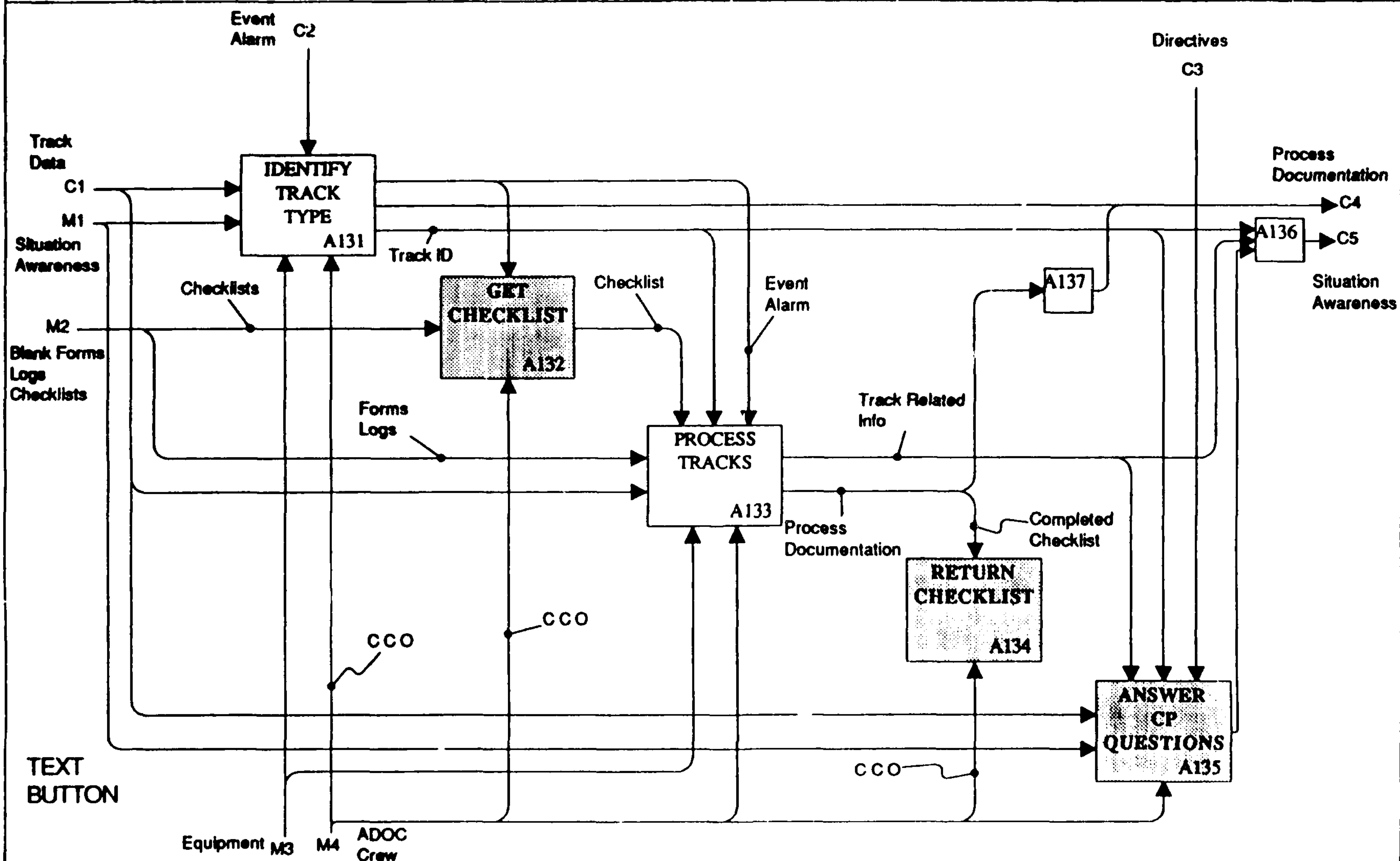
				RECOMMENDED			
				PUBLICATION			



NODE: A114	TITLE: GENERATE OPTIONS	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/14/88 REV: 1/9/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



NODE: A13	TITLE: PROCESS AIRCRAFT TRACKS	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 11/17/88 REV: 1/27/898	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			

Event Alarm - alarm
- alarm type, e.g. new unknown track
- identifier, e.g. track number

Track ID - Track #

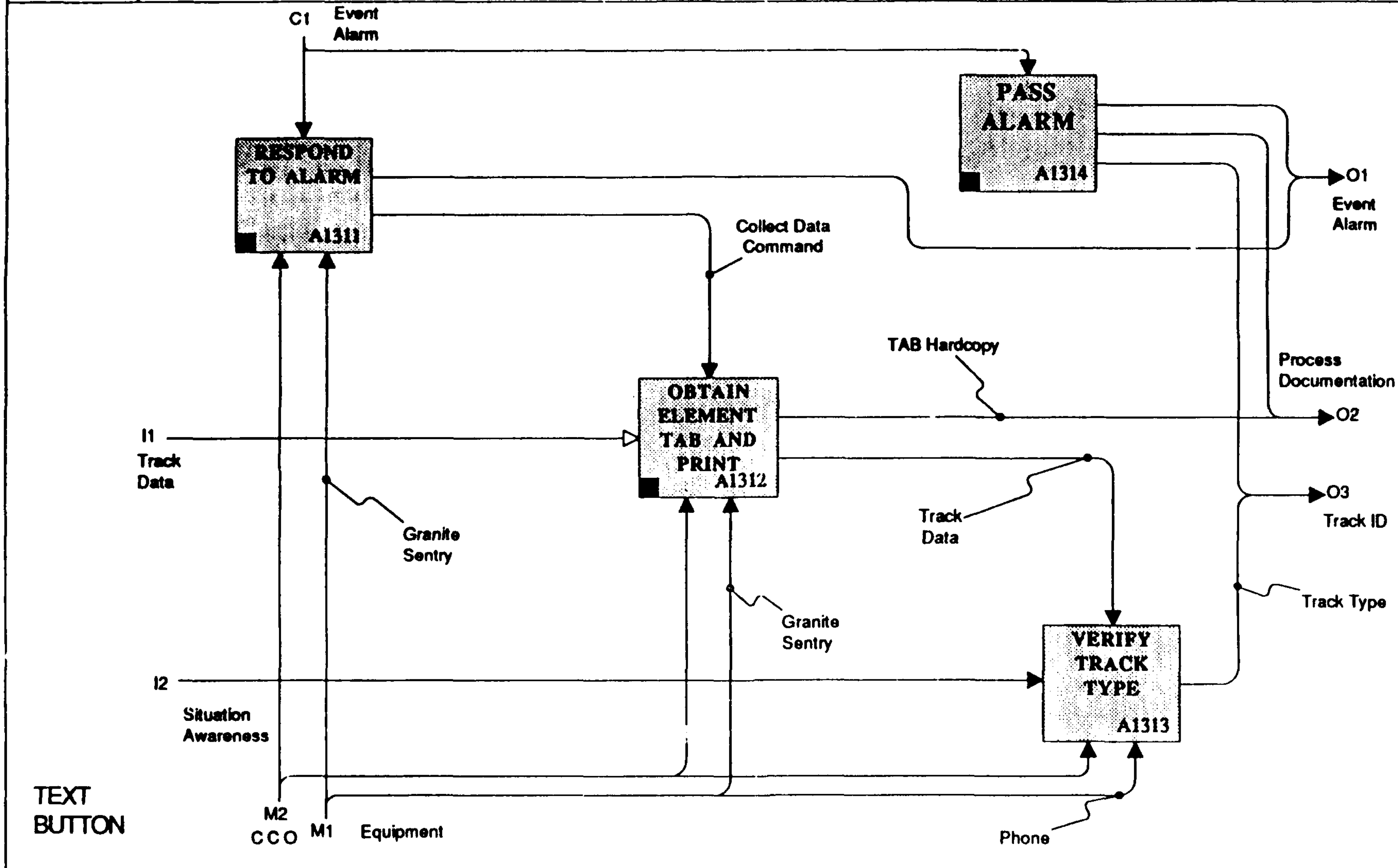
- Track type

RETURN

This text page associated with A13.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/14/88 REV: 1/18/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



NODE: A131	TITLE: IDENTIFY TRACK TYPE	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:01:53 PM	DATE: 12/6/88 REV: 12/12/88 3/30/89	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			

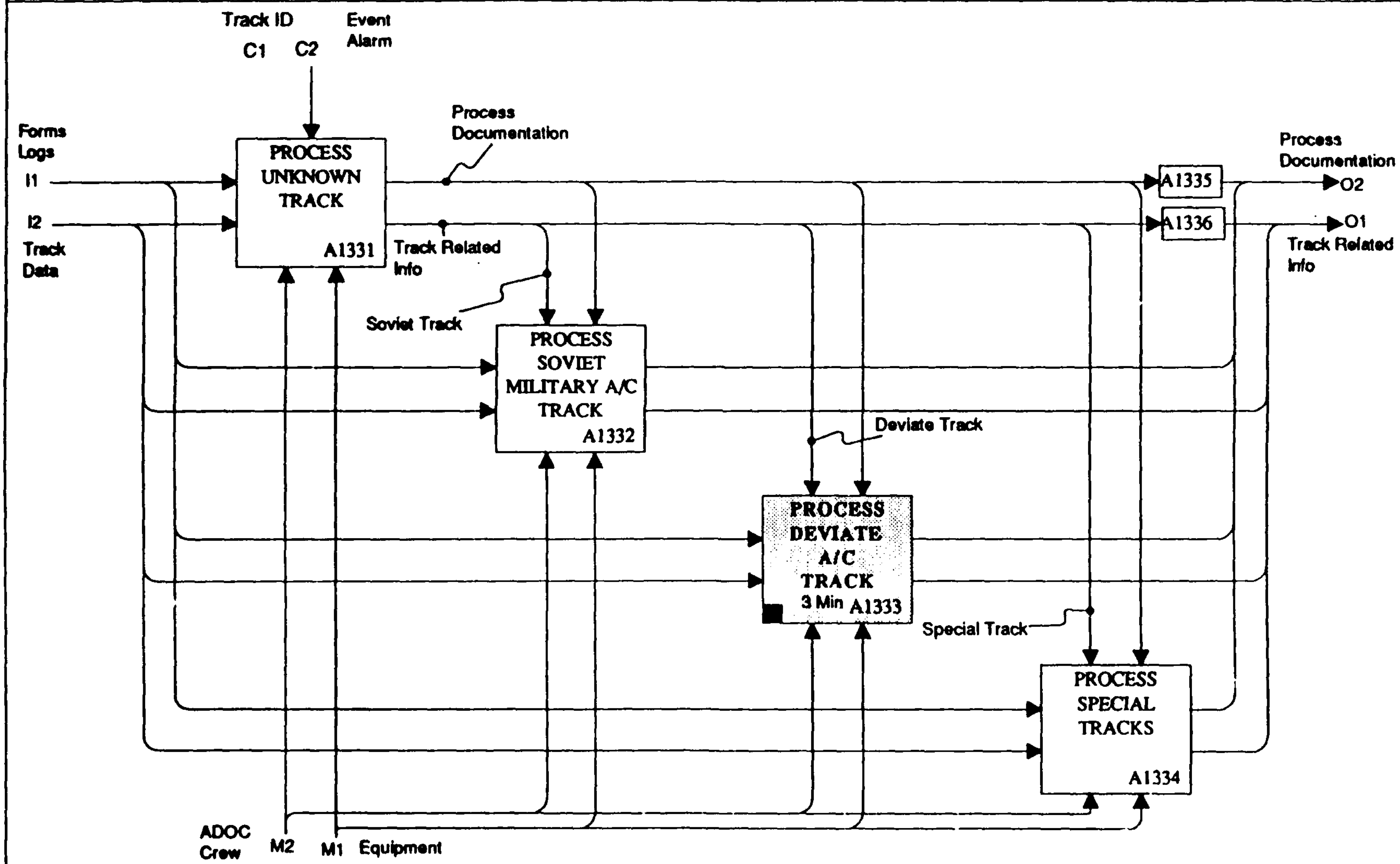
Verify track type(A1313) can change an unknown track to a suspected Soviet military aircraft track.

RETURN

This text page is associated with A131.

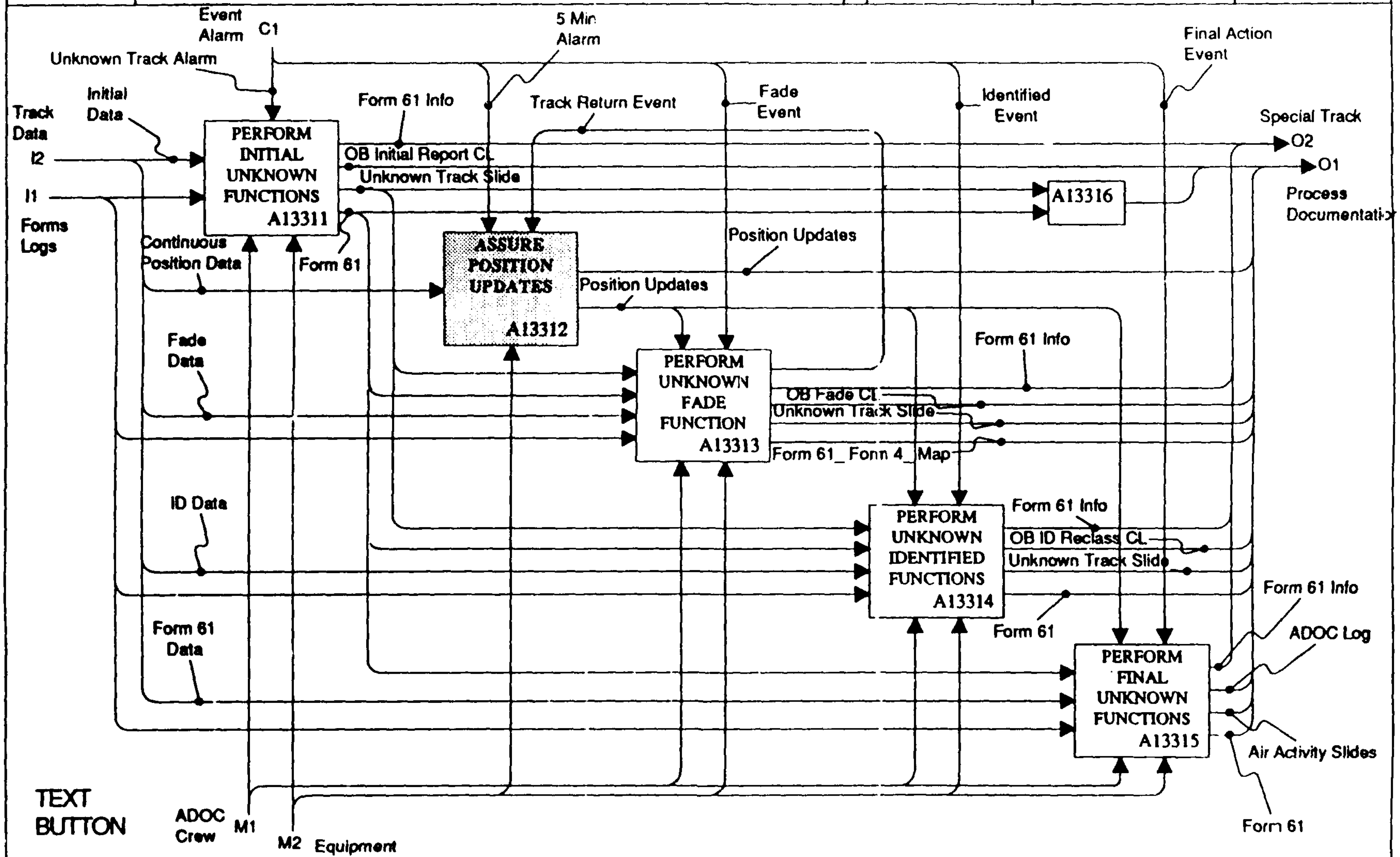
NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. MCFARREN, D. MONK, R. SMITH PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 10/14/88 REV: 1/27/89		WORKING	READER	DATE	CONTEXT:
			X	DRAFT			
				RECOMMENDED			
				PUBLICATION			



NODE: A133	TITLE: PROCESS TRACKS	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 11/18/88 REV: 1/27/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A1331	TITLE: PROCESS UNKNOWN TRACK	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:02:28 PM	DATE: 12/9/88 REV: 1/3/89 3/30/89	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			

A13312, Assure Position Updates, is meant to be the operator checking for periodic position updates and if these updates are not forthcoming, then the operator manually getting the updates from the site. It also allows the model to retrieve a faded track and collect trickling data.

All Form 61's are reviewed by the Assistant for Displays, then signed by the Command Director(55-312). The originial of each Form 61 is filed in the ADOC Unknown Track Book(55-312).

ADOC Crew Commander/Supervisor will brief the Command Post and Air Defense Intelligence Center(ADIC) via the Operations Loop when track track is declared unknown & provide NORAD Form 61 info as it becomes available(55-312).

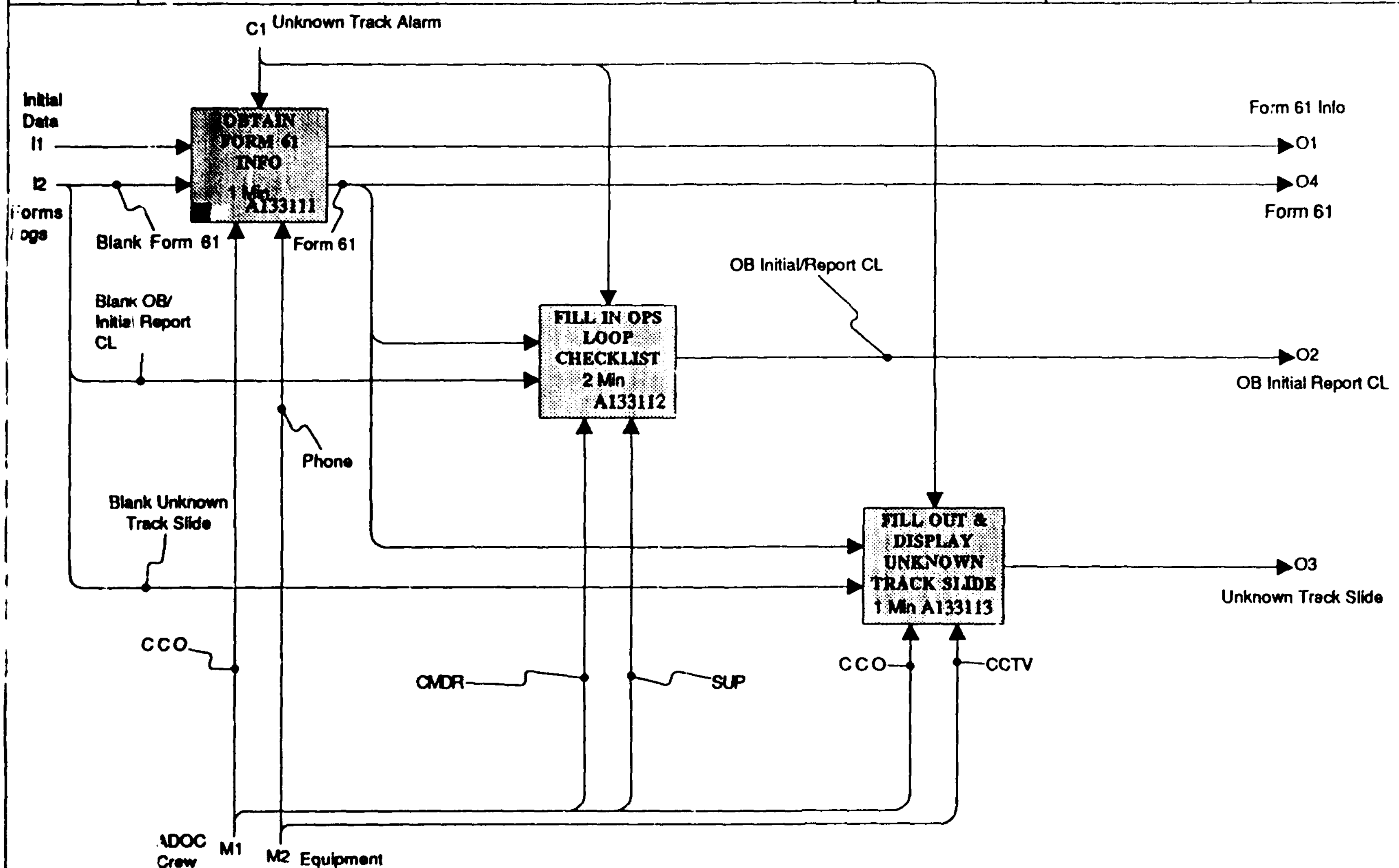
Unknowns resulting from bad radar data will not be briefed, but will be included in Form 57(55-312).

RETURN

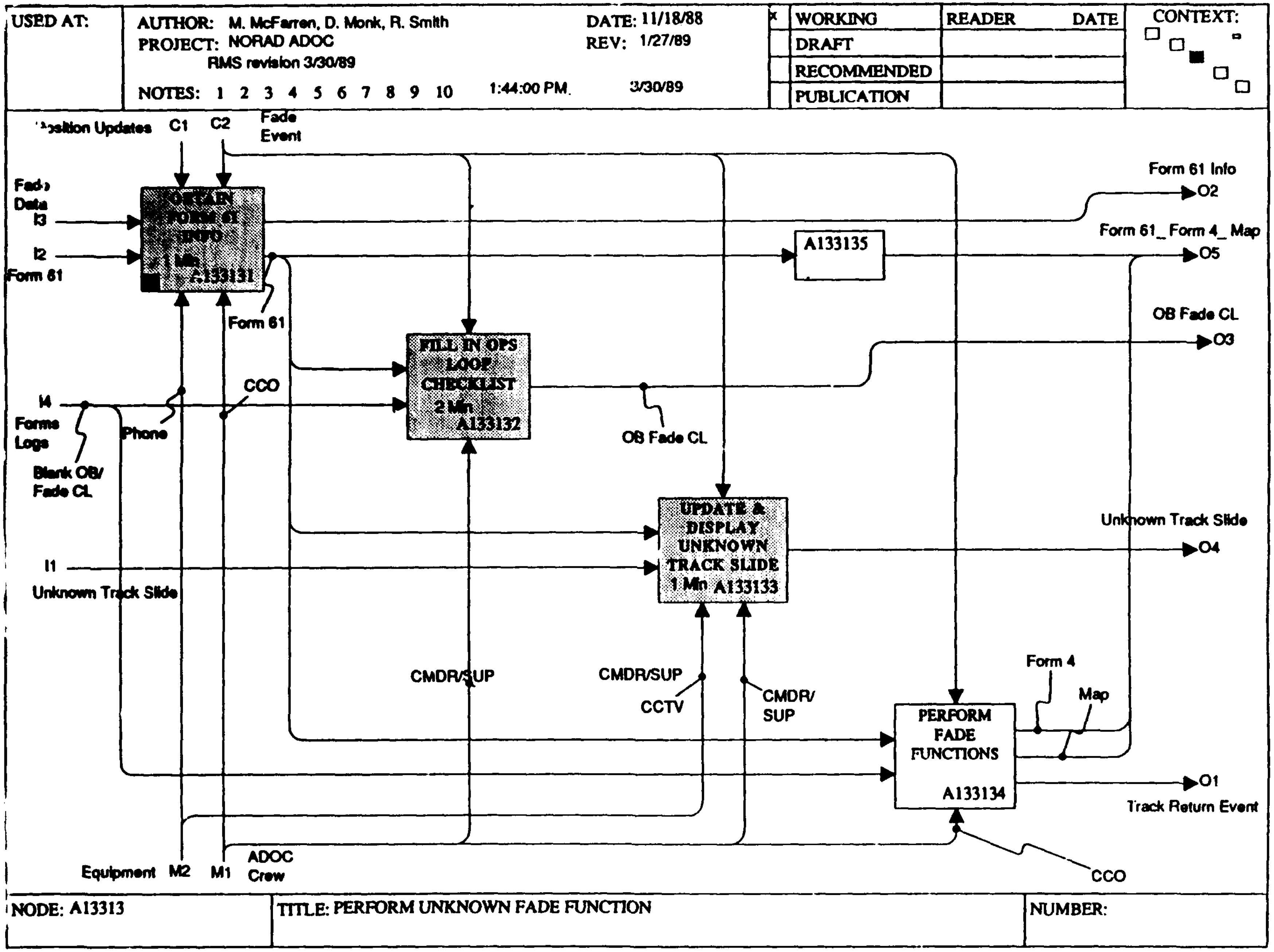
This page associated with A1331.

NODE:	TITLE:	NUMBER:

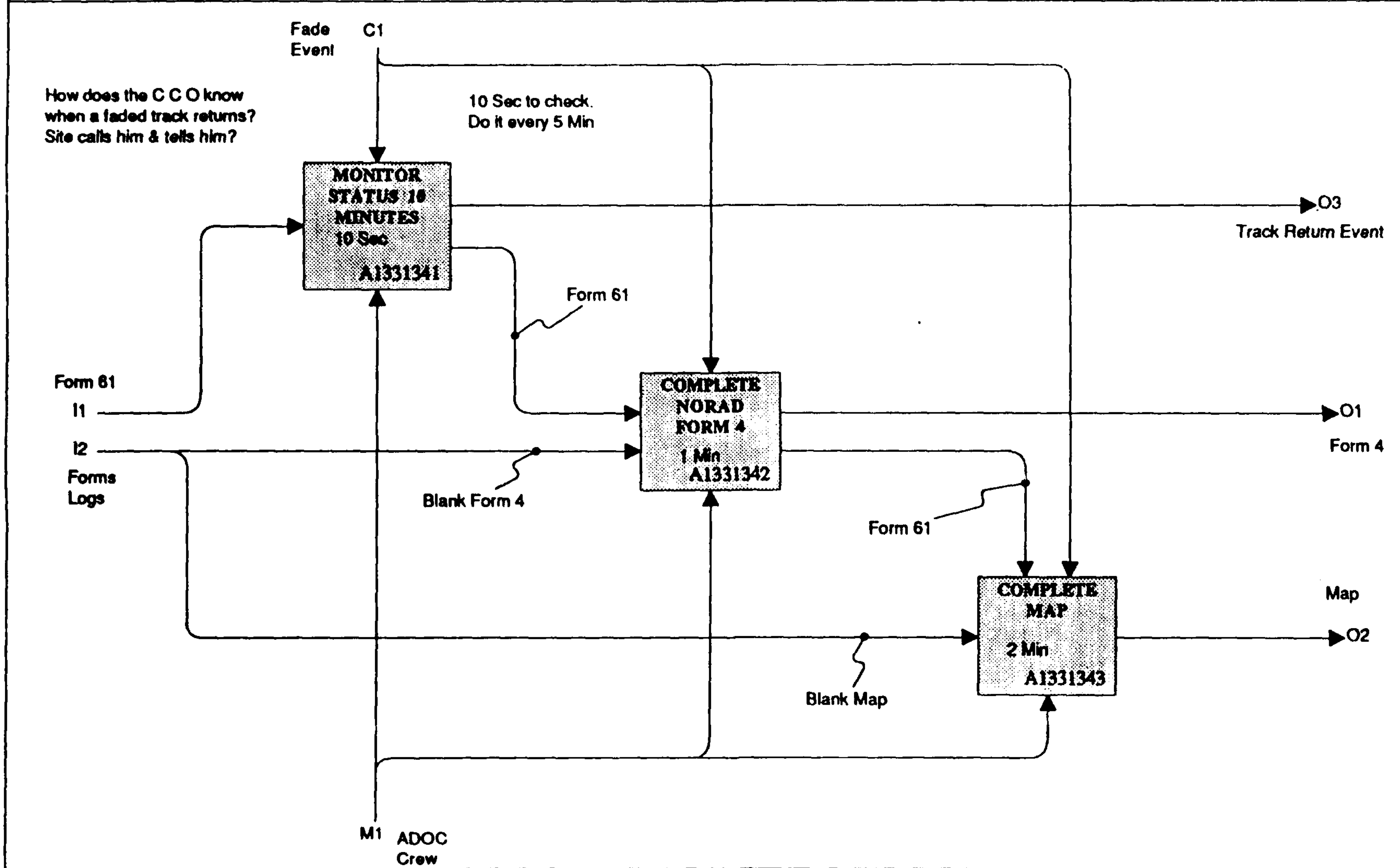
USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:39:05 PM	DATE: 11/18/88 REV: 1/3/89 3/30/89	x	WORKING DRAFT RECOMMENDED PUBLICATION	READER	DATE	CONTEXT:



NODE: A13311	TITLE: PERFORM INITIAL UNKNOWN FUNCTIONS	NUMBER:


USED AT:
AUTHOR: M. McFarren, D. Monk, R. Smith
PROJECT: NORAD ADOC
RMS revision 3/30/89
NOTES: 1 2 3 4 5 6 7 8 9 10 1:44:00 PM. 3/30/89
DATE: 11/18/88
REV: 1/27/89
x WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER DATE
CONTEXT:
Position Updates C1 C2
Fade Event
Fade Data I3
I2 Form 61
OBTAIN FORM 61 INFO 1 Min A133131
Form 61
FILL IN OPS LOOP CHECKLIST 2 Min A133132
A133135
UPDATE & DISPLAY UNKNOWN TRACK SLIDE 1 Min A133133
PERFORM FADE FUNCTIONS A133134
I4 Forms Logs
Blank OB/ Fade CL
Phone
CCO
OB Fade CL
I1 Unknown Track Slide
CMDR/SUP
CMDR/SUP
CCTV
CMDR/ SUP
Form 4
Map
CCO
Equipment M2 M1 ADOC Crew
Form 61 Info O2
Form 61_ Form 4_ Map O5
OB Fade CL O3
Unknown Track Slide O4
O1 Track Return Event
NODE: A13313
TITLE: PERFORM UNKNOWN FADE FUNCTION
NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:46:34 PM	DATE: 11/18/88 REV: 1/3/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE
				11/18/88



NODE: A133134	TITLE: PERFORM FADE FUNCTIONS	NUMBER:

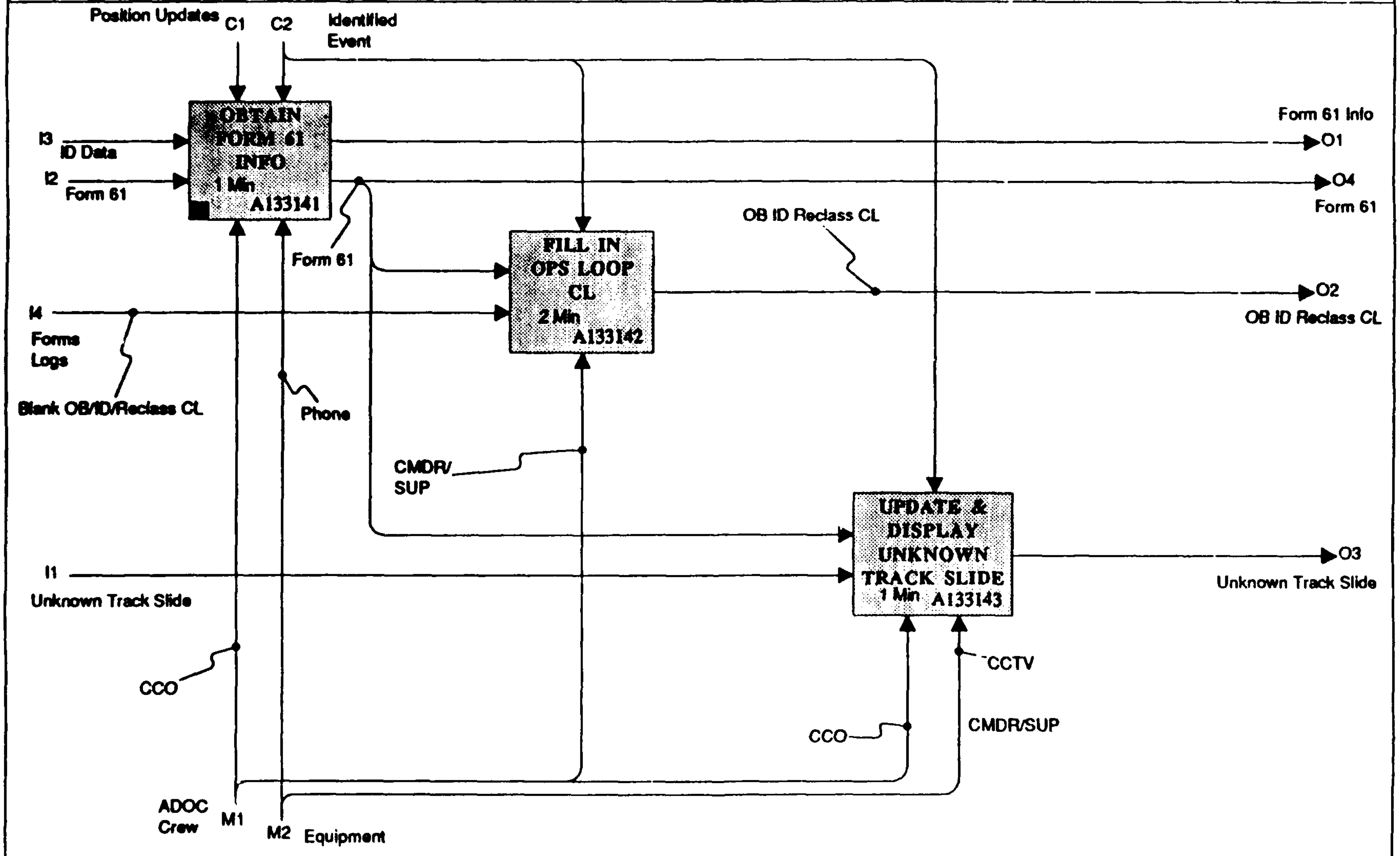
USED AT:

AUTHOR: M. McFarren, D. Monk, R. Smith
PROJECT: NORAD ADOC
RMS revision 3/30/89
NOTES: 1 2 3 4 5 6 7 8 9 10   1:48:04 PM   3/30/89

DATE: 11/21/88
REV: 1/3/89

x	WORKING	READER	DATE
	DRAFT		
	RECOMMENDED		
	PUBLICATION		

CONTEXT:

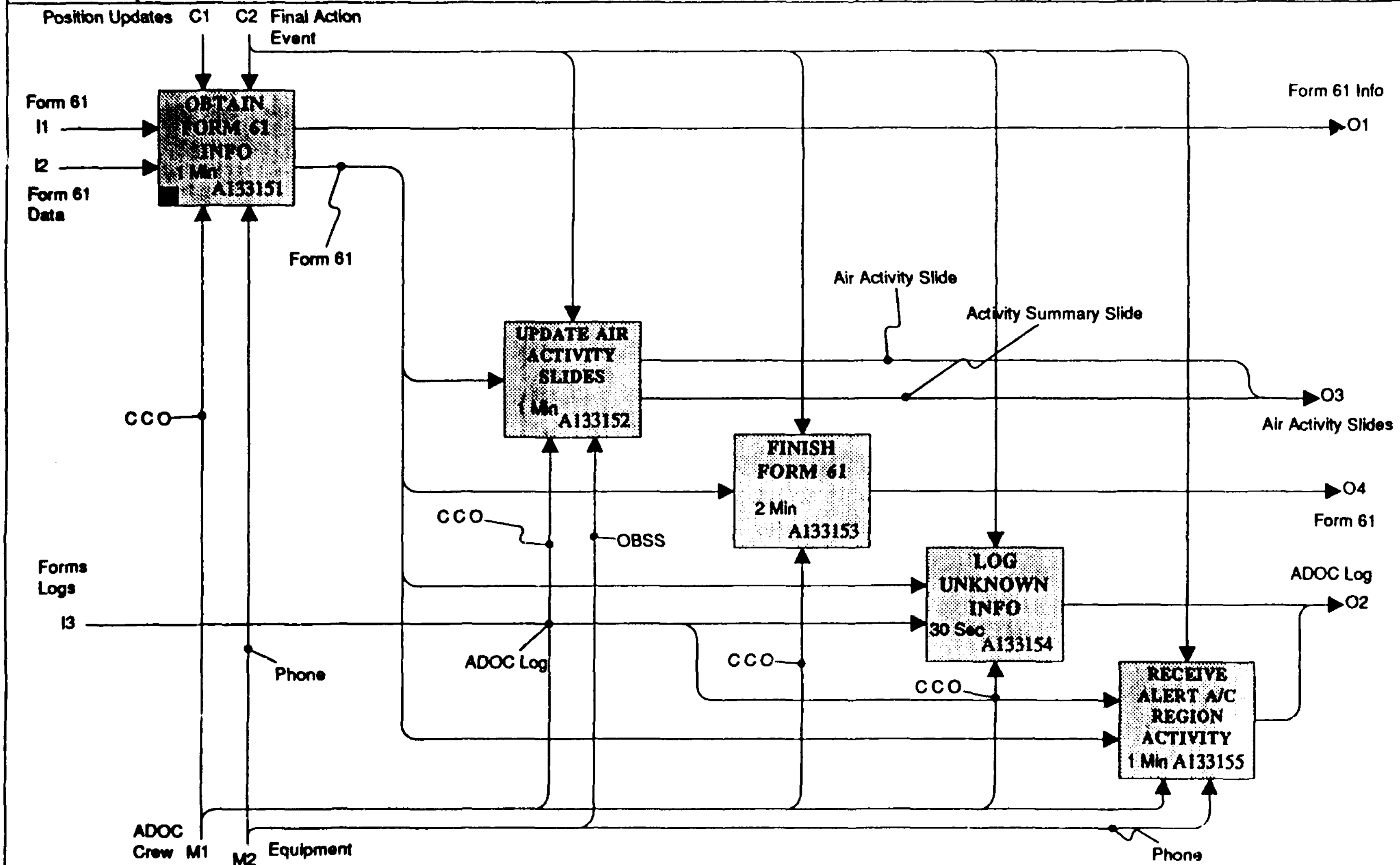


NODE: A13314

TITLE: PERFORM UNKNOWN IDENTIFIED FUNCTIONS

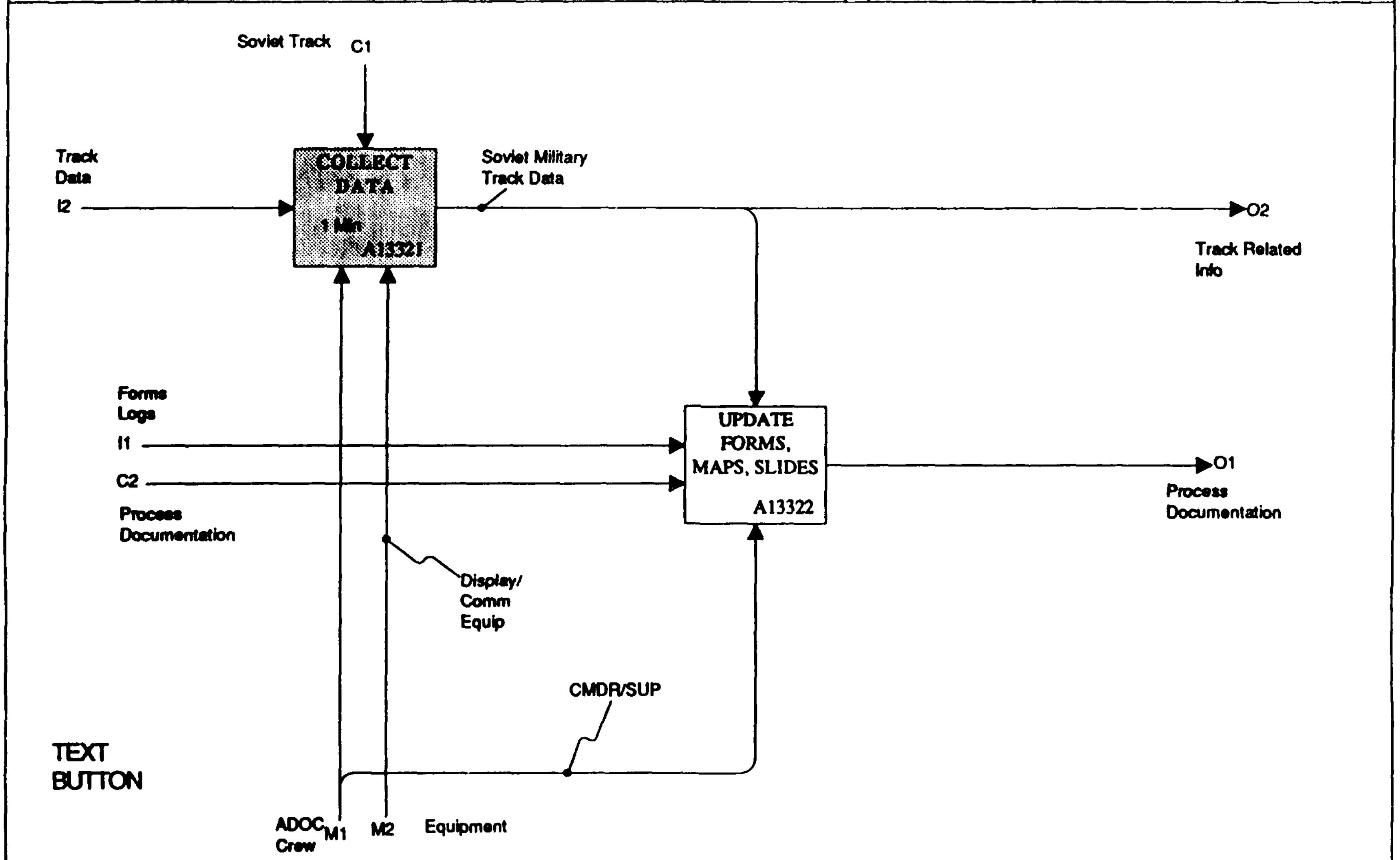
NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:50:46 PM	DATE: 11/22/88 REV: 1/27/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A13315	TITLE: PERFORM FINAL UNKNOWN FUNCTIONS	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:52:18 PM	DATE: 11/30/88 REV: 1/27/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER	DATE	CONTEXT:



NODE: A1332	TITLE: PROCESS SOVIET MILITARY A/C TRACK	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:03:06 PM	DATE: 12/2/88 REV: 12/2/88 3/30/89	x	WORKING	READER DATE	CONTEXT:
				DRAFT		
				RECOMMENDED		
				PUBLICATION		

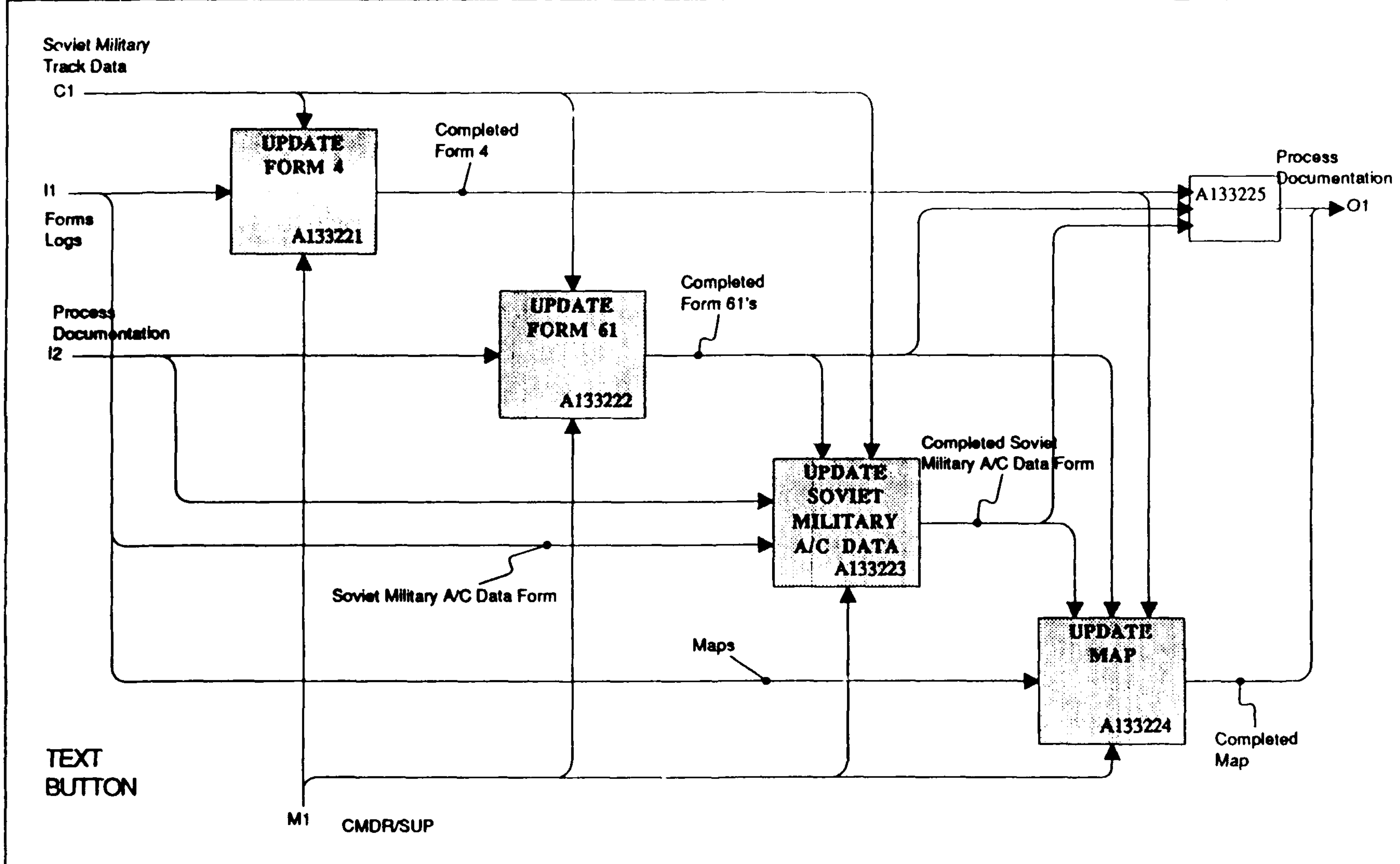
Note: Collect Data should include a confirm Soviet military a/c track and ensure 5 min position updates functions.

RETURN

This text page is associated with A1332.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:53:43 PM	DATE: 11/30/88 REV: 1/30/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A13322	TITLE: UPDATE FORMS, MAPS, SLIDES	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:03:33 PM	DATE: 12/2/88 REV: 1/5/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

Notes:

Some forms require E-3, fighter info. How does this info get to A13322? Through process documentation, if the information required is on a form.

For those documents that need an approval, must put in an approval function. Also a distribution function. Both the approval & distribution can be in the update function.

The way this is drawn, each function could take small *increments* of time over hours. Not really. The completed form doesn't come out till the last update. The partially filled out form is recycled inside each function.

Maybe I should decompose 3 to show info modelling?

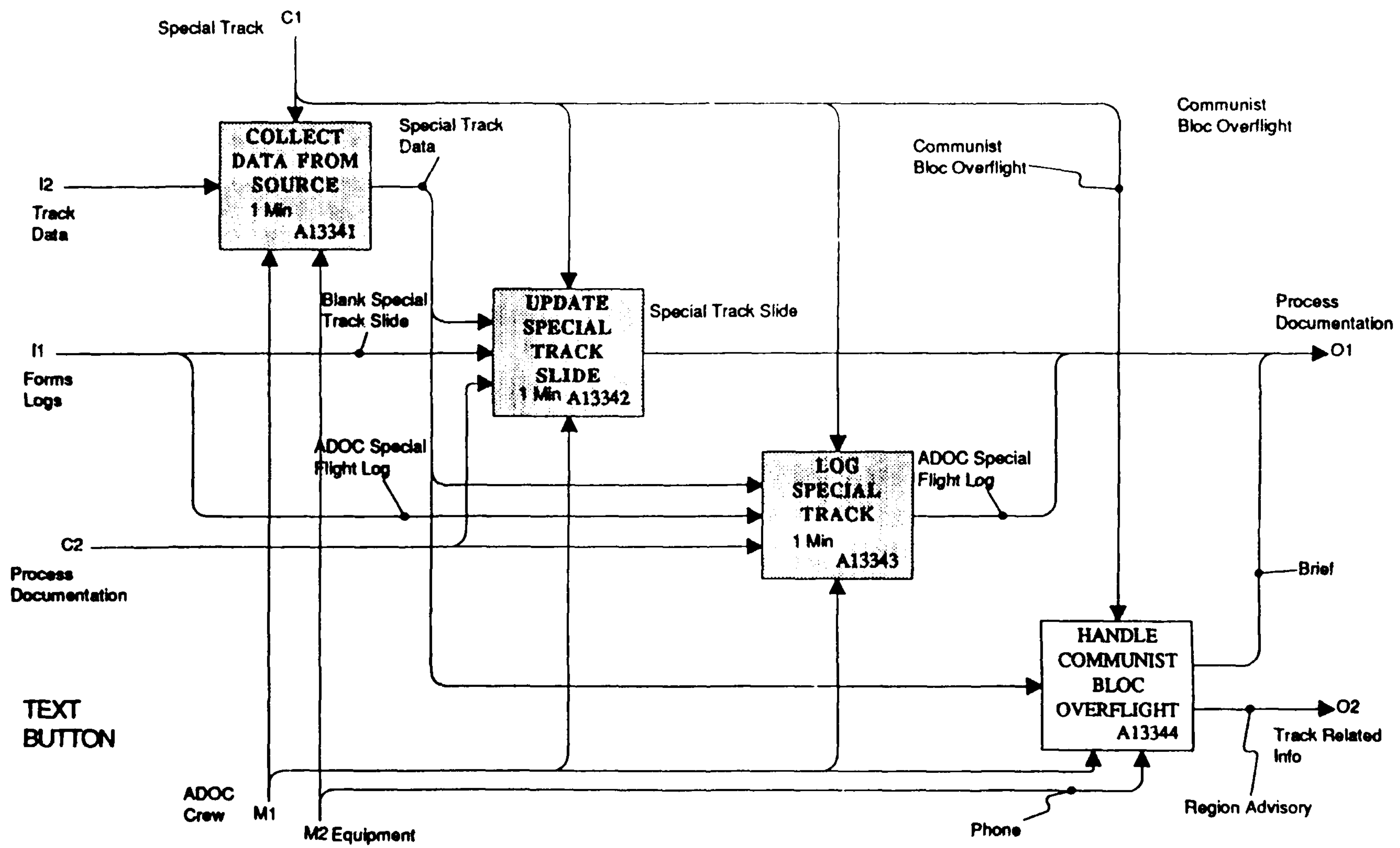
Minimum data for Form 4 when an unknown is changed to a Soviet Military a/c:
initial plot, intercept point, E-3 position, significant heading changes, radar sites that pick up the track, interceptor break-off point, ADIZ entry/exit points(55-312).

RETURN

This page associated with A13322.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:56:21 PM	DATE: 12/12/88 REV: 1/4/89 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A1334	TITLE: PROCESS SPECIAL TRACKS	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:04:01 PM	DATE: 12/12/88 REV: 12/12/88 3/30/89	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			

Data collected includes:
Special number, type of a/c, a/c call sign, country of ownership, departure & destination.

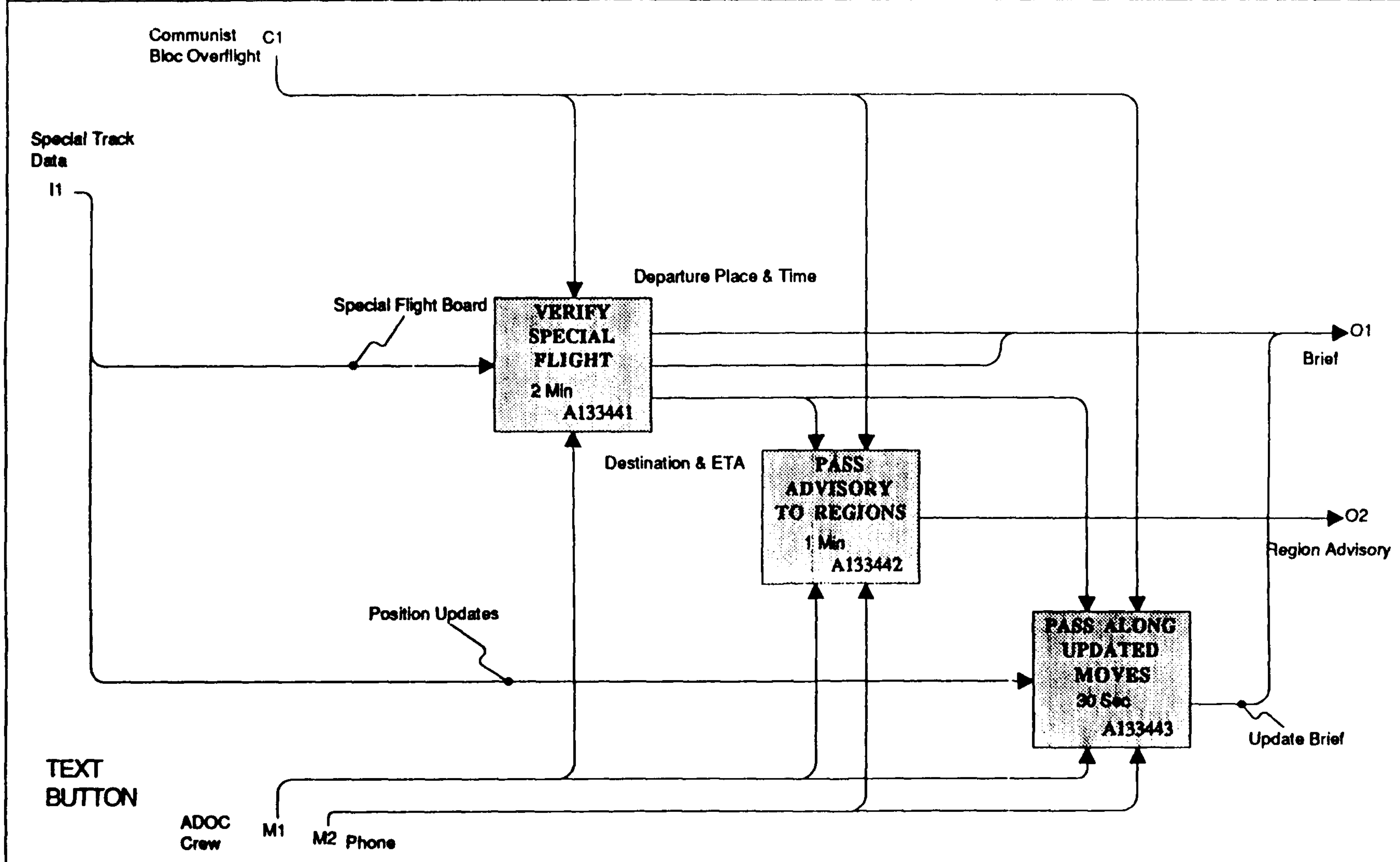
In addition, communist bloc overflights require departure time & ETA.

RETURN

This text page associated with A1334.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC RMS revision 3/30/89 NOTES: 1 2 3 4 5 6 7 8 9 10 1:57:58 PM 3/30/89	DATE: 12/12/88 REV: 1/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:



NODE: A13344	TITLE: HANDLE COMMUNIST BLOC OVERFLIGHT	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10 2:04:32 PM	DATE: 12/12/88 REV: 1/28/89 3/30/89	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			

Position updates of Peoples Republic of China Cross Country Overflights are supplied to SAC CP, GP AUTOVON every 30 minutes. This is represented by the output of A133444.

What is the output or result of checking the special flight board, A13344?

Only the affected regions will be advised(O2) of a scheduled overflight.

RETURN

This text page associated with A13344.

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 12/9/88 REV: 1/18/89 12:00:59 PM 3/30/89	x	WORKING	READER	DATE	CONTEXT:
				DRAFT			
				RECOMMENDED			
				PUBLICATION			

OPEN QUESTION PAGE

1. What are SPADE/SUADE's referred to in 55-312?

2. A FAKER/Hostile is an aircraft that appears to be something other than what it really is. E.g., it could be classified as a special track, then deviate from its flight plan or perform a hostile act?

NODE:	TITLE:	NUMBER:

USED AT:	AUTHOR: M. McFarren, D. Monk, R. Smith PROJECT: NORAD ADOC NOTES: 1 2 3 4 5 6 7 8 9 10	DATE: 2/11/89 REV: 2/11/89 12:02:16 PM 3/30/89	x WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT:

Page A0:
A5 added ««259»»
A6 added

Page A1:
box A13 'sit. awareness' output:
Slide points so that all merges
preceed all branches.

Page A11:
Box A116 added ««396»»
Box A117 added ««1468»»

Page A12:
Jaggy verticals: M2 & M3.
Add Box A126
Add Box A127

Page A13:
Add box A136 ««1321»»
Add box A137 ««1291»»

Page A131:
jaggy on C1.

Page A133:
Added box A1335 ««1463»»
Added box A1336 ««3239»»

Page A1331:
Added Box A13316
Added Box A13317
Added Box A13318
Added Box A13319 ««3515»»

Page A13313:
Added Box A133137 ««1798»»

Page A13322:
Added Box A133225 ««3543»»

A0: add activity box near c9
add activity box for feedback into A1 I3.
A1: box A13 sit awareness output: slide points so that all merges preced all branches.
A11: preceeding O3 put box to eliminate late merges.
preceeding O2 same construct.
A12: M2 jaggy vertical.
M3 jaggy vertical.
preceeding O3 put box to eliminate late merges.
preceeding O2 put box to eliminate late merges(checka122 & 124)
A13: C1 and A131 merge needs box.
preceeding O2 put box to eliminate late merges
A131: jaggy on C1.[O2]!!
A133: preceeding O2 put box to eliminate late merges.
preceeding O1 put box to eliminate late merges.
A1331: preceeding O1 put box to eliminate late merges.
I2 late merges from A13312 and A13311.
A13313: O5 late merge.
A13322: O late merge.

A133442 has no outputs««4033»»

A134 checklist not output««805»»

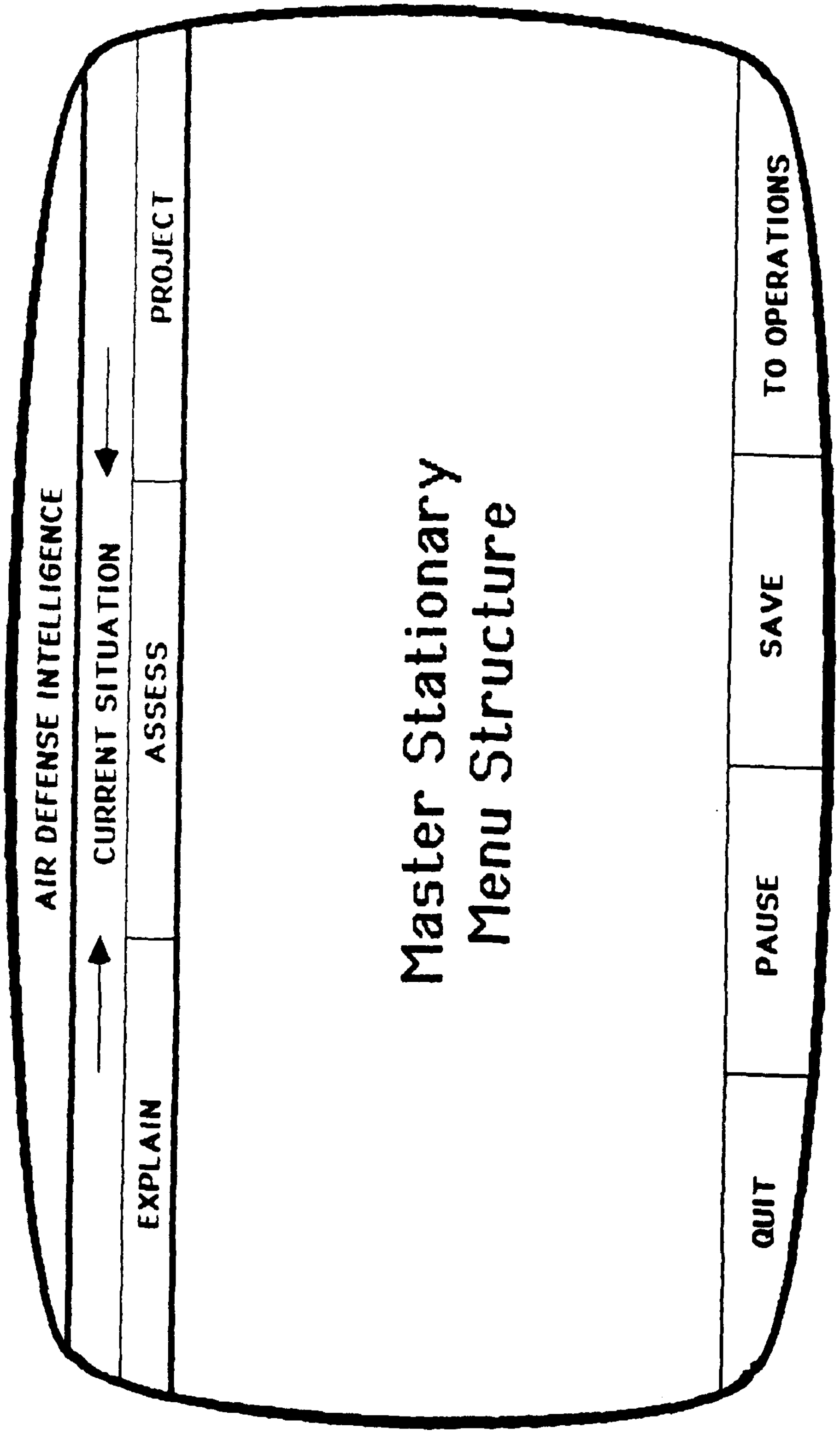
NODE:	TITLE:	NUMBER:

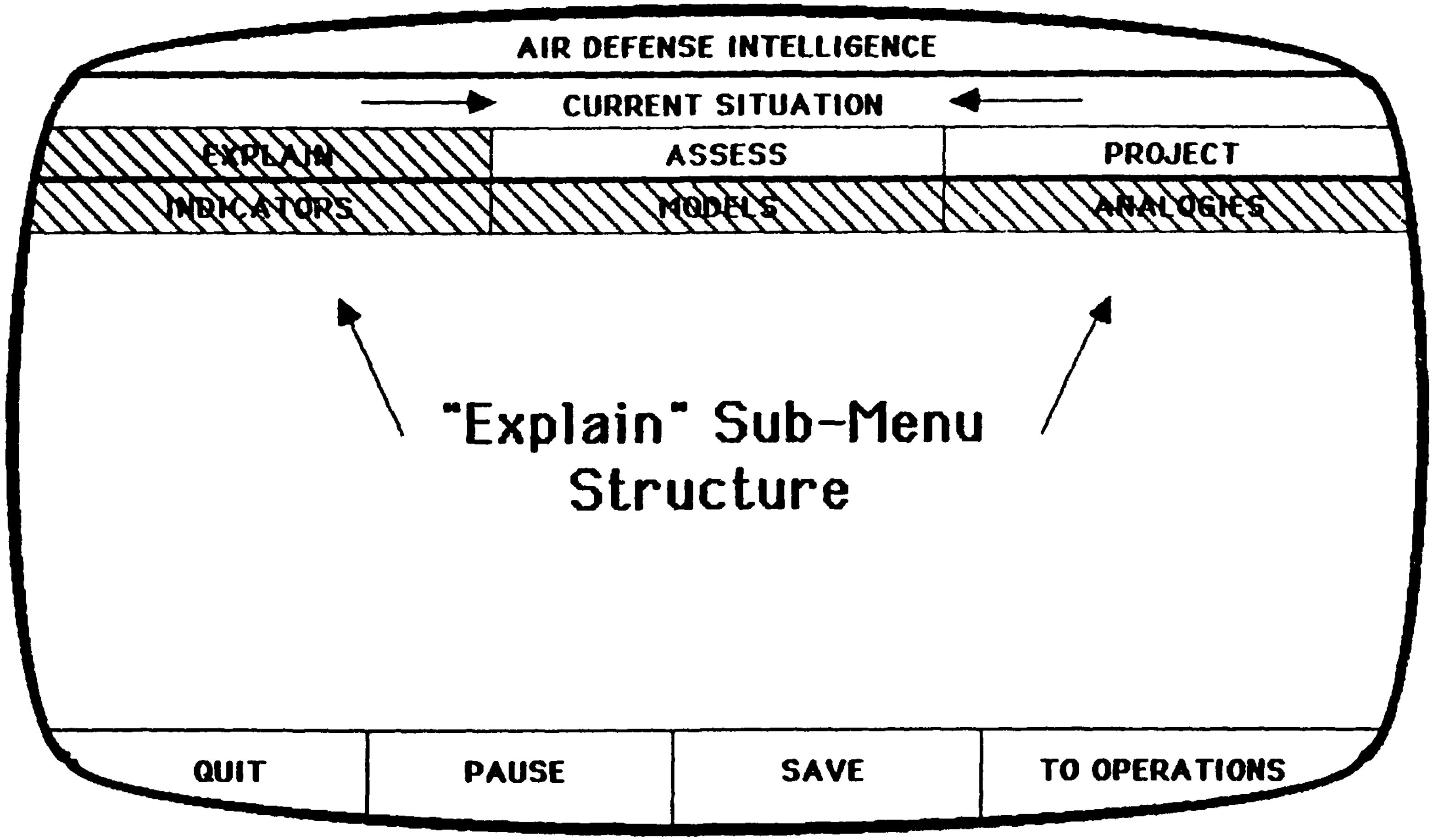
APPENDIX B

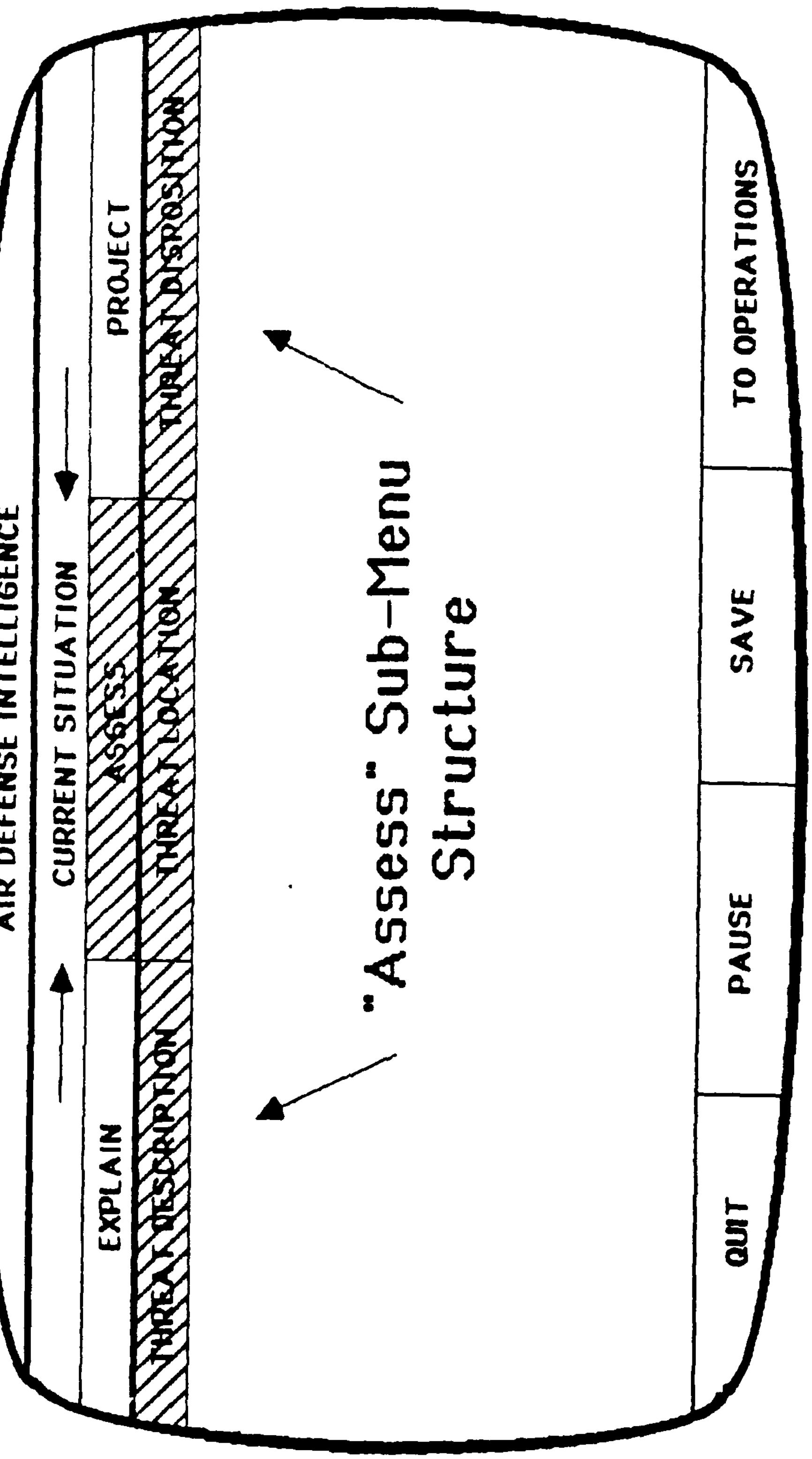
AIR DEFENSE INTELLIGENCE, OPERATIONS & INTELLIGENCE/OPERATIONS PROTOTYPES

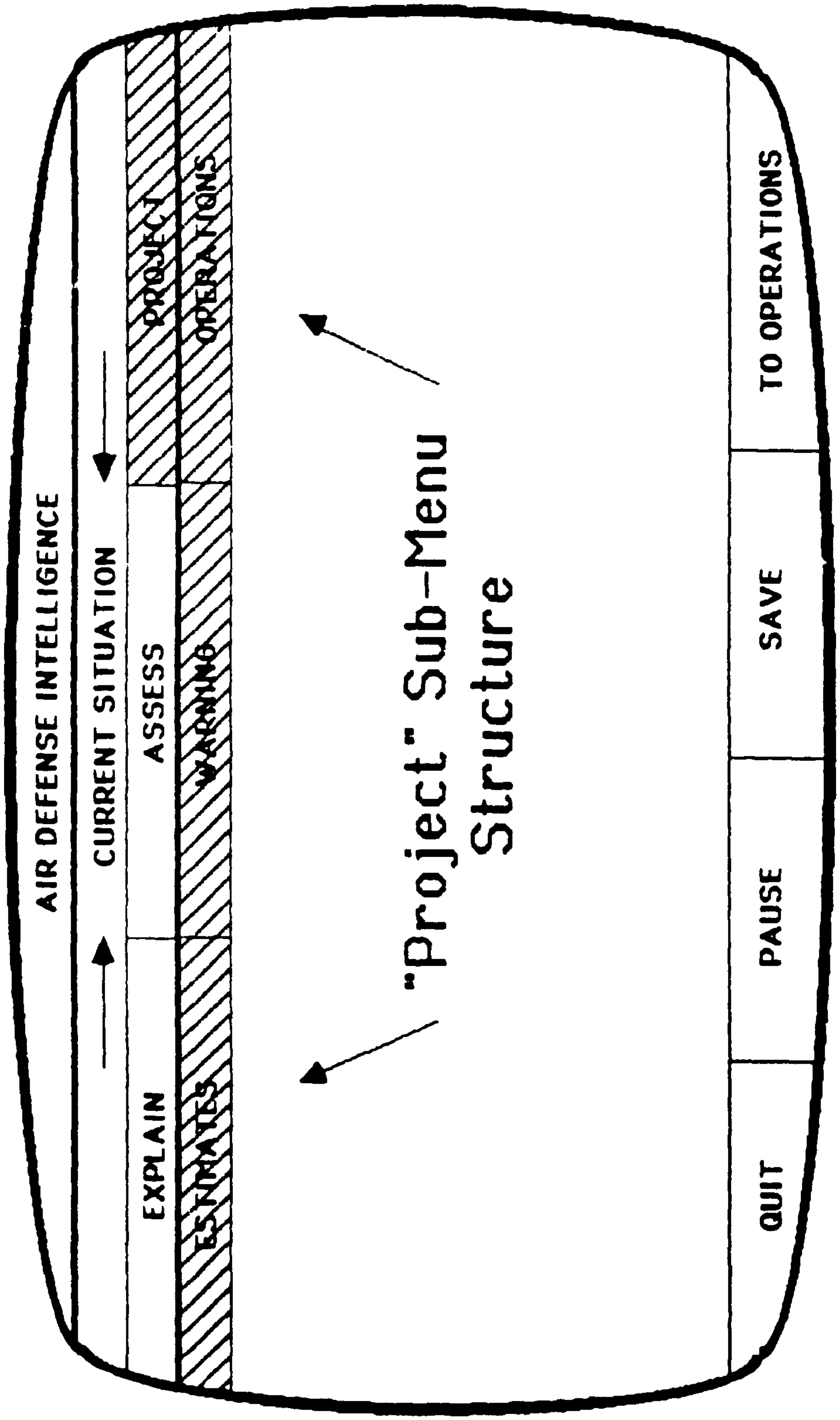
Storyboard Prototypes For
Strategic Air Defense Intelligence,
Operations & The
Intelligence/Operations Interface

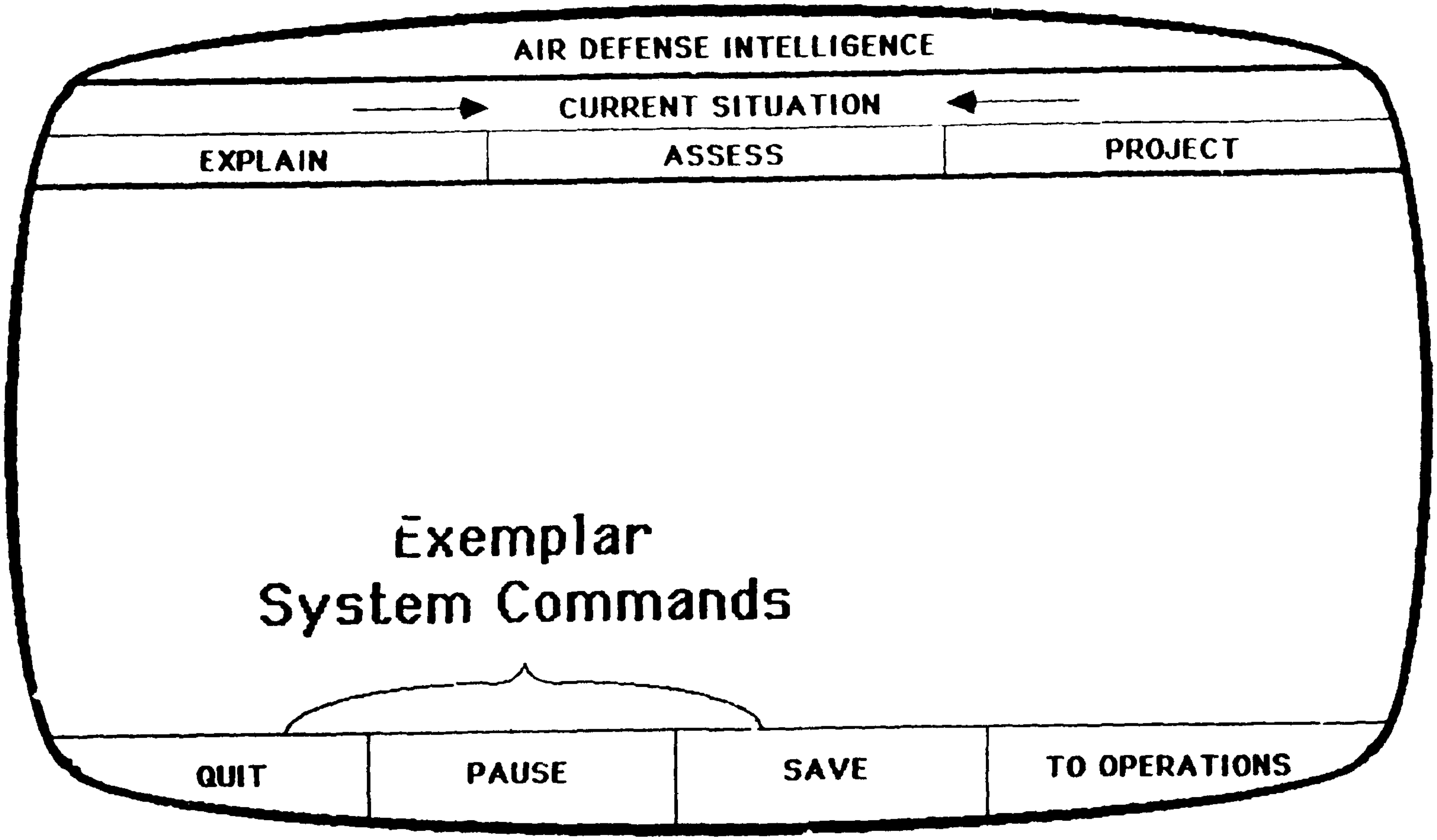
Air Defense Intelligence Prototype

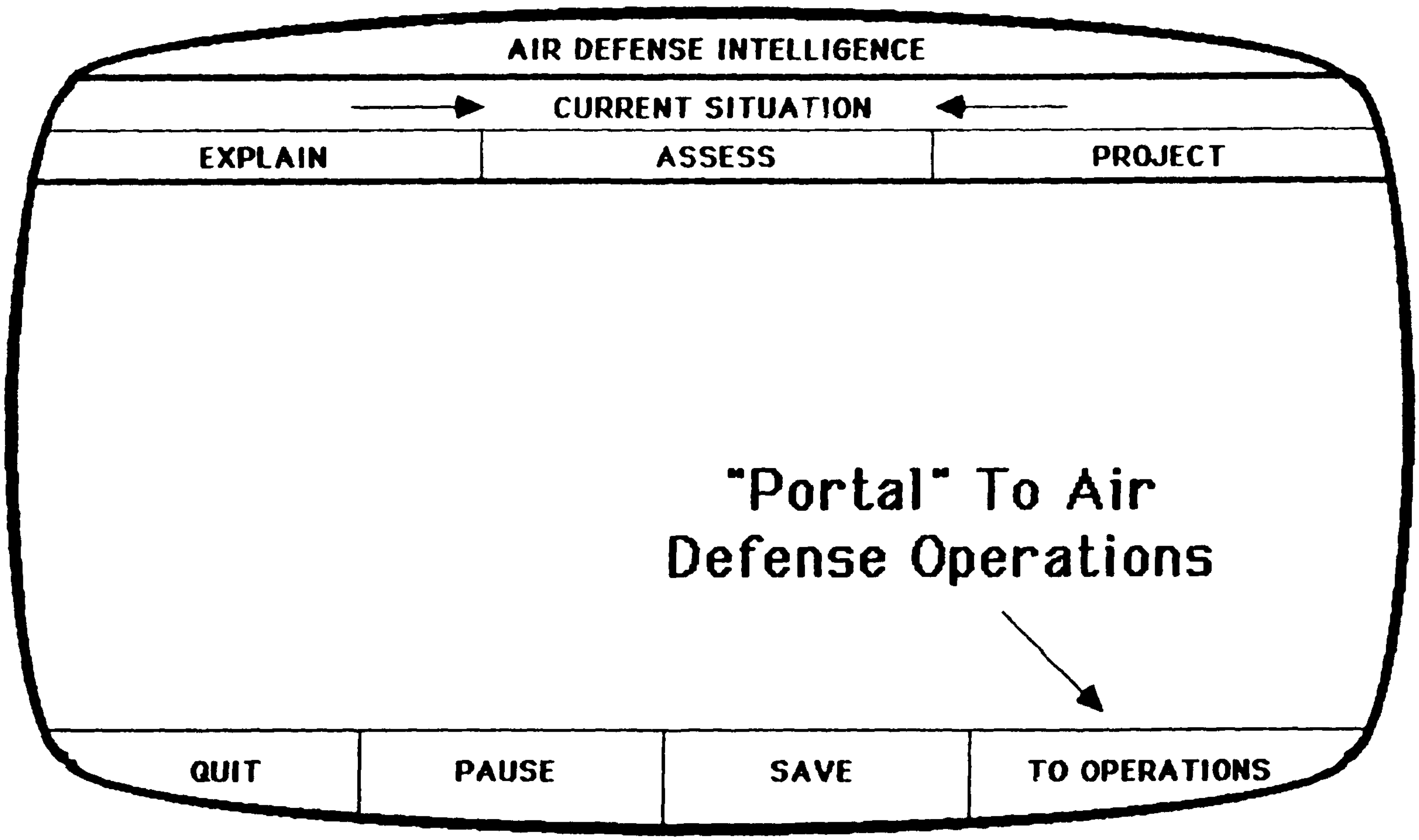

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Master Stationary
Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

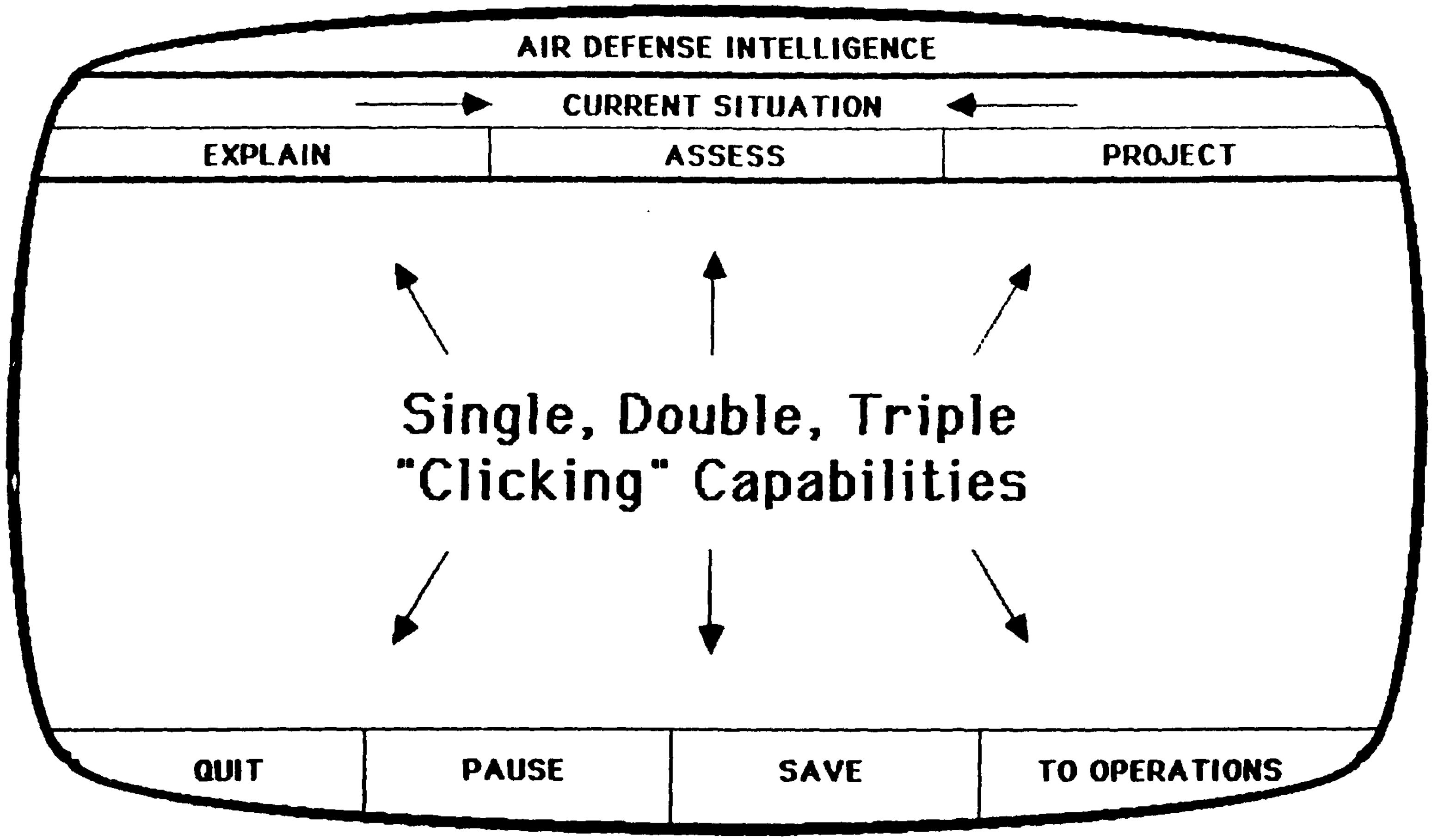

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
INDICATORS
MODELS
ANALOGIES
"Explain" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

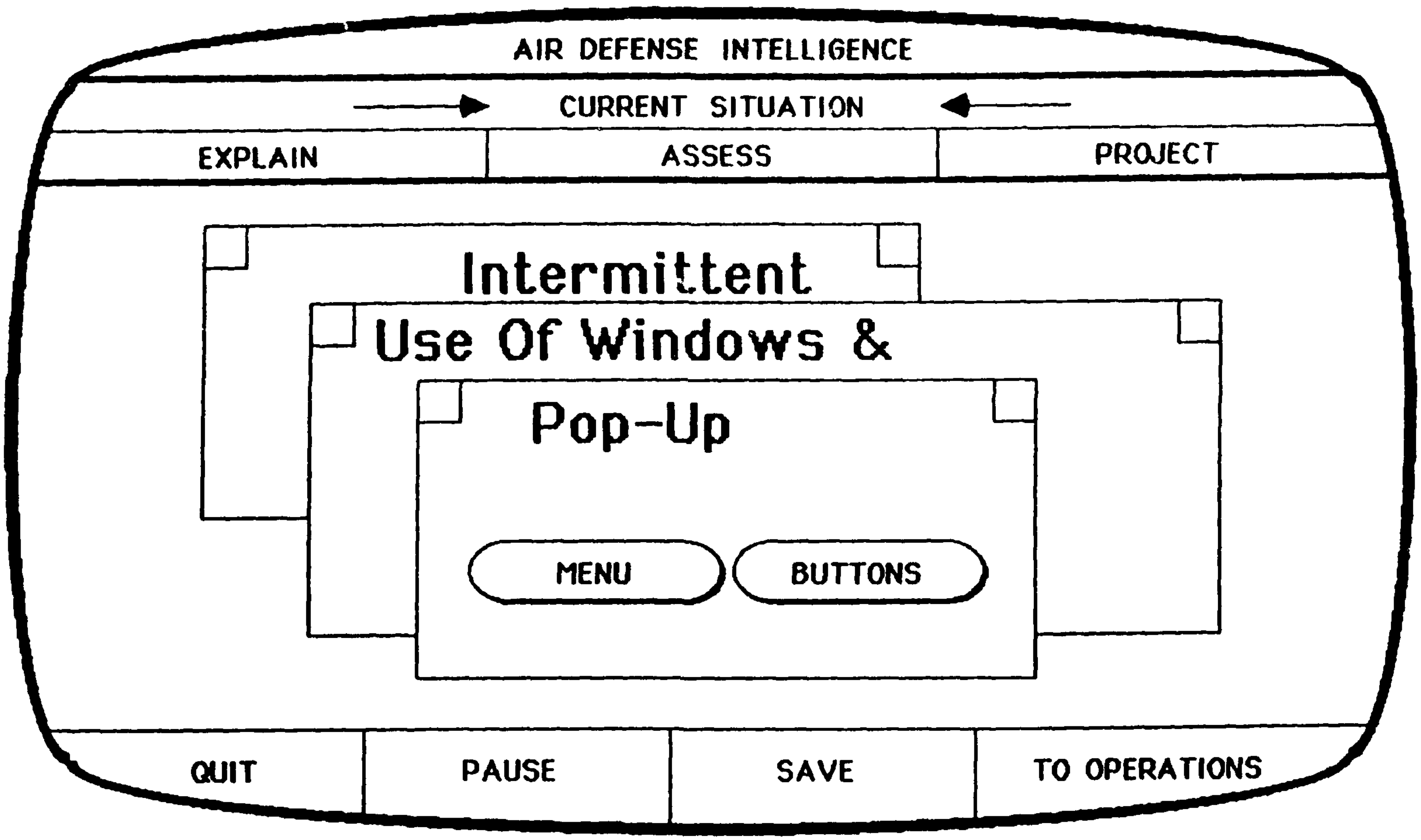

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
THREAT DESCRIPTION
THREAT LOCATION
THREAT DISPOSITION
"Assess" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

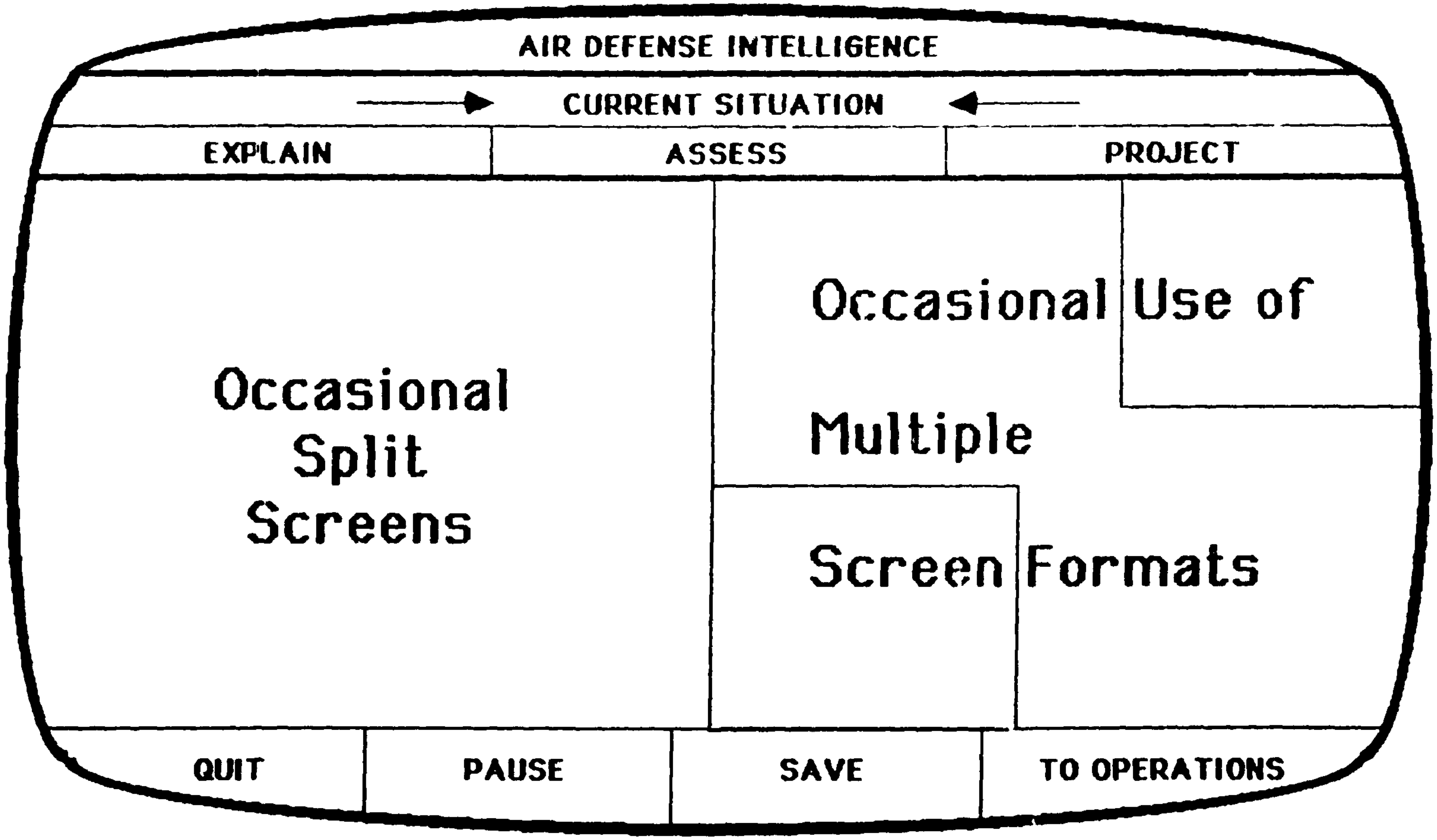

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
"Project" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO OPERATIONS

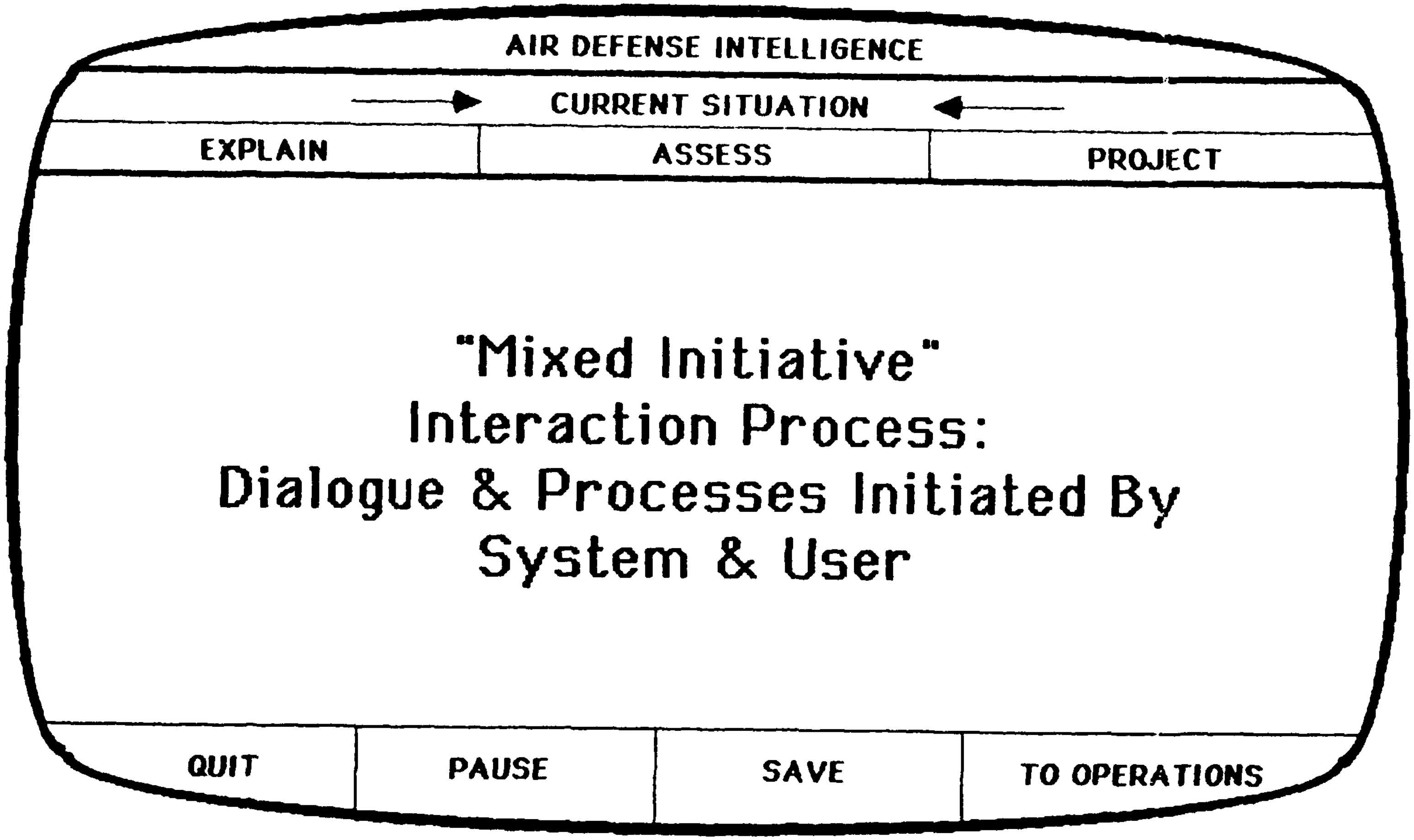

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Exemplar
System Commands
QUIT
PAUSE
SAVE
TO OPERATIONS

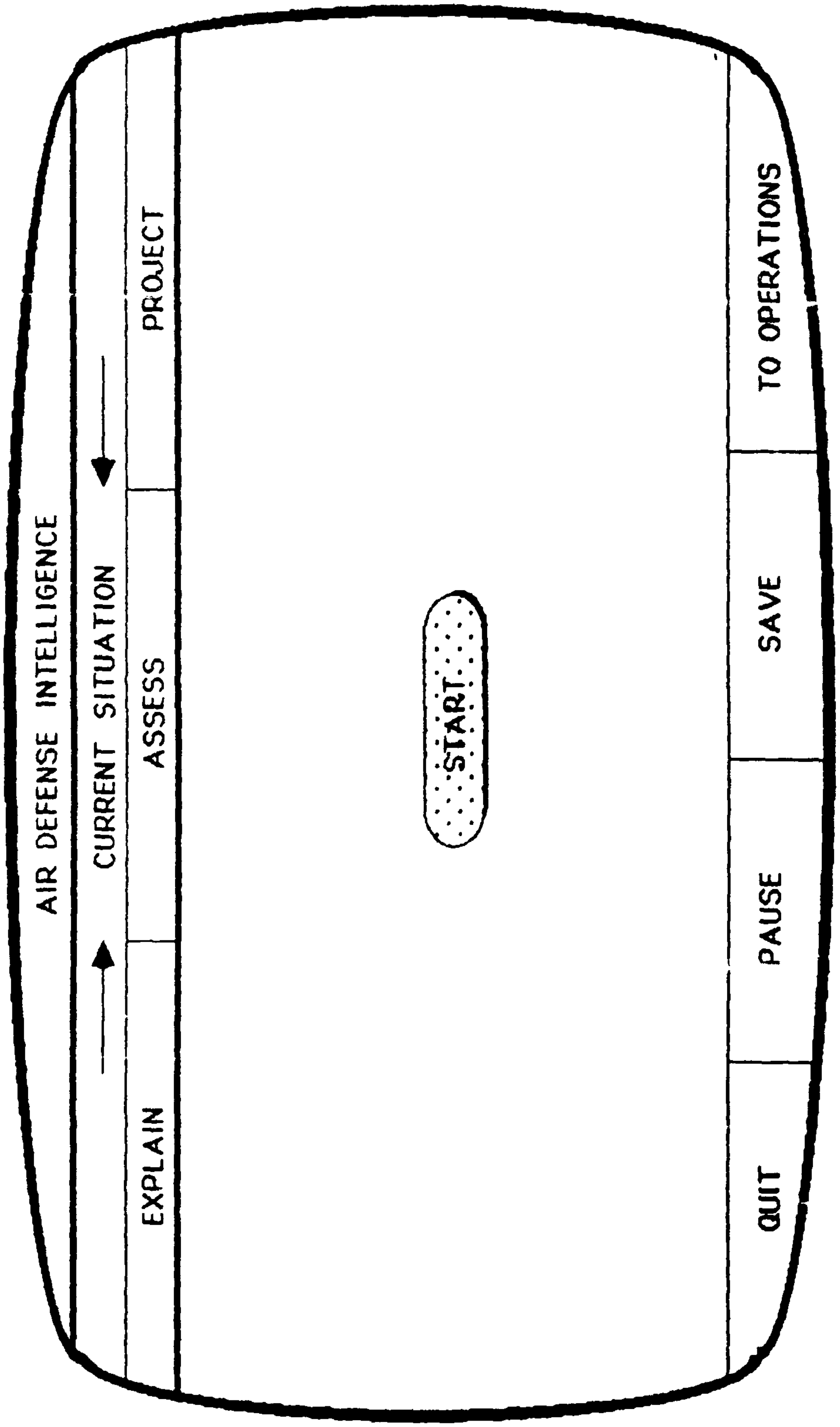

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
"Portal" To Air
Defense Operations
QUIT
PAUSE
SAVE
TO OPERATIONS

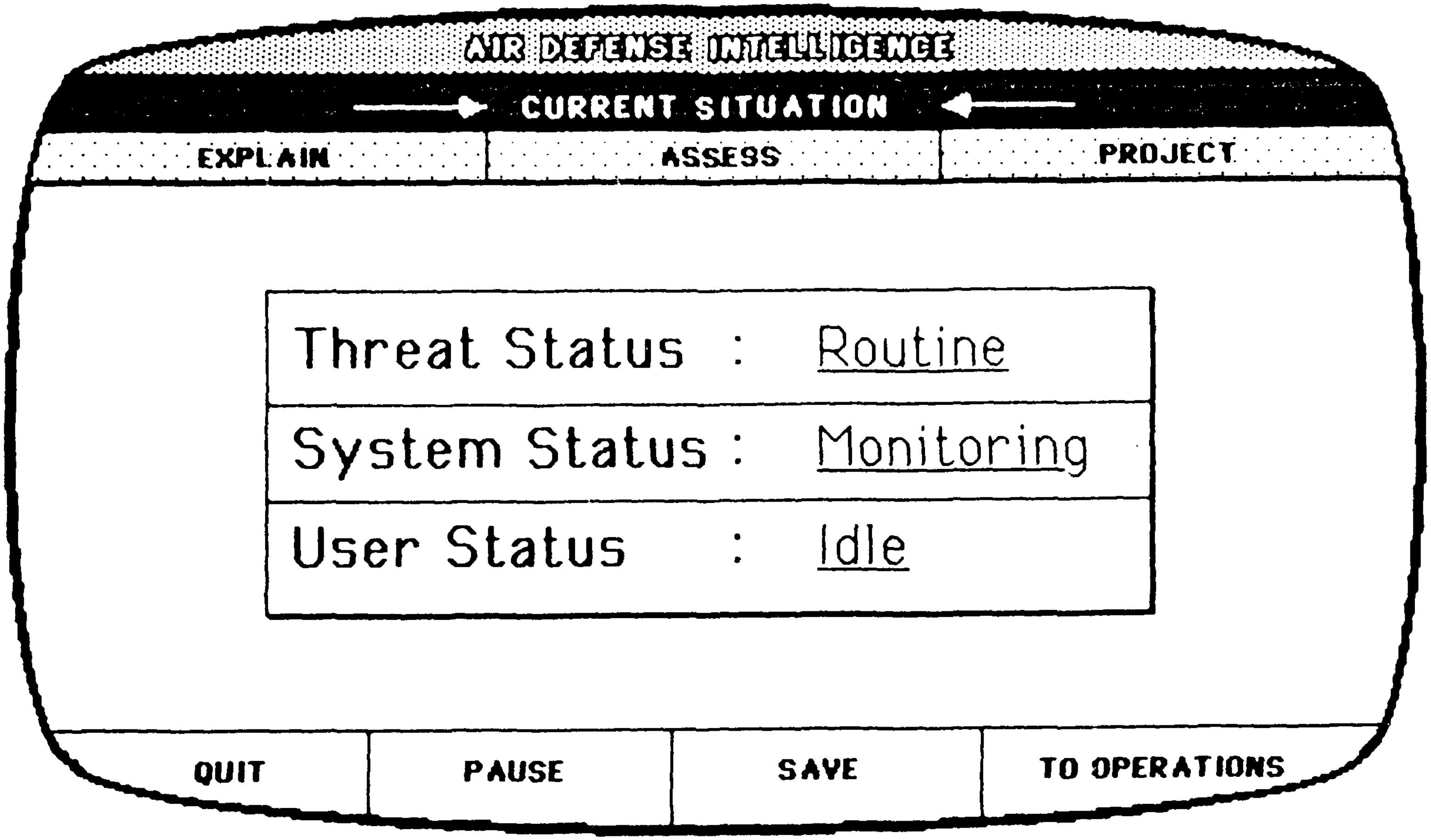

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Single, Double, Triple
"Clicking" Capabilities
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Intermittent
Use Of Windows &
Pop-Up
MENU
BUTTONS
QUIT
PAUSE
SAVE
TO OPERATIONS

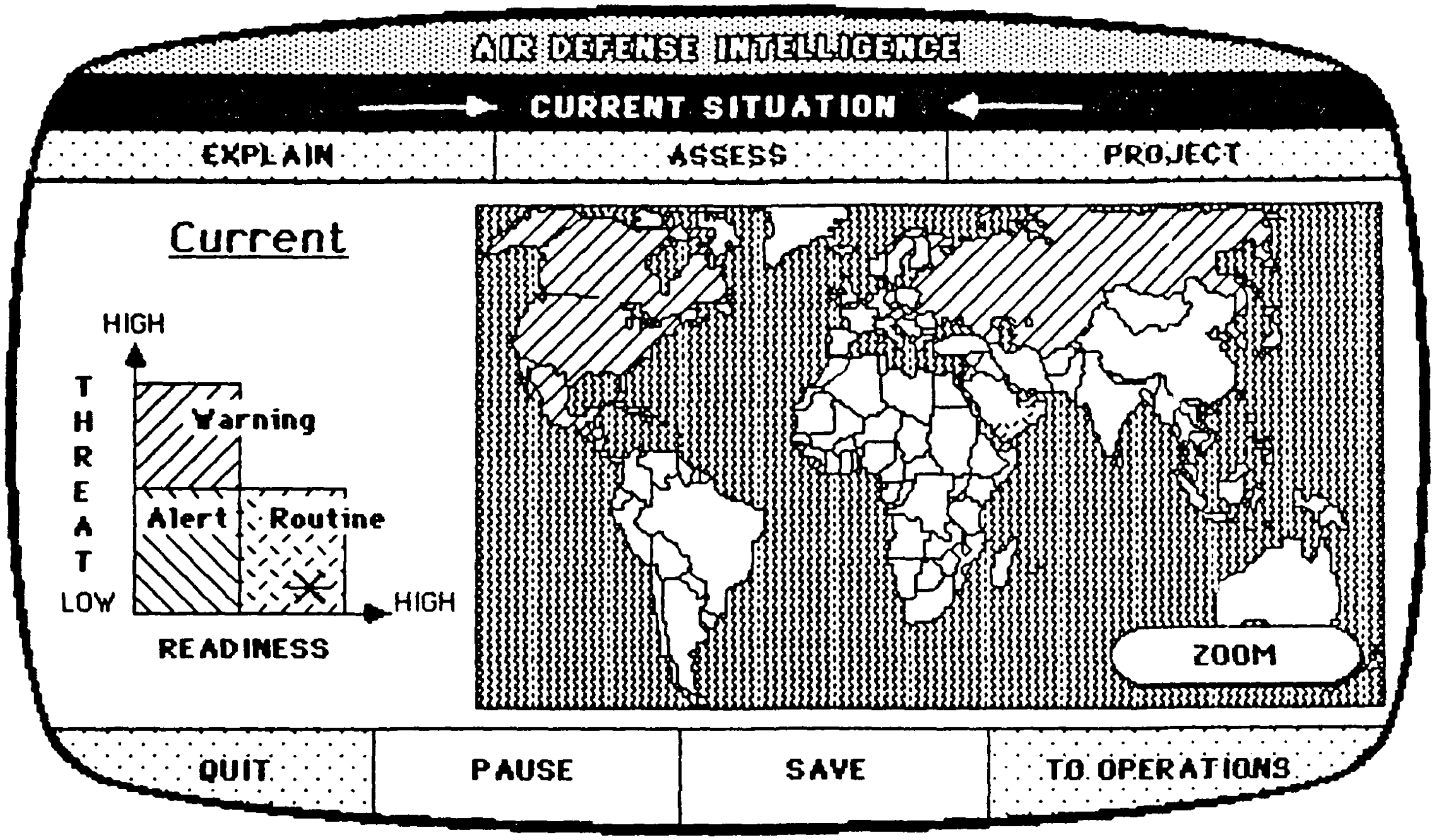

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Occasional Split Screens
Occasional Use of Multiple Screen Formats
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
"Mixed Initiative"
Interaction Process:
Dialogue & Processes Initiated By
System & User
QUIT
PAUSE
SAVE
TO OPERATIONS

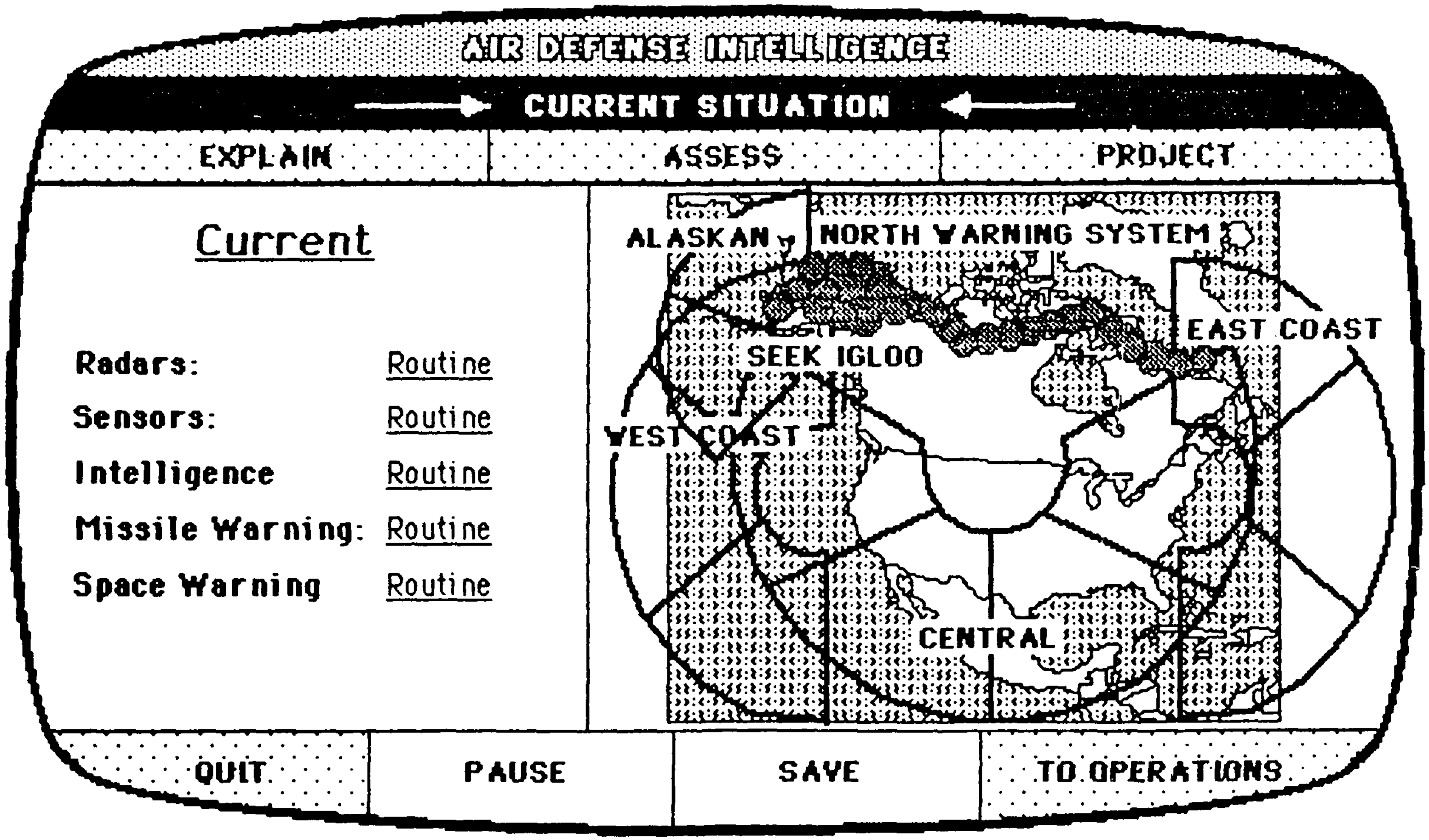

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
START
QUIT
PAUSE
SAVE
TO OPERATIONS



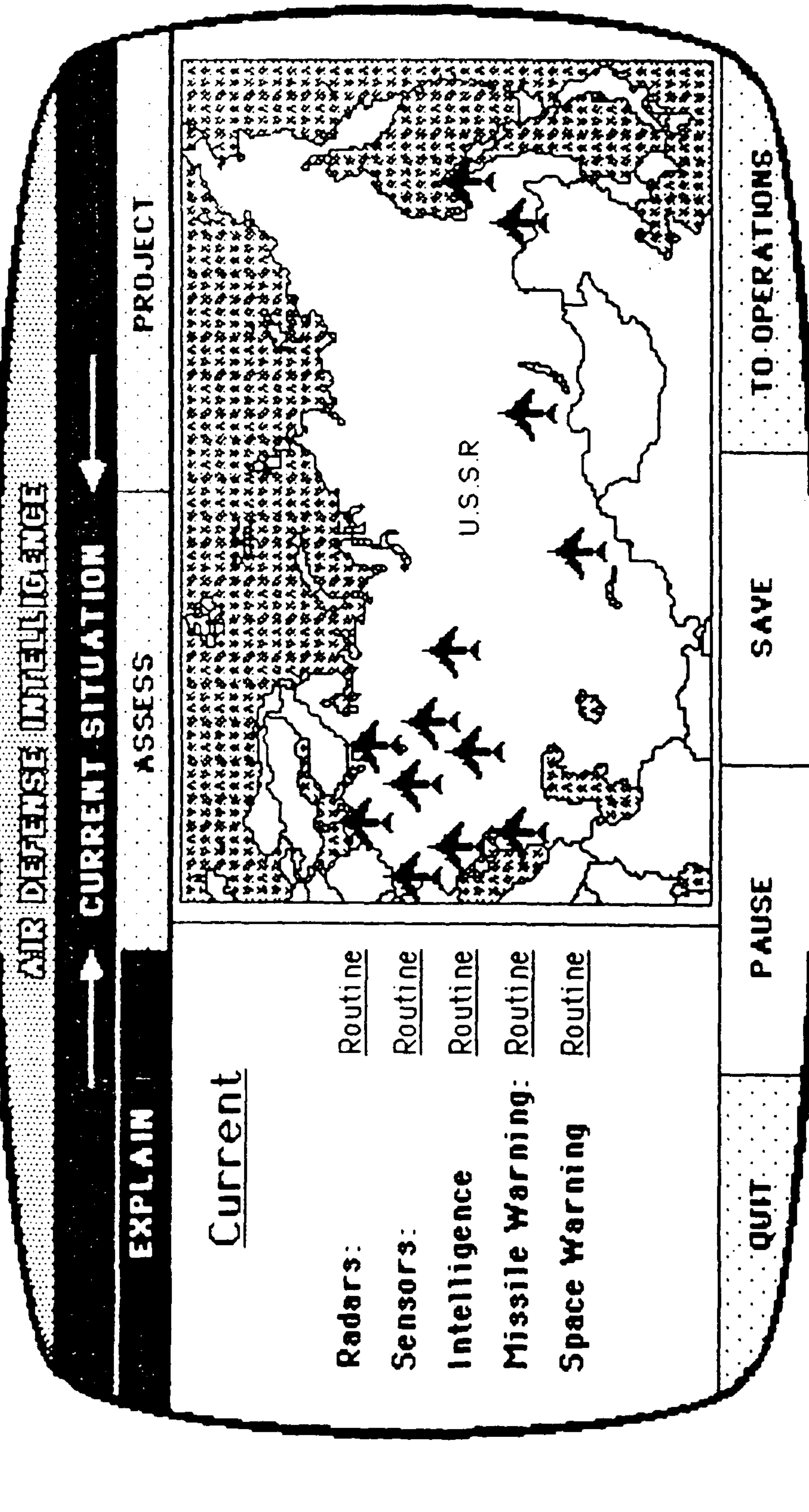
System set to monitor air environment; reports that all is normal and that currently the system is not in use by any intelligence analysts. This storyboard suggests that the system can monitor the threat environment and detect abnormal activity largely on its own via embedded quantitative and qualitative pattern recognition/deductive inferential models. The user "clicks" on **Current Situation** and the system responds with an overview . . .

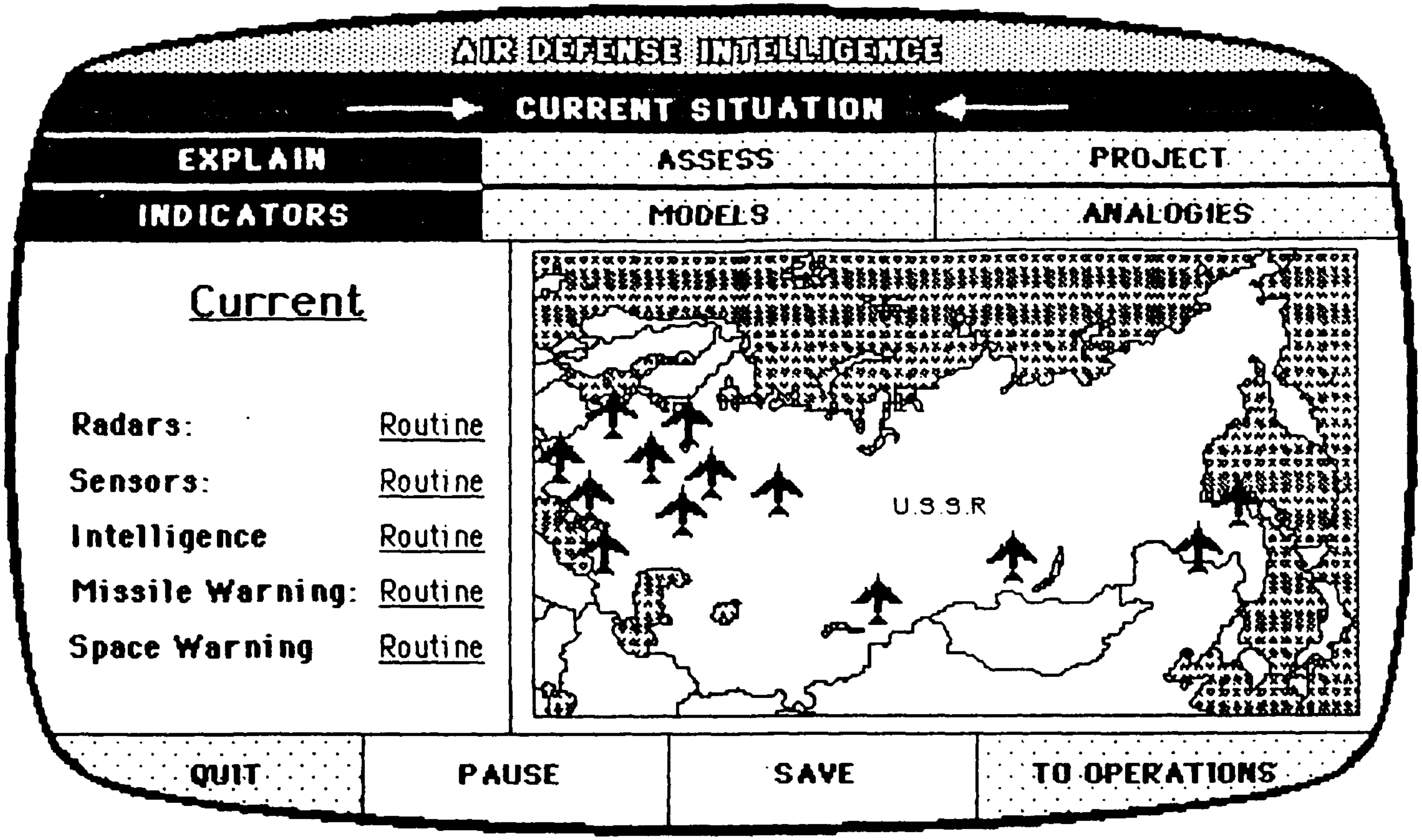


The system presents the user with a global perspective on the air defense situation. It also presents a summary assessment about the current situation, which falls into the "routine" zone (comprised of aggregate threat indicators and indicators of US readiness). The map provides zoom capabilities to specific parts of the world, especially to the USSR and US. The user zooms into the US air defense environment . . . This display suggests the notion of "graphic equivalence" and the ability to directly manipulate the user-computer interaction process.

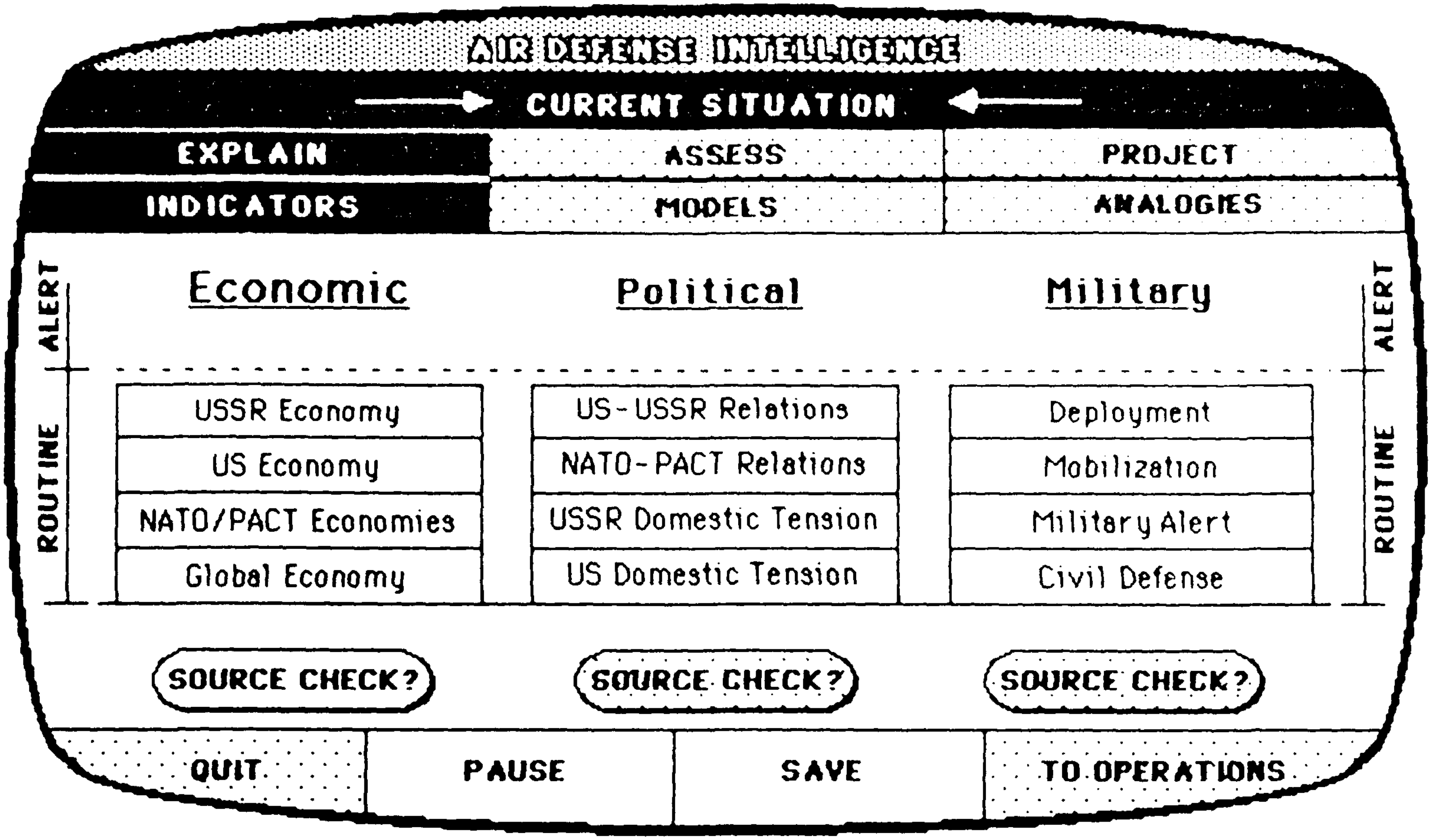


This display provides insight into the radar, sensor and other intelligence assessments that led the system to "conclude" that the threat is "normal." The map suggests the detection capabilities of the US (with no active zones or locations). The system also provides the analyst with data on the missile and space threat, since the system assumes that an integrated attack is the most likeiy. If bombers or cruise missiles had been detected they would be located on the map and in the appropriate coverage area(s).

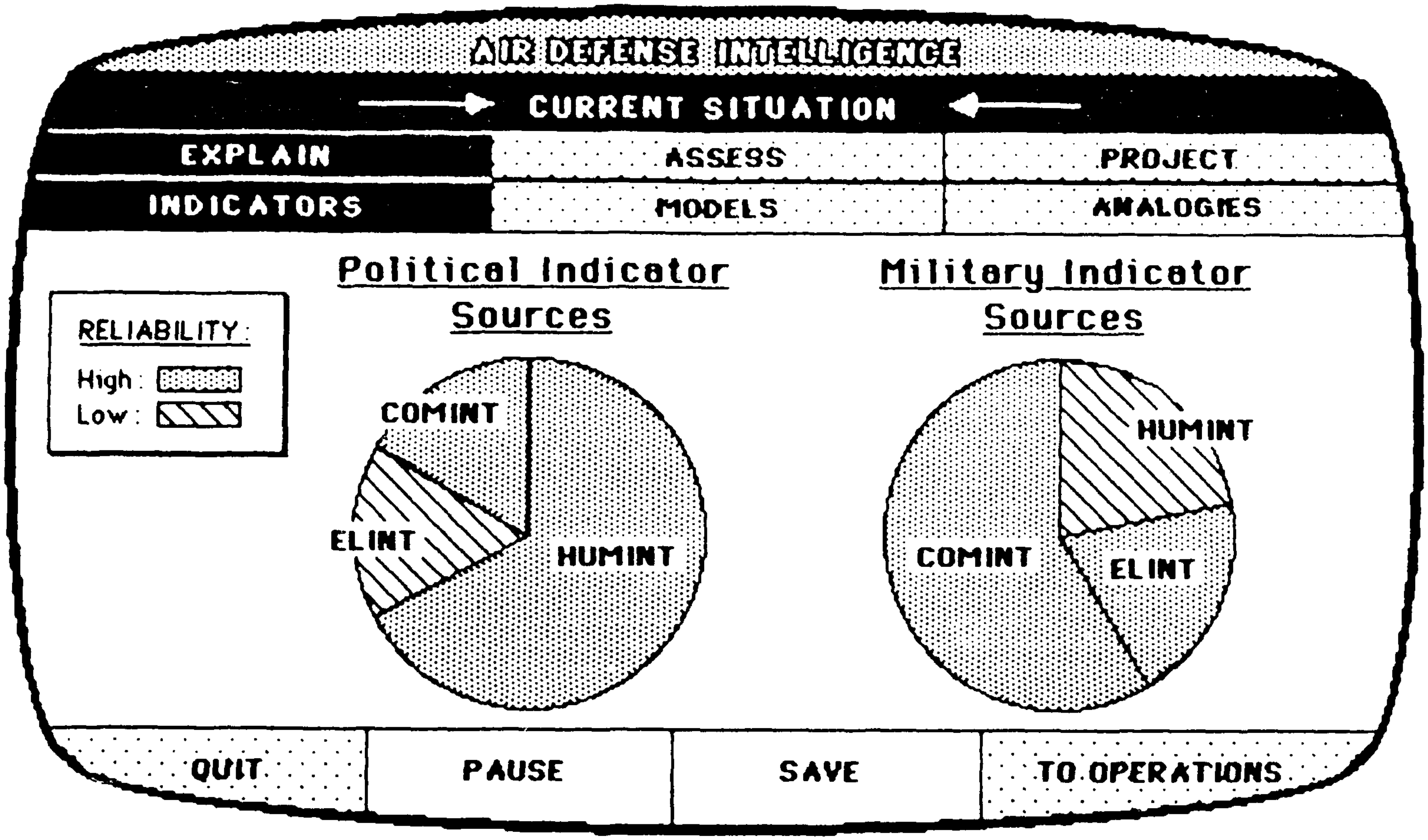

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
Current
Radars: Routine
Sensors: Routine
Intelligence Routine
Missile Warning: Routine
Space Warning Routine
U.S.S.R
QUIT
PAUSE
SAVE
TO OPERATIONS



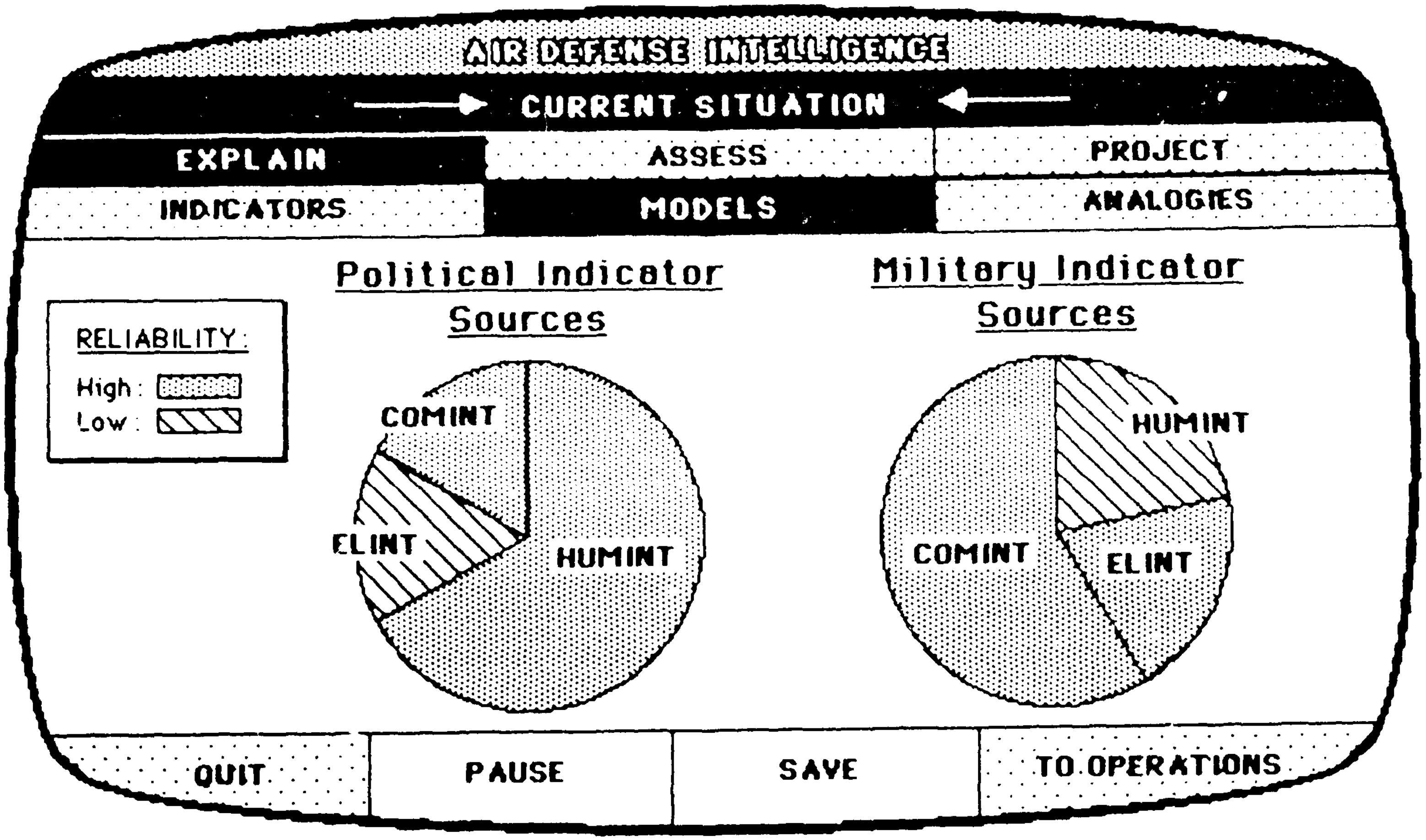
This display presents a map of the Soviet Union that locates its long range aviation (bomber) capabilities. The system also presents data on the missile and space threat. The user -- having received an overview of the current situation -- decides more information is necessary. He selects the **Explain Indicators** option (with two clicks). Hierarchical data, information and knowledge organization and storage is by design: human information processors store information hierarchically (from general-to-specific and specific-to-general). The system is structured to be compatible with human data, information and knowledge organization and storage.

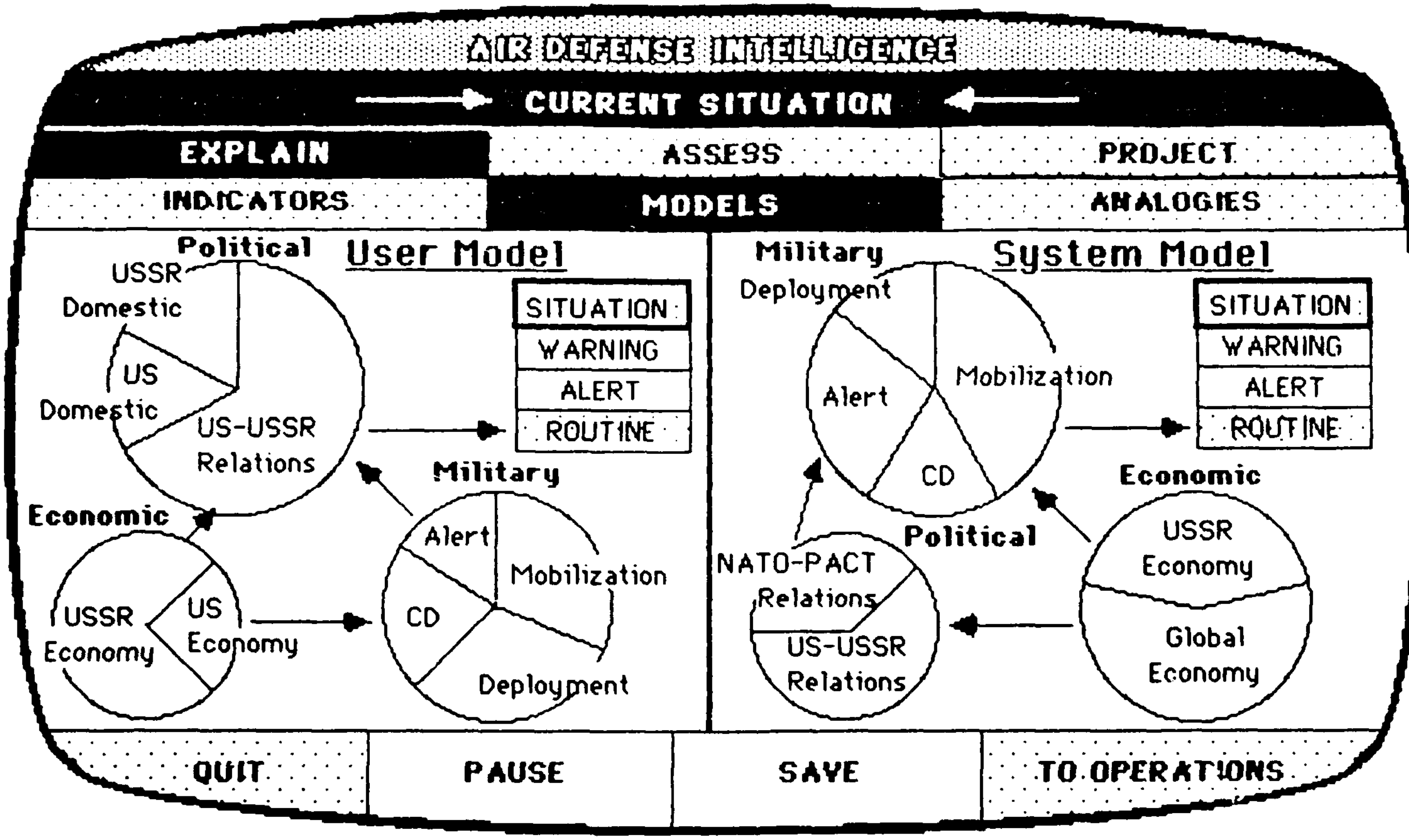


The system presents a list of indicators to the analyst. The indicators are organized around economic, political and military behavior patterns, patterns that would explain routine, alert and warning situations. The system asks the user if he wants more information about the indicators, especially about their source and reliability. User queries and responses are recorded by the system and correlated with previous user-system interaction. User profiles are developed over time and on-line.

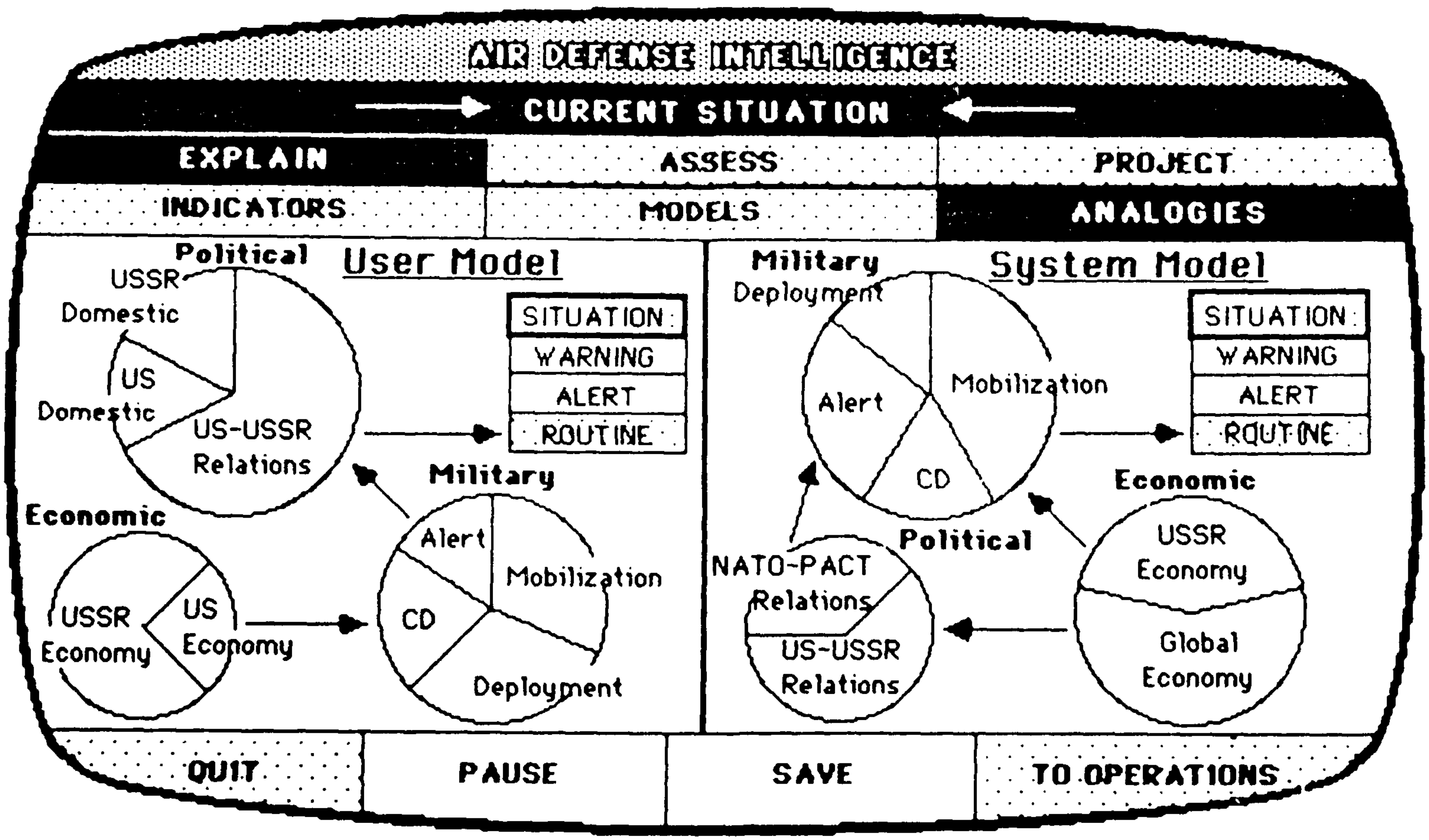


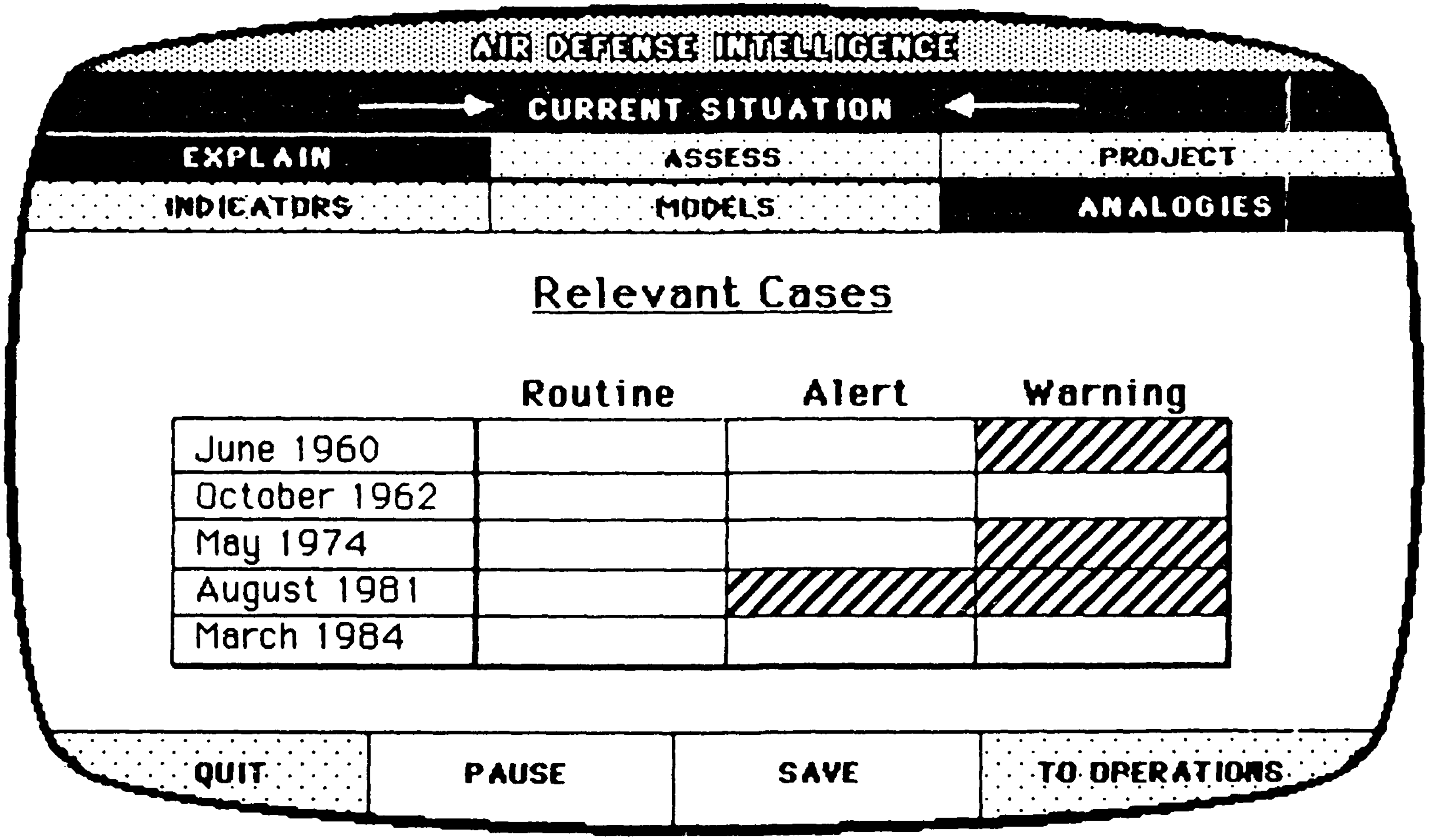
The system displays information about where the political and military indicator information came from, and whether or not it is reliable. The system records the user's interest in the indicators; the user requests information about the models used to generate the intelligence estimate (by clicking on **Models**).


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
INDICATORS
MODELS
ANALOGIES
RELIABILITY:
High:
Low:
Political Indicator Sources
COMINT
ELINT
HUMINT
Military Indicator Sources
HUMINT
COMINT
ELINT
QUIT
PAUSE
SAVE
TO OPERATIONS

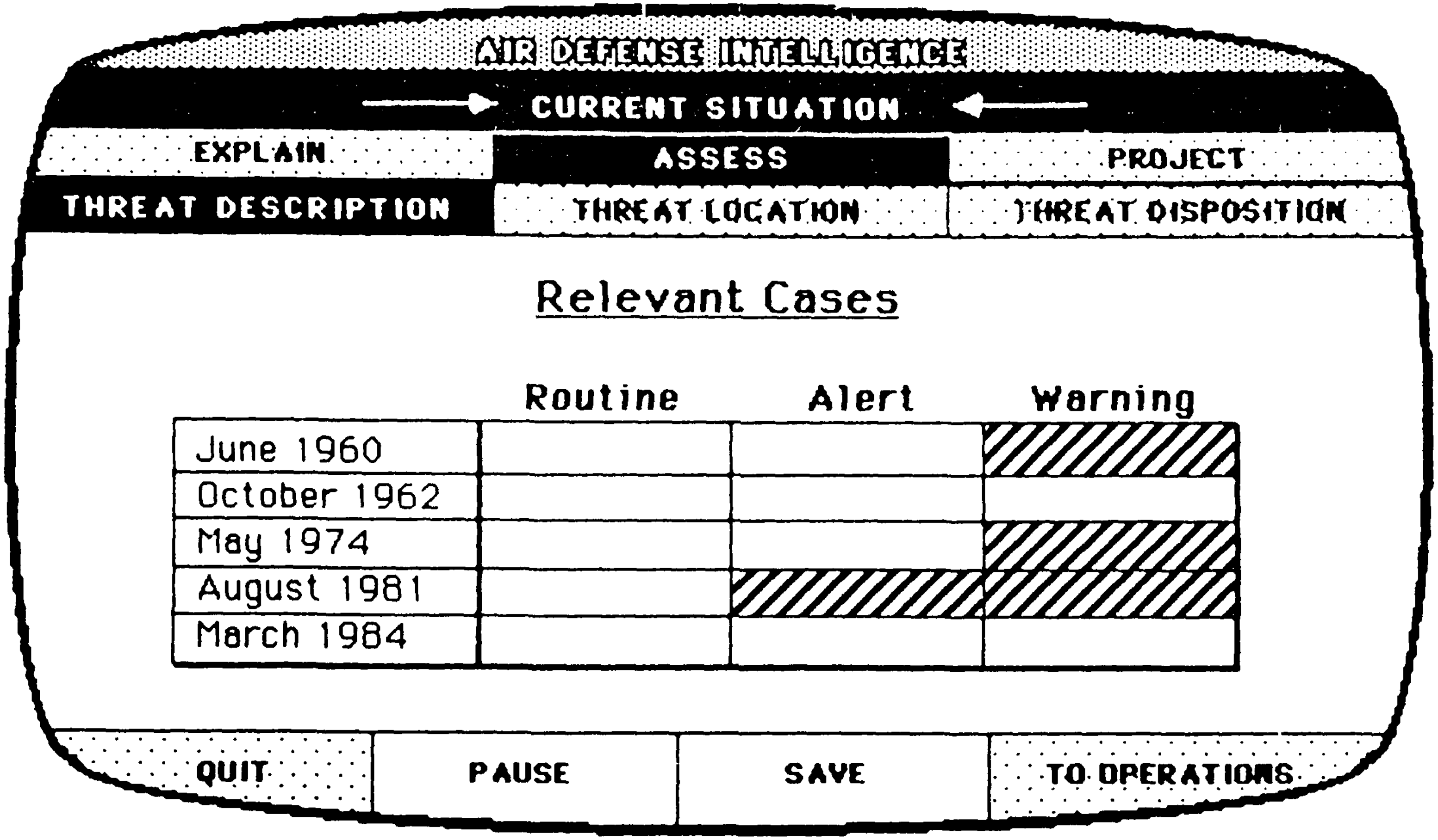


The system displays two models to the user -- that differ in some important ways. The "user model" was constructed by the system from previous user-system interaction and from the queries and responses by the user during the session at hand. The system is providing feedback to the user on his cognitive modeling of the current situation. The "system model" was developed from the system's embedded models. They are presented side-by-side to call attention to the differences and stimulate additional user analysis. The models are presented as "causal'/"influence" diagrams of the situation assessment process, since analysts tend to diagnose problems causally. The user then selects **Analogies**.

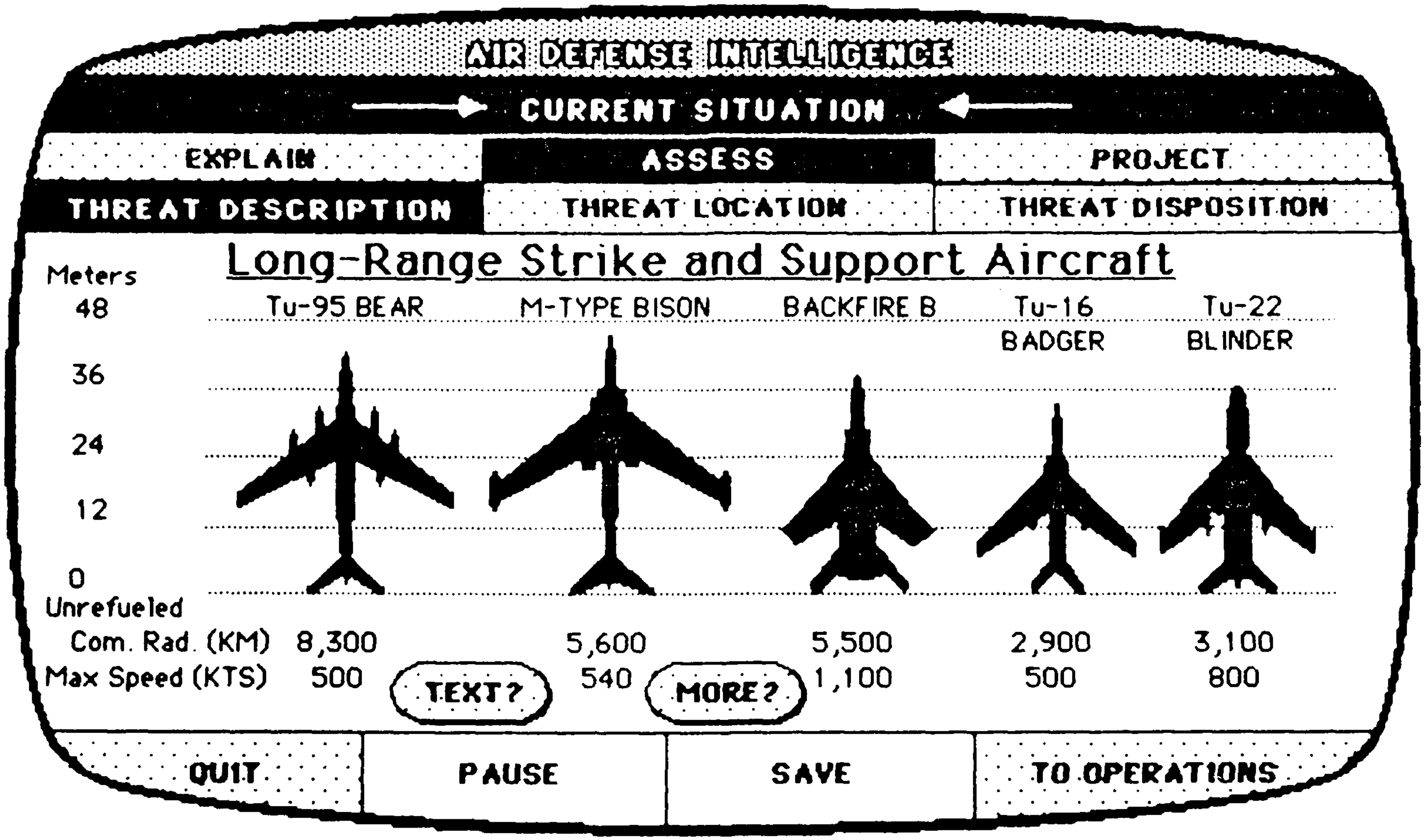

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
INDICATORS
MODELS
ANALOGIES
User Model
Political
USSR Domestic
US Domestic
US-USSR Relations
Economic
USSR Economy
US Economy
Military
Alert
CD
Mobilization
Deployment
SITUATION
WARNING
ALERT
ROUTINE
System Model
Military
Deployment
Alert
CD
Mobilization
Political
NATO-PACT Relations
US-USSR Relations
Economic
USSR Economy
Global Economy
SITUATION
WARNING
ALERT
ROUTINE
QUIT
PAUSE
SAVE
TO OPERATIONS



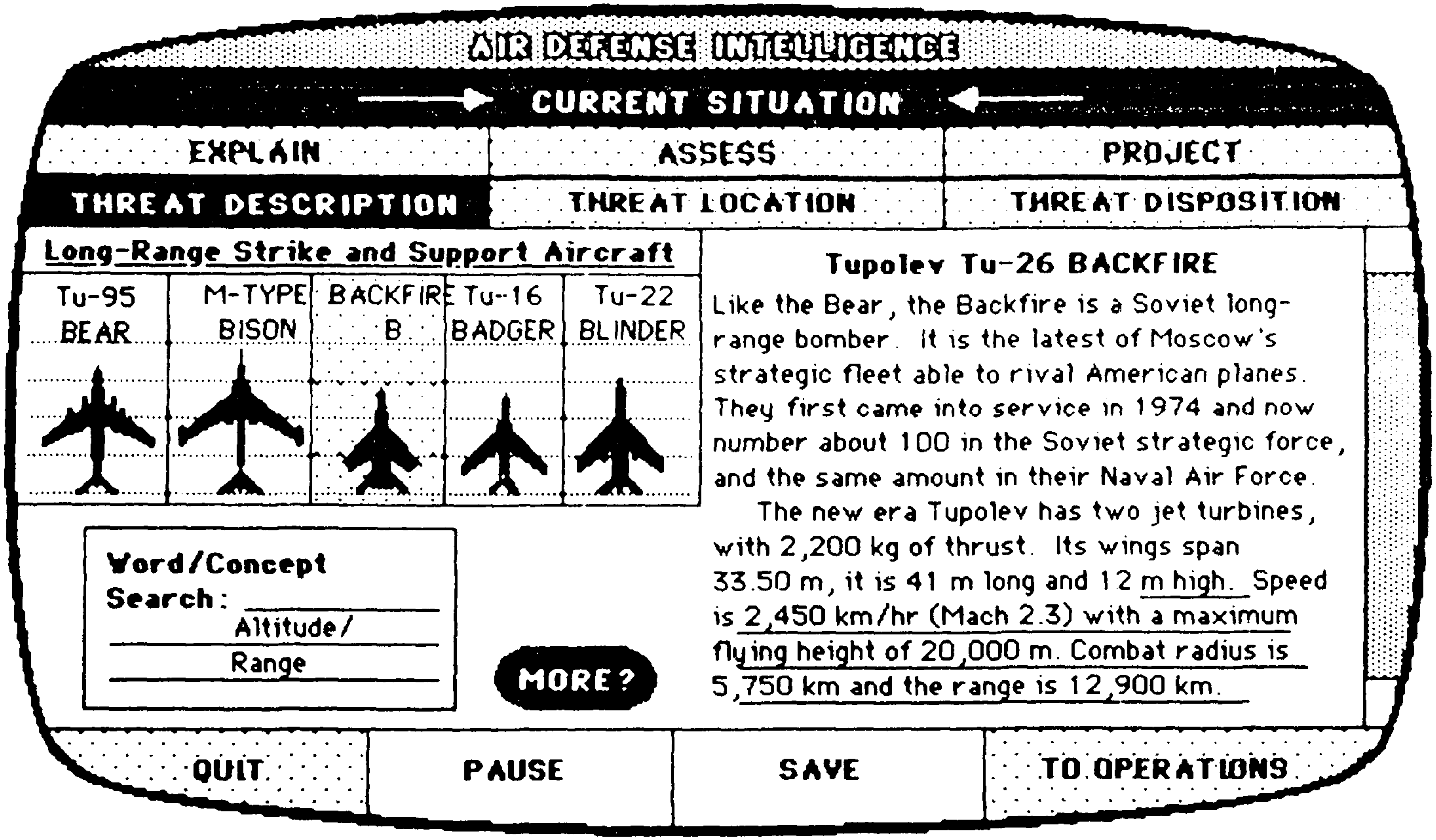
AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
INDICATORS
MODELS
ANALOGIES
Relevant Cases
Routine
Alert
Warning
June 1960
October 1962
May 1974
August 1981
March 1984
QUIT
PAUSE
SAVE
TO OPERATIONS



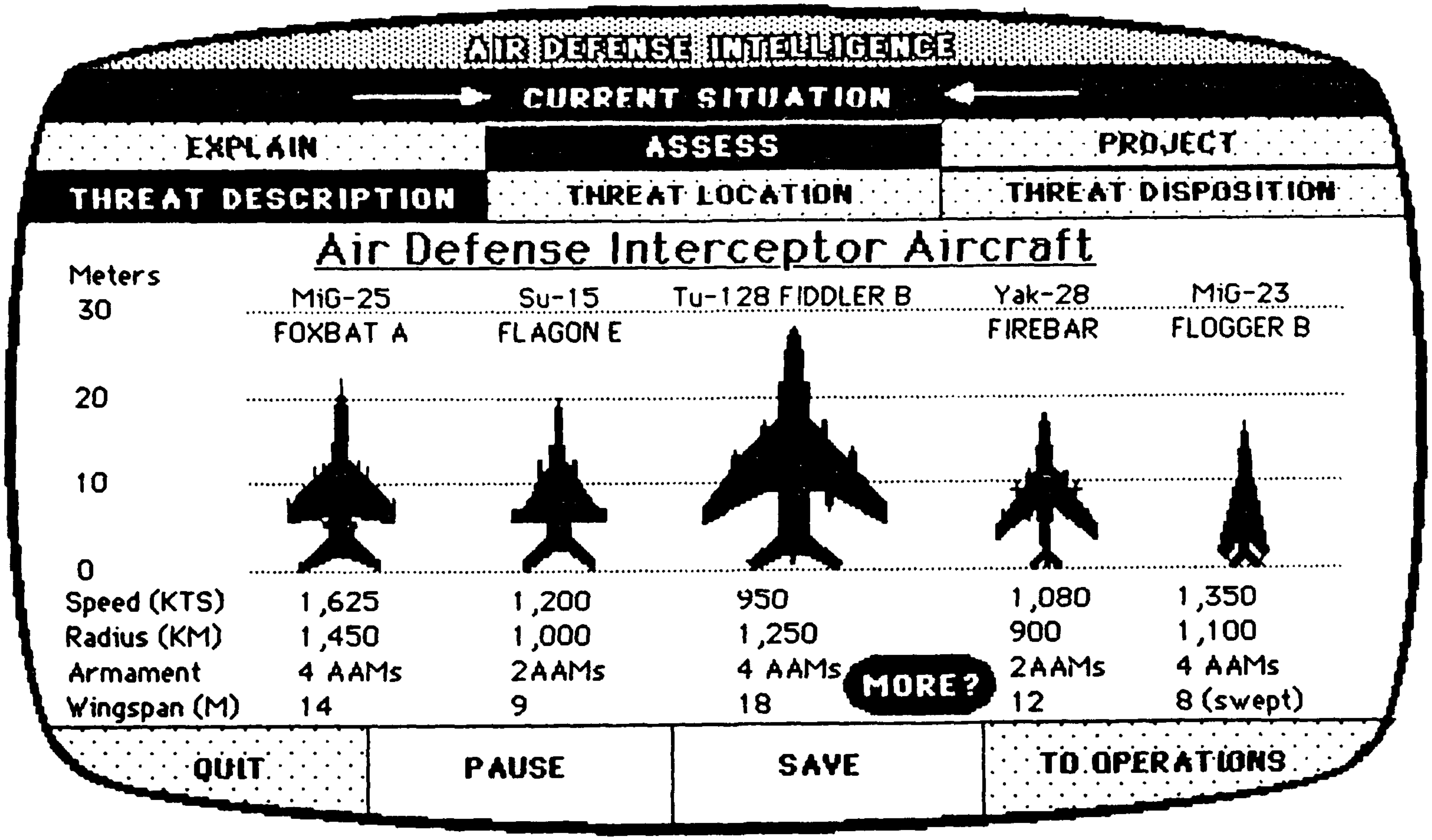
The system identifies the "cases" that are relevant to the current situation. It identifies -- via a simple pattern recognition process -- a set of dates and situations for inspection by the analyst. While the storyboard does not illustrate the process, the analyst would be capable of calling up "causal/influence" diagrams of the past and overlaying them onto the current situation for comparison. The user then clicks on **Assess Threat** for additional information.



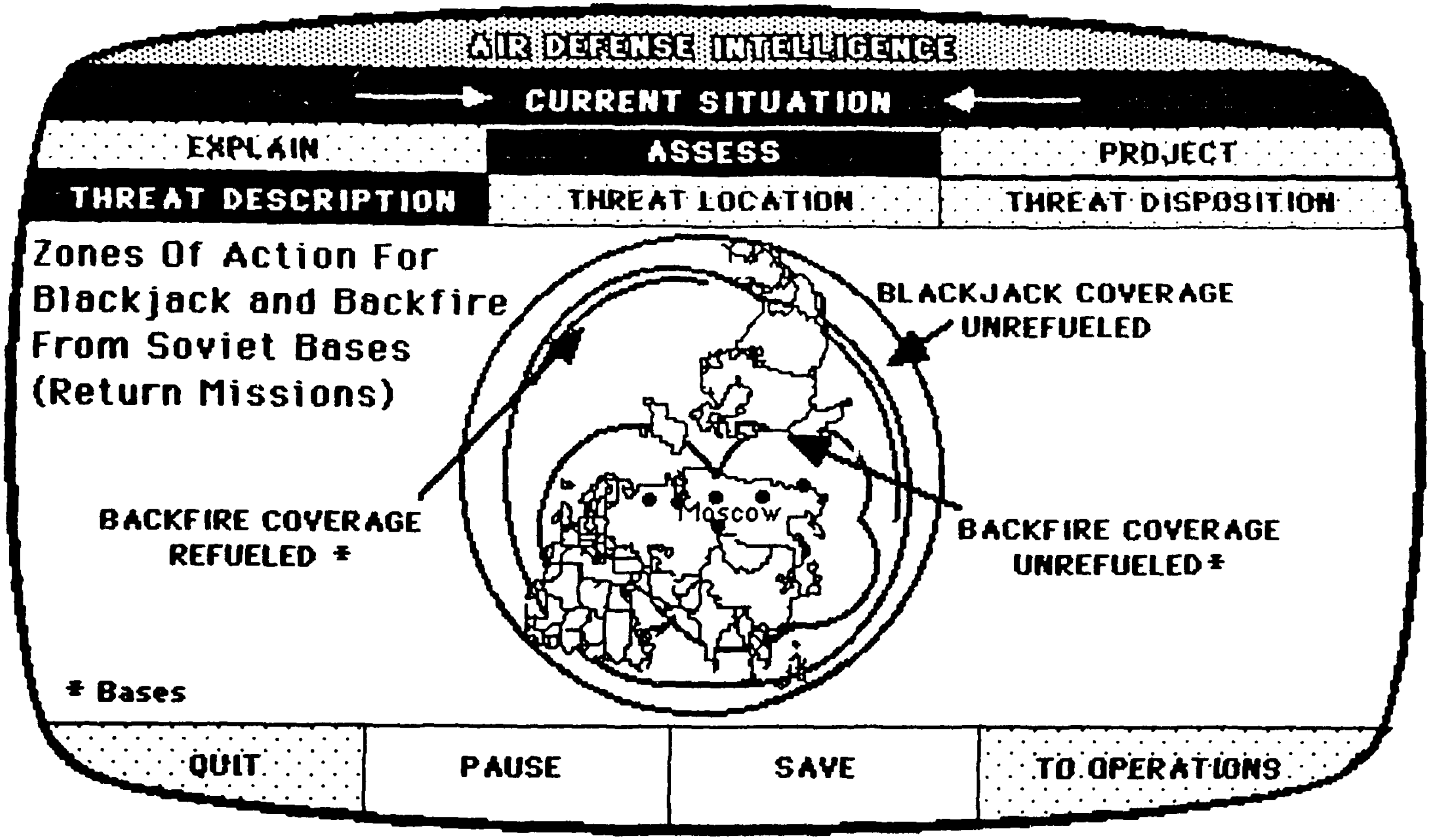
The system presents information on the long range bomber (and support aircraft) that comprise a large segment of the Soviet threat. The system provides options for **Text** and **More?** data. The analyst clicks on **Text**.



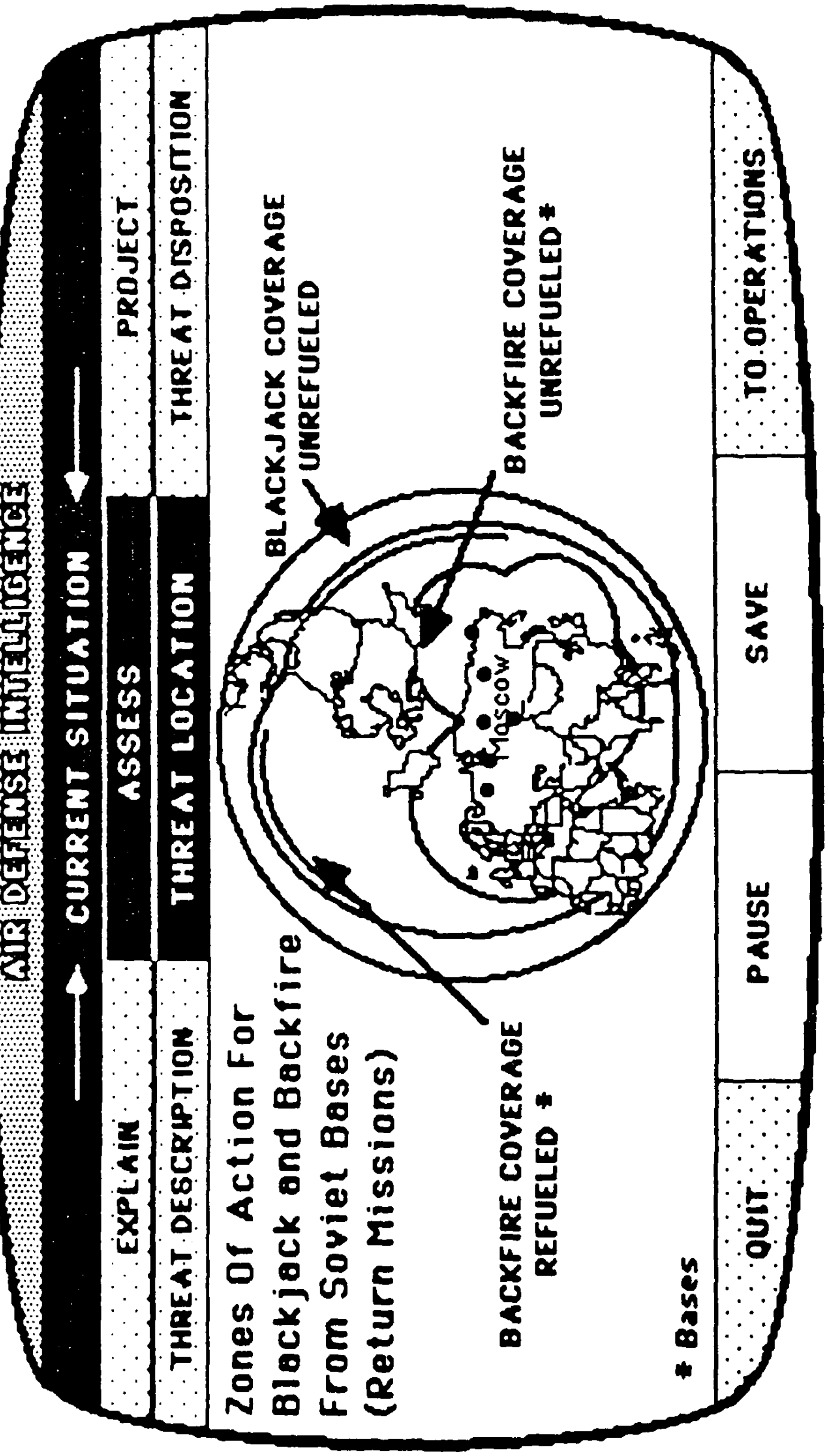
The system provides a scrolling textual data base on the bombers as well as a hypertext search capability. In the example, the user inputs two key words ("altitude" and "range") and the system highlights the places in the text where references to the words/concepts appear. Icons are used to search through the data base; the user then clicks on **More?**.

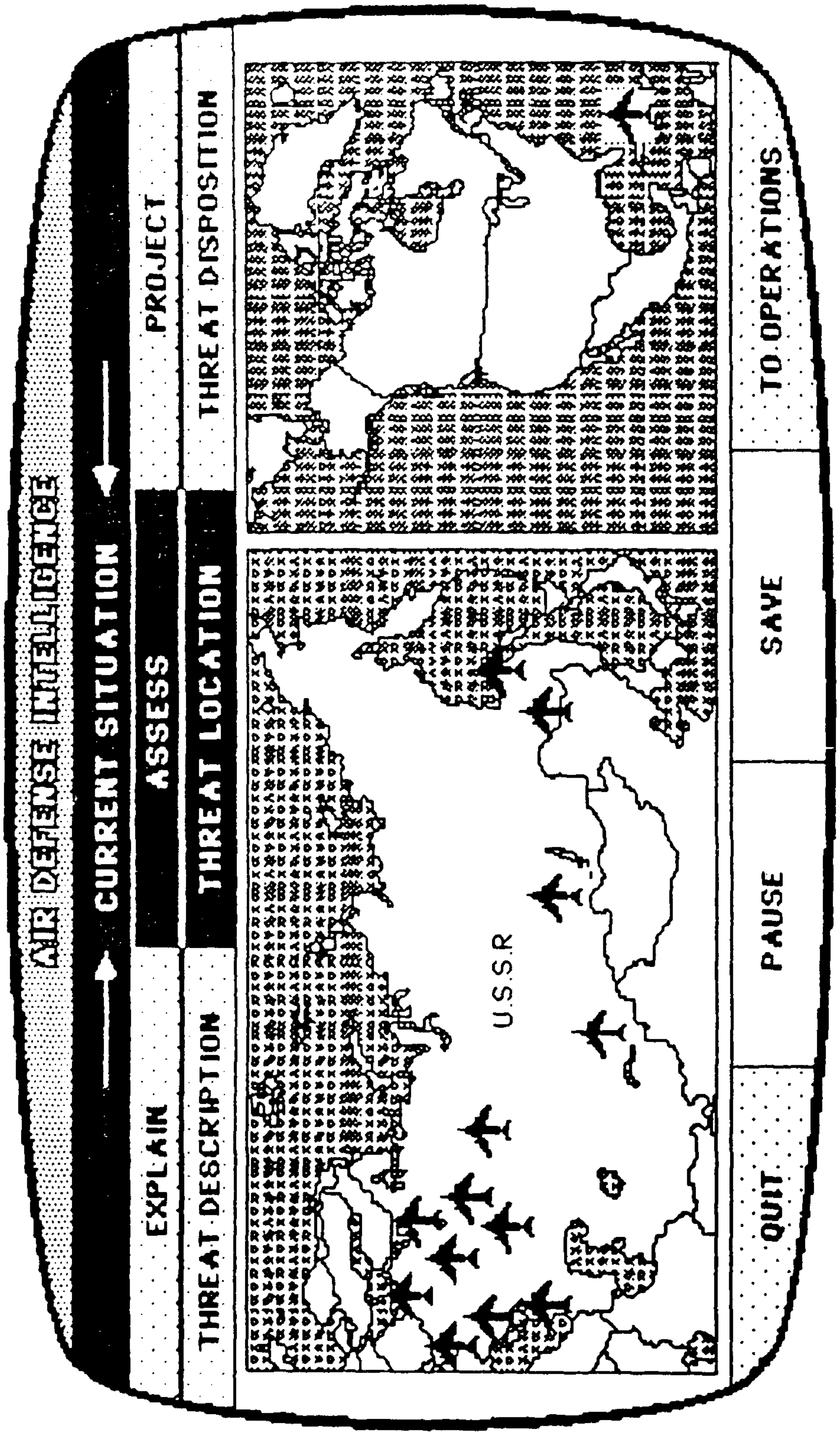


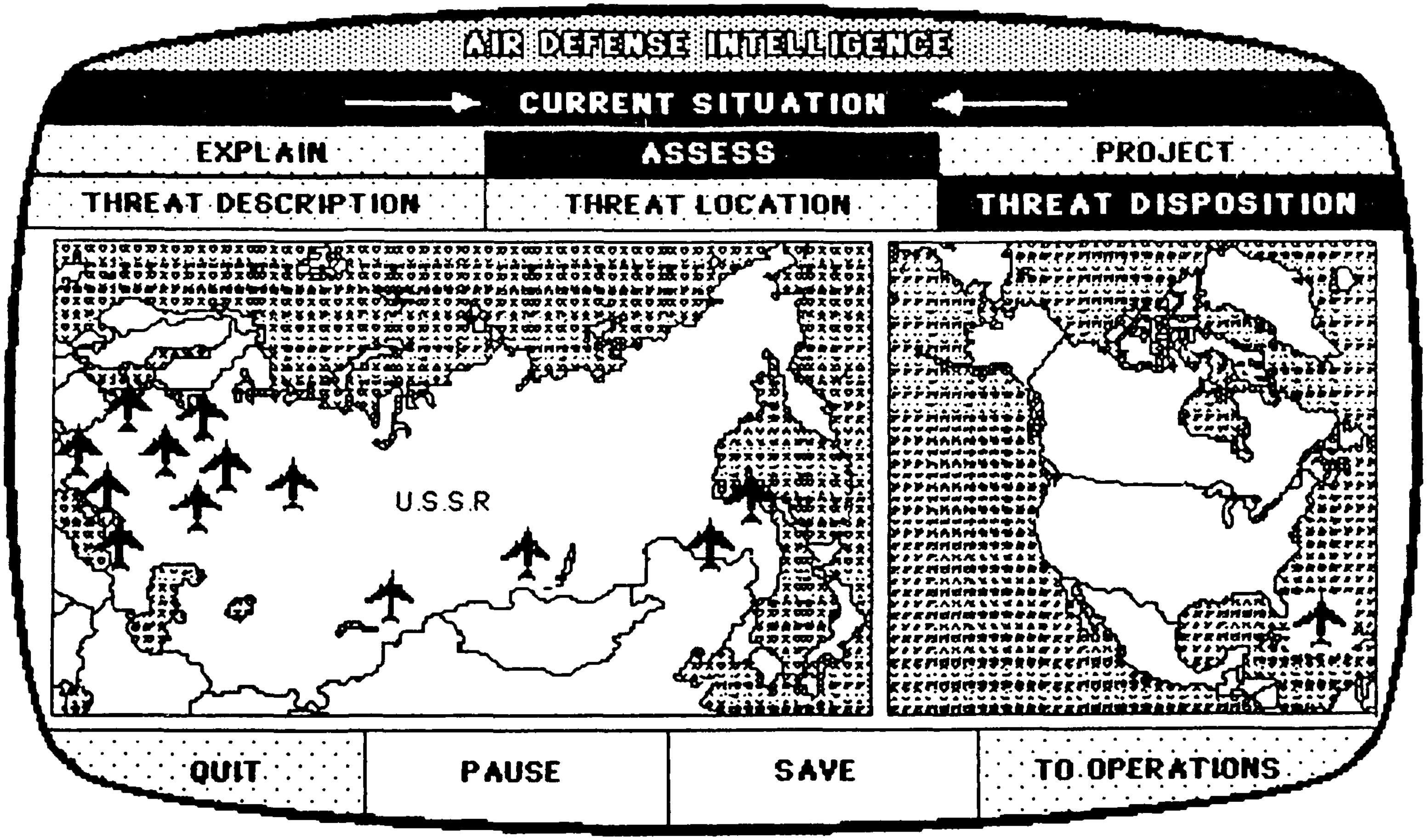
The system presents data on Soviet air defense interceptor aircraft; the user clicks on **More?**.



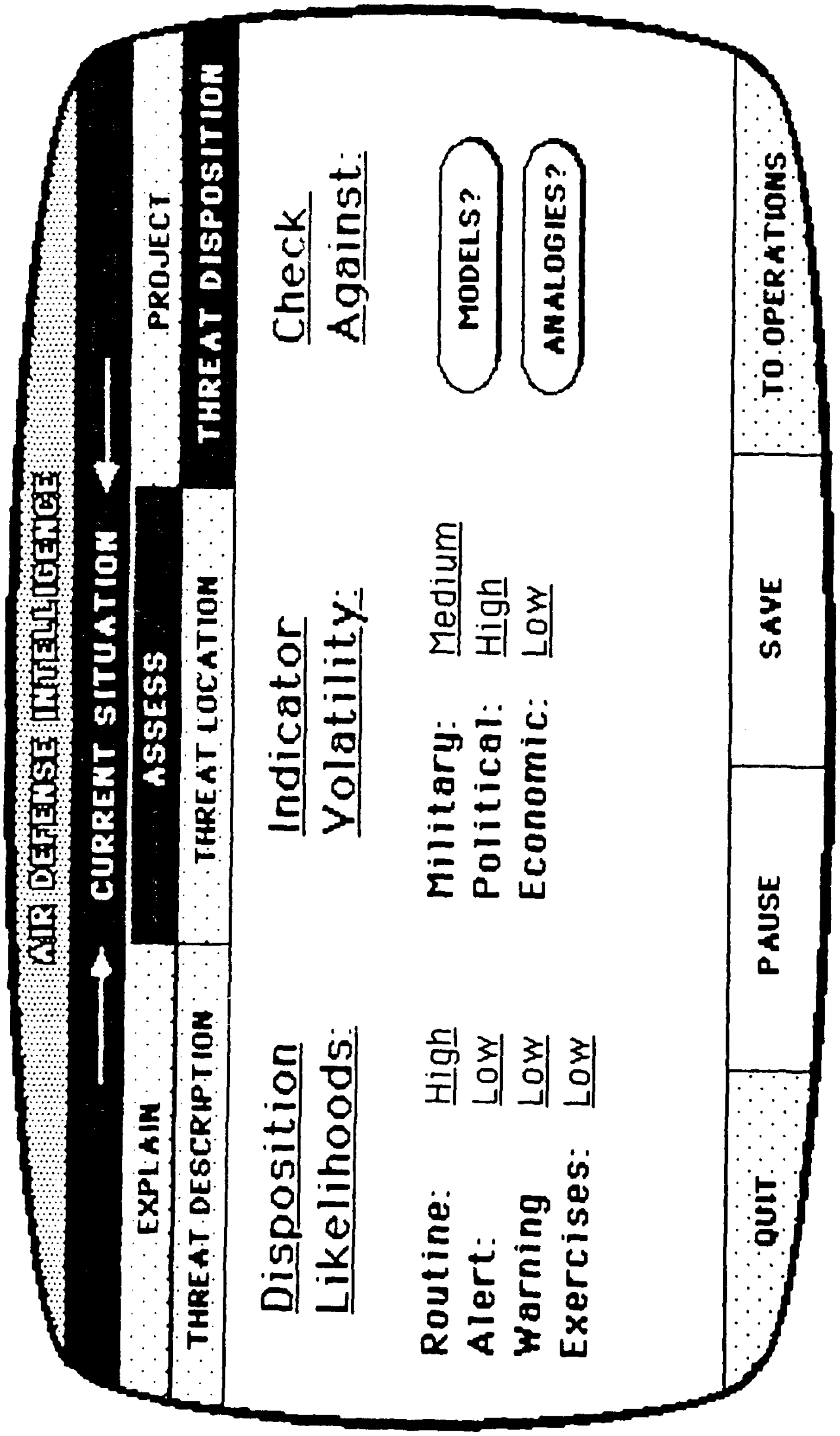
The system displays information about the ranges of two Soviet long range bombers to provide graphic/geographic perspective on the Soviet threat. The user then selects **Threat Location**.


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
THREAT DESCRIPTION
THREAT LOCATION
THREAT DISPOSITION
Zones Of Action For
Blackjack and Backfire
From Soviet Bases
(Return Missions)
BLACKJACK COVERAGE
UNREFUELED
BACKFIRE COVERAGE
UNREFUELED *
BACKFIRE COVERAGE
REFUELED *
MOSCOW
* Bases
QUIT
PAUSE
SAVE
TO OPERATIONS

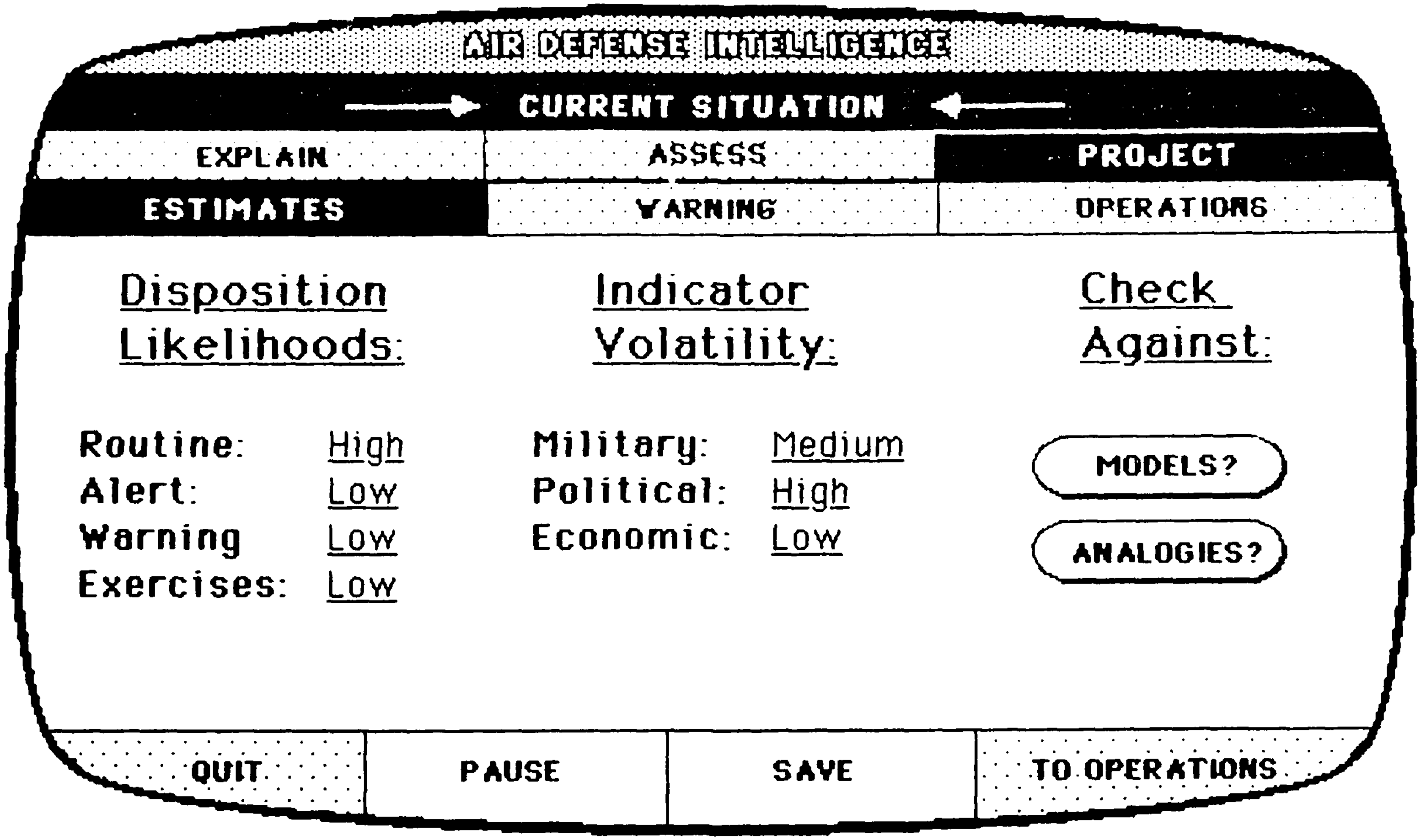

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
THREAT DESCRIPTION
THREAT LOCATION
THREAT DISPOSITION
U.S.S.R.
QUIT
PAUSE
SAVE
TO OPERATIONS



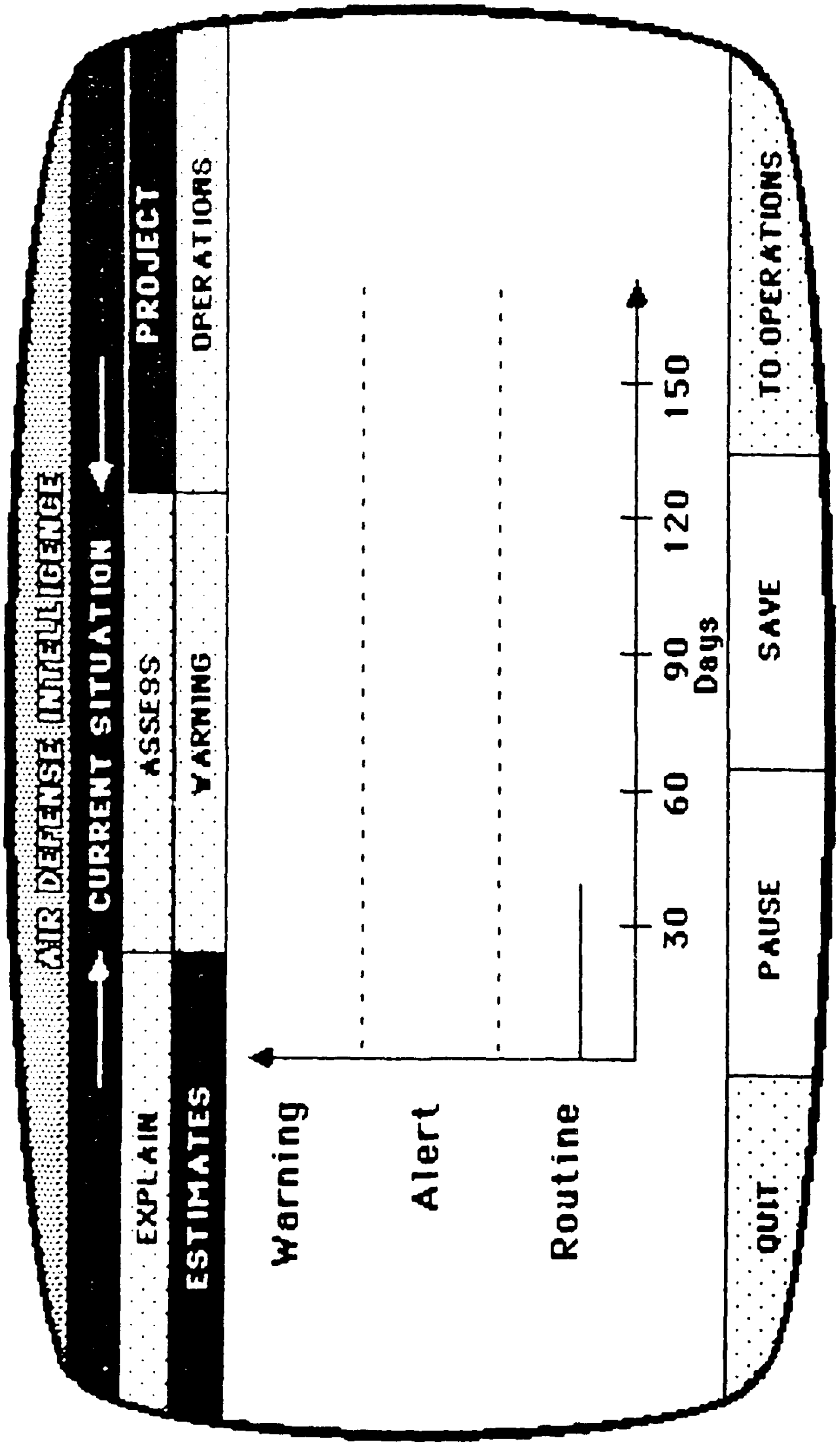
The system provides locations of Soviet threat; user selects **Threat Disposition**.

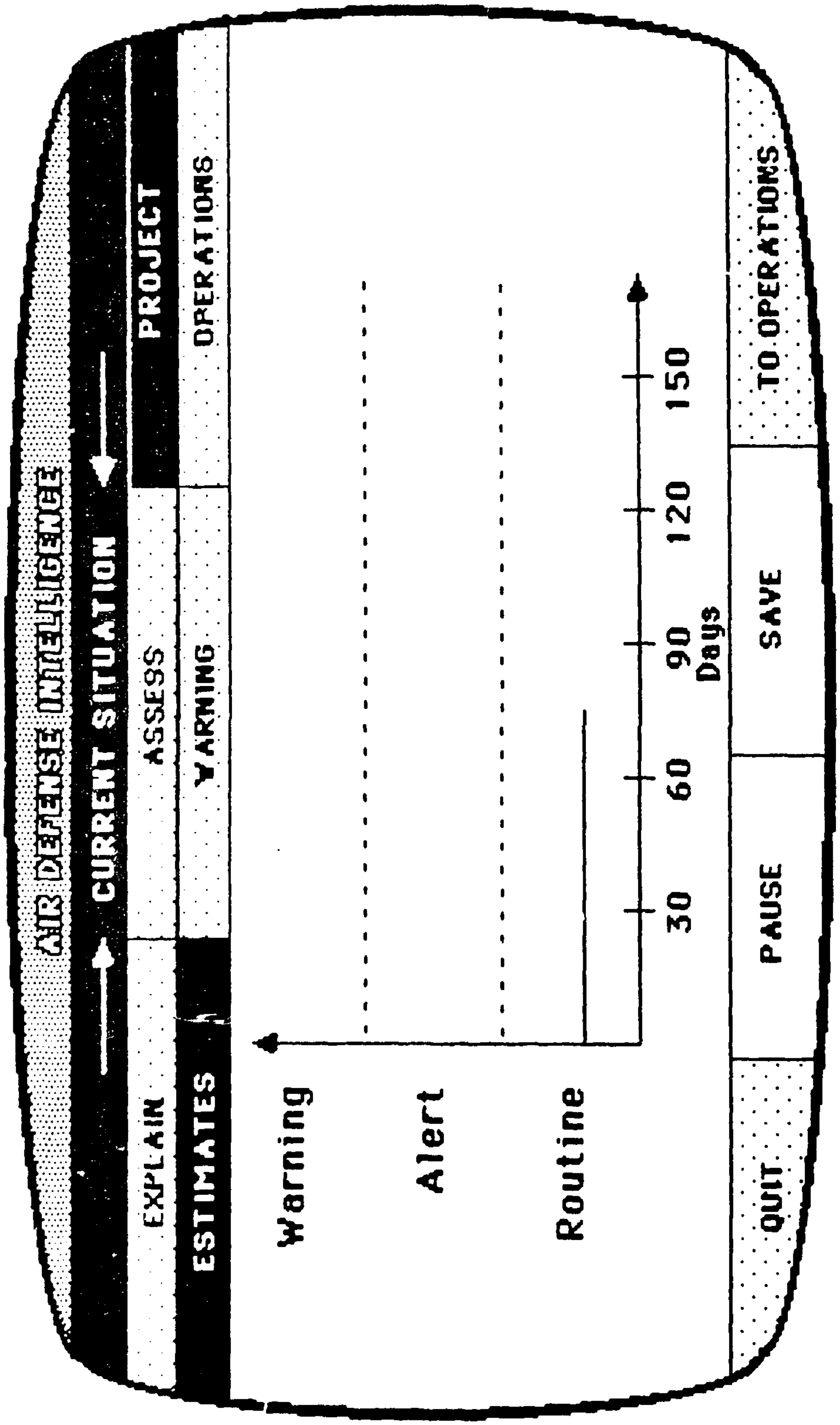


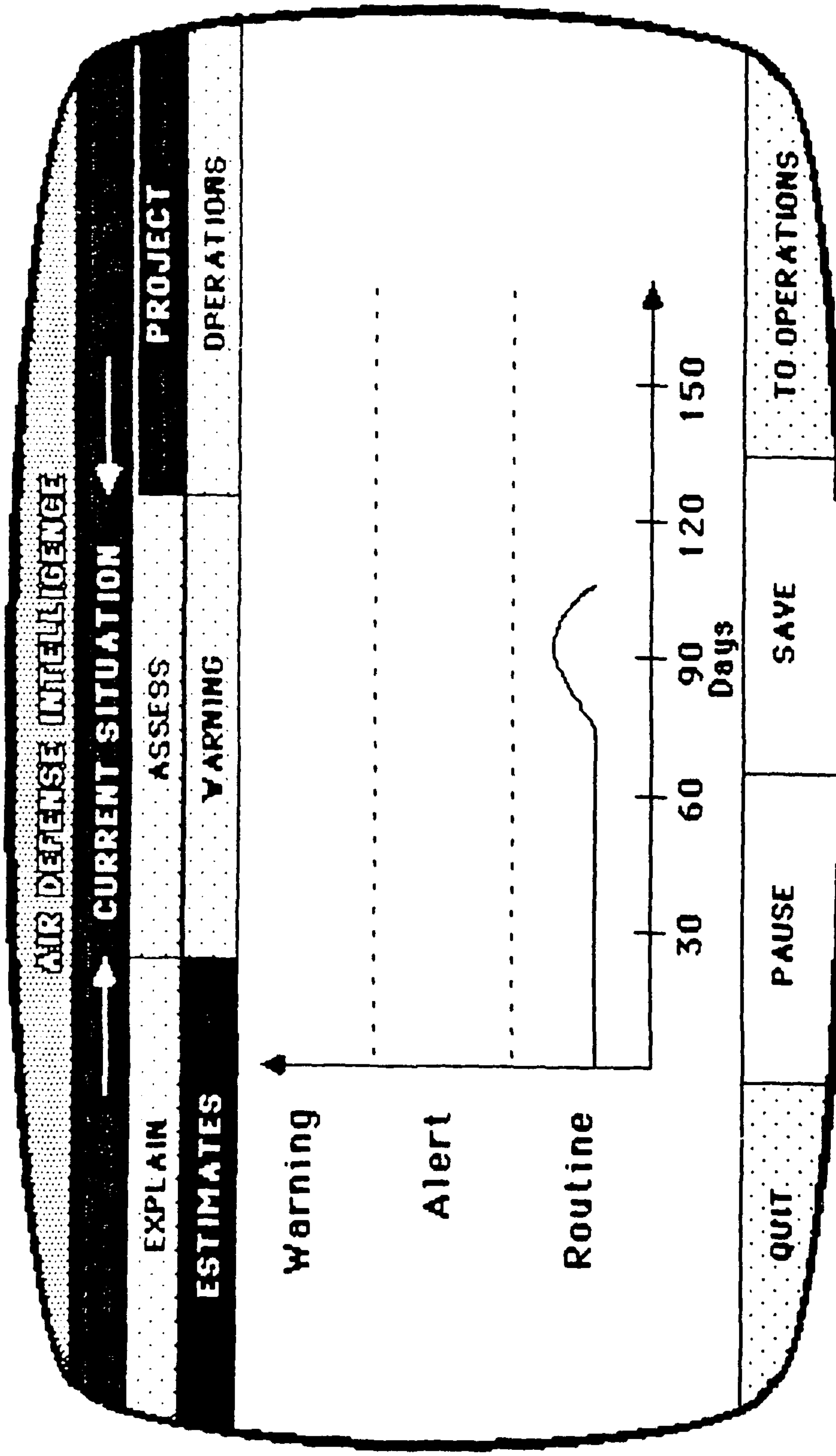
AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
THREAT DESCRIPTION
THREAT LOCATION
THREAT DISPOSITION
Disposition Likelihoods:
Routine: High
Alert: Low
Warning Low
Exercises: Low
Indicator Volatility:
Military: Medium
Political: High
Economic: Low
Check Against:
MODELS?
ANALOGIES?
QUIT
PAUSE
SAVE
TO OPERATIONS

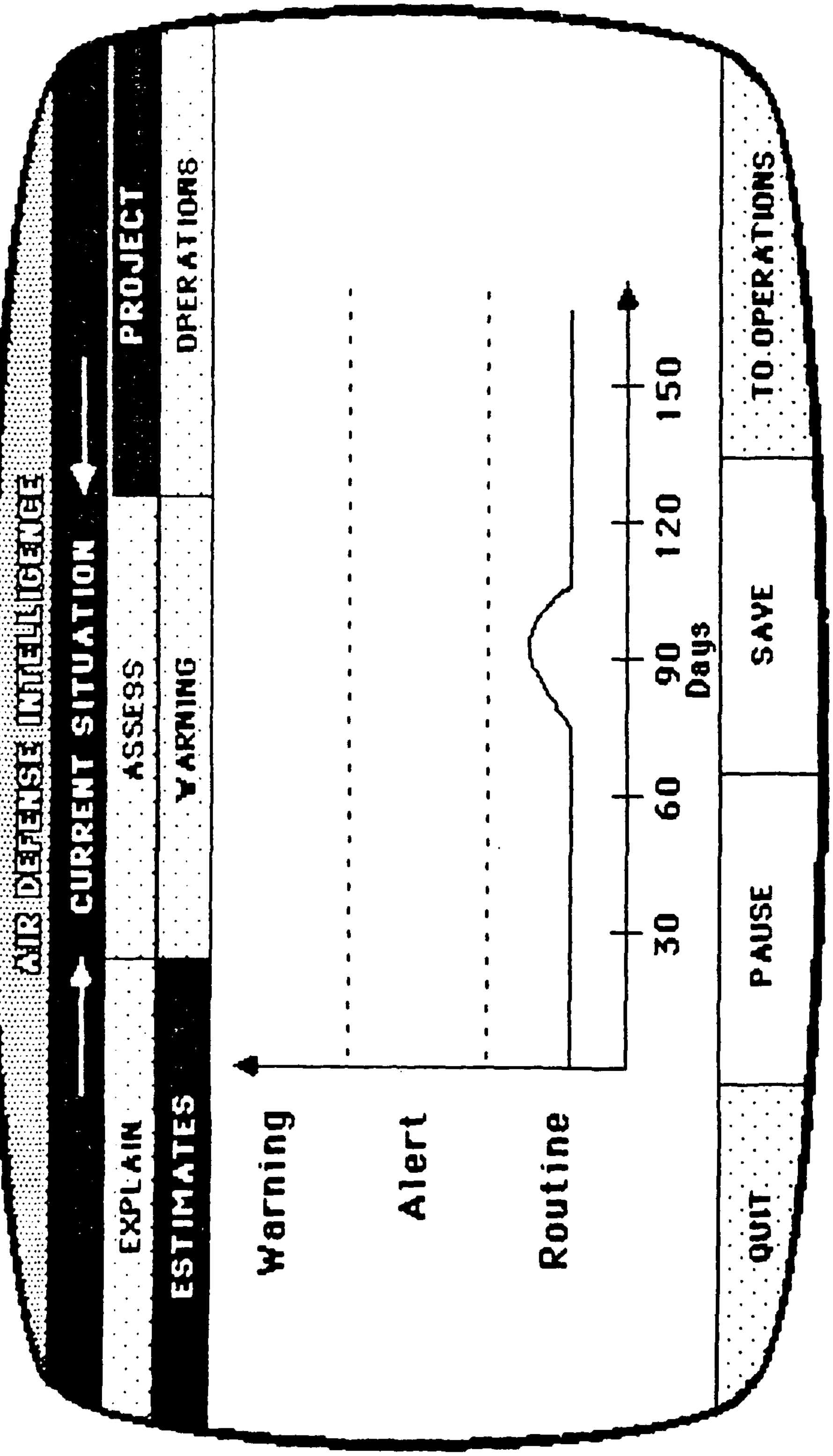


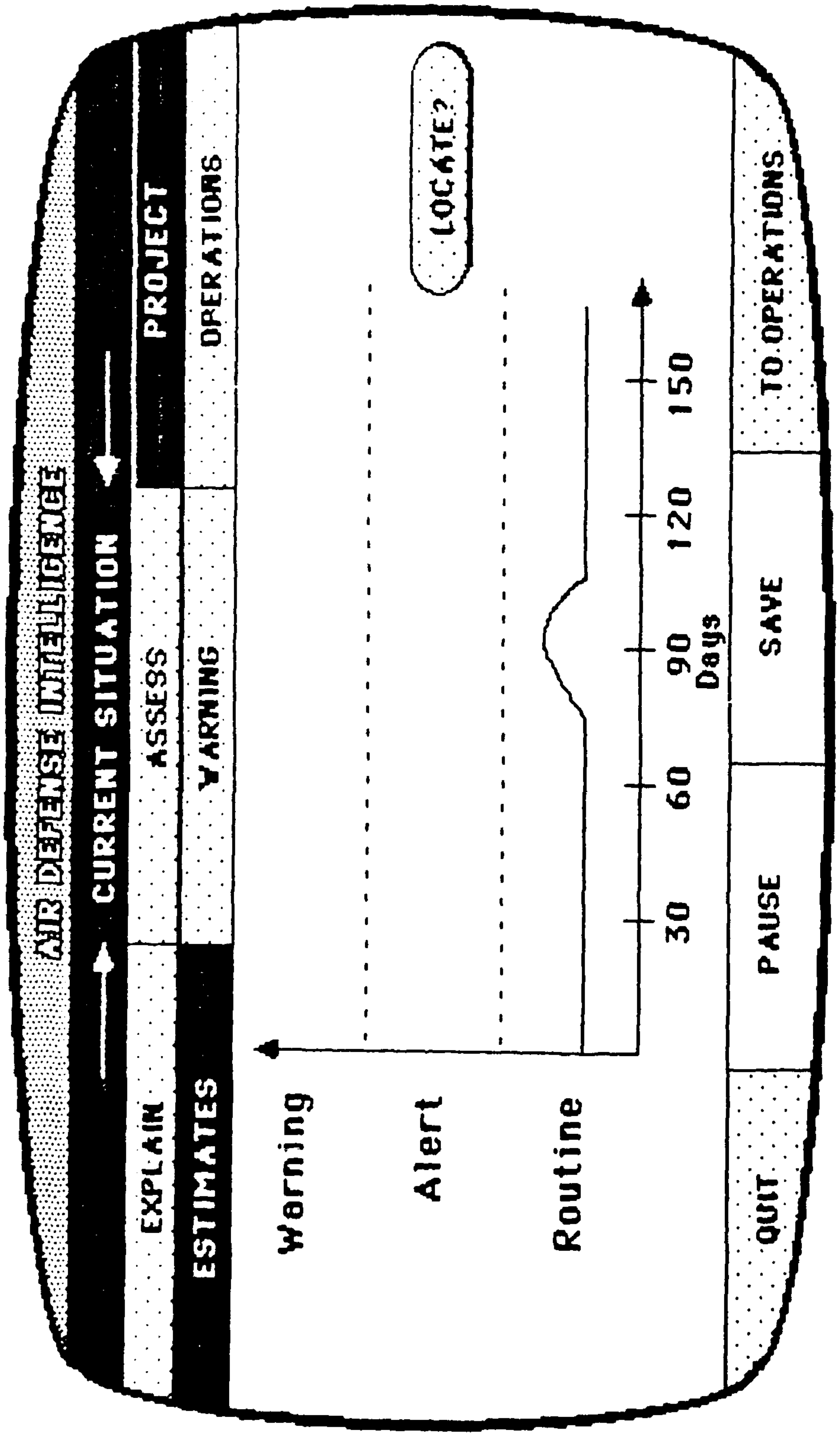
The system presents disposition likelihoods to the analyst and provides the analyst with the opportunity to check the likelihoods against inference modelas and pertinent analogies. The analyst then clicks on **Project Estimates**.

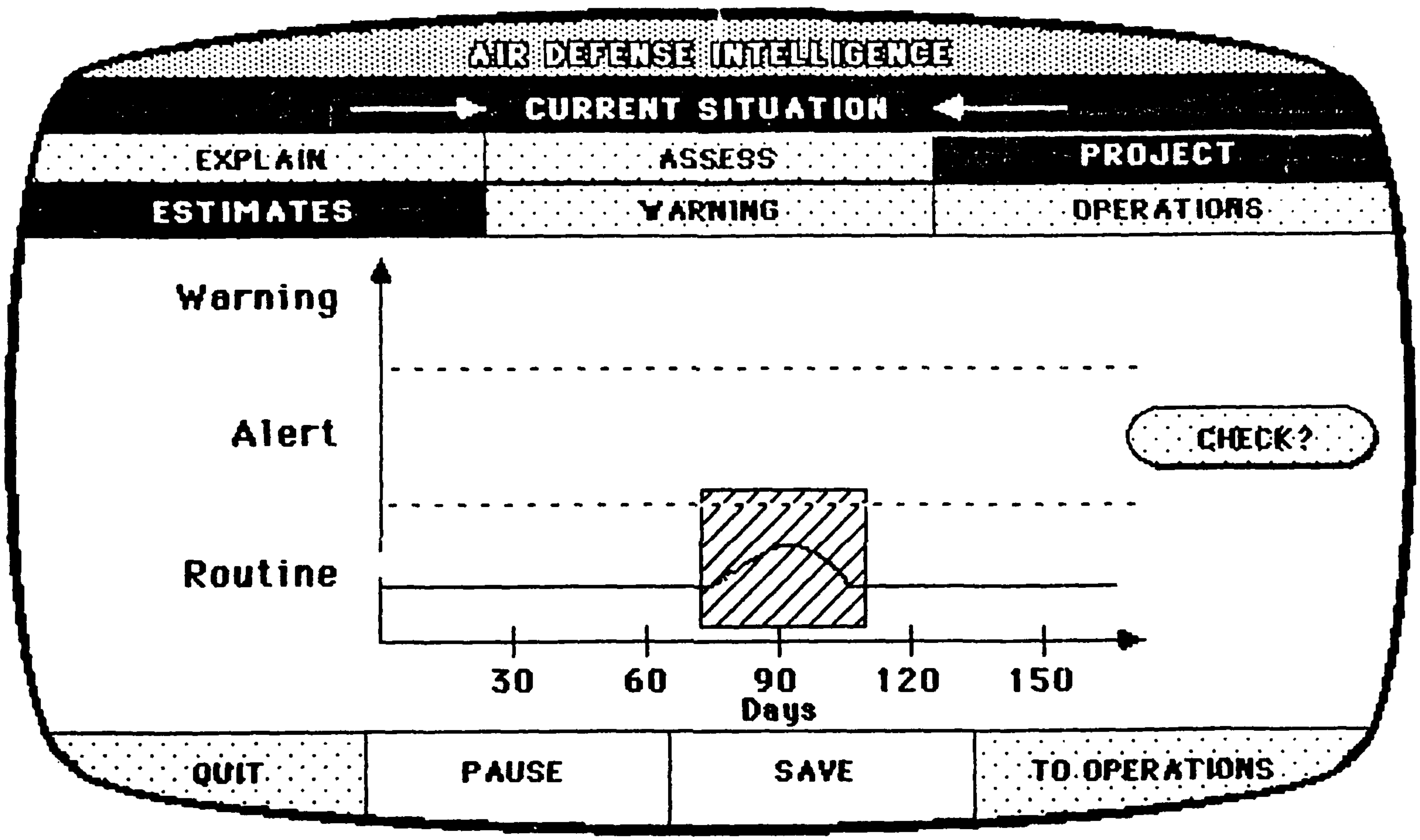

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS

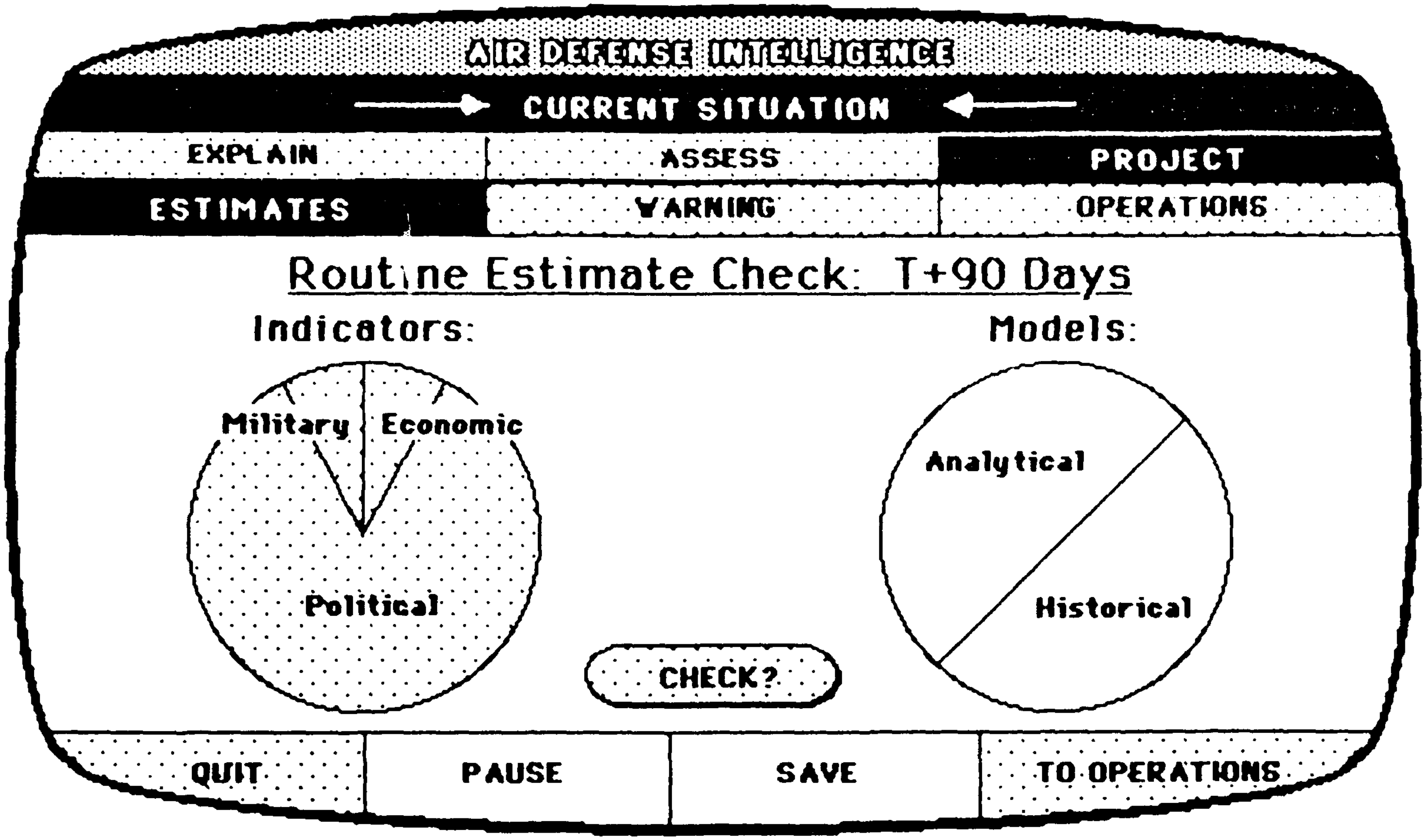

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS

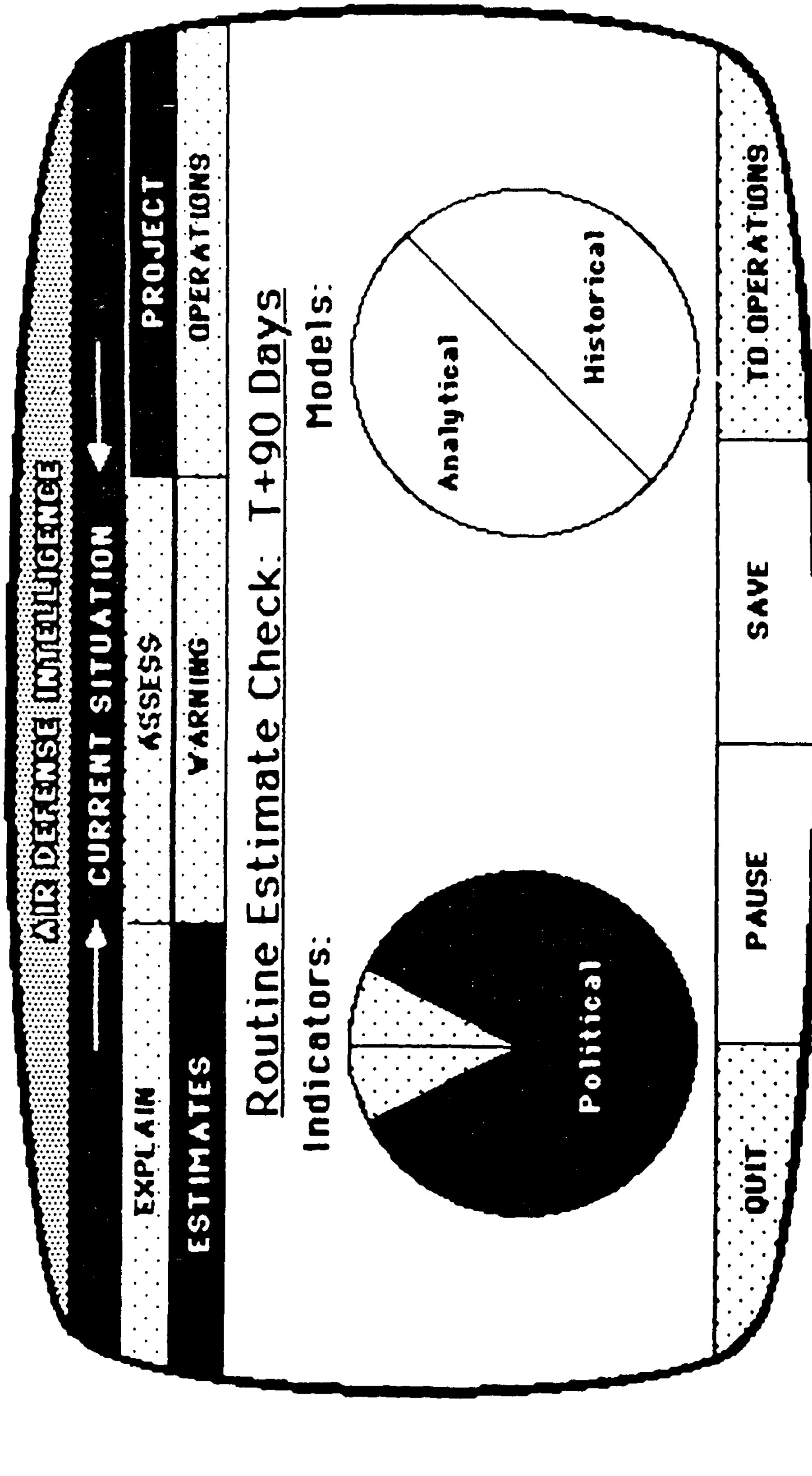

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
LOCATE?
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS

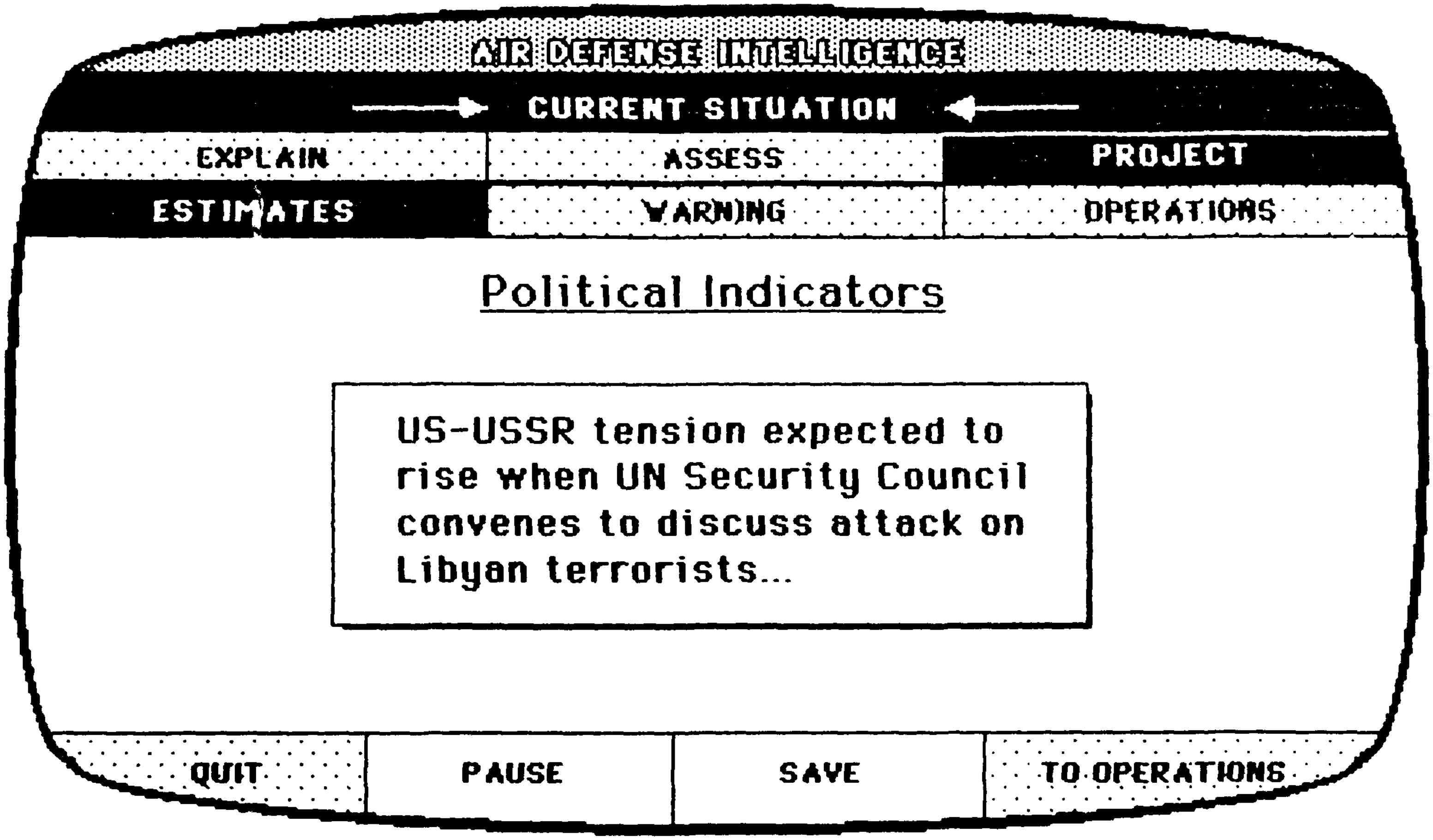


The system calculates an intelligence estimate over a 0 - 150+ period of time. The system calculates the likelihood of the situation achieving the three states: routine, alert and warning. The user requests information about the change over time by clicking on **Check?**. The system presents a graphic trend of things to come, at least based on the embedded models.

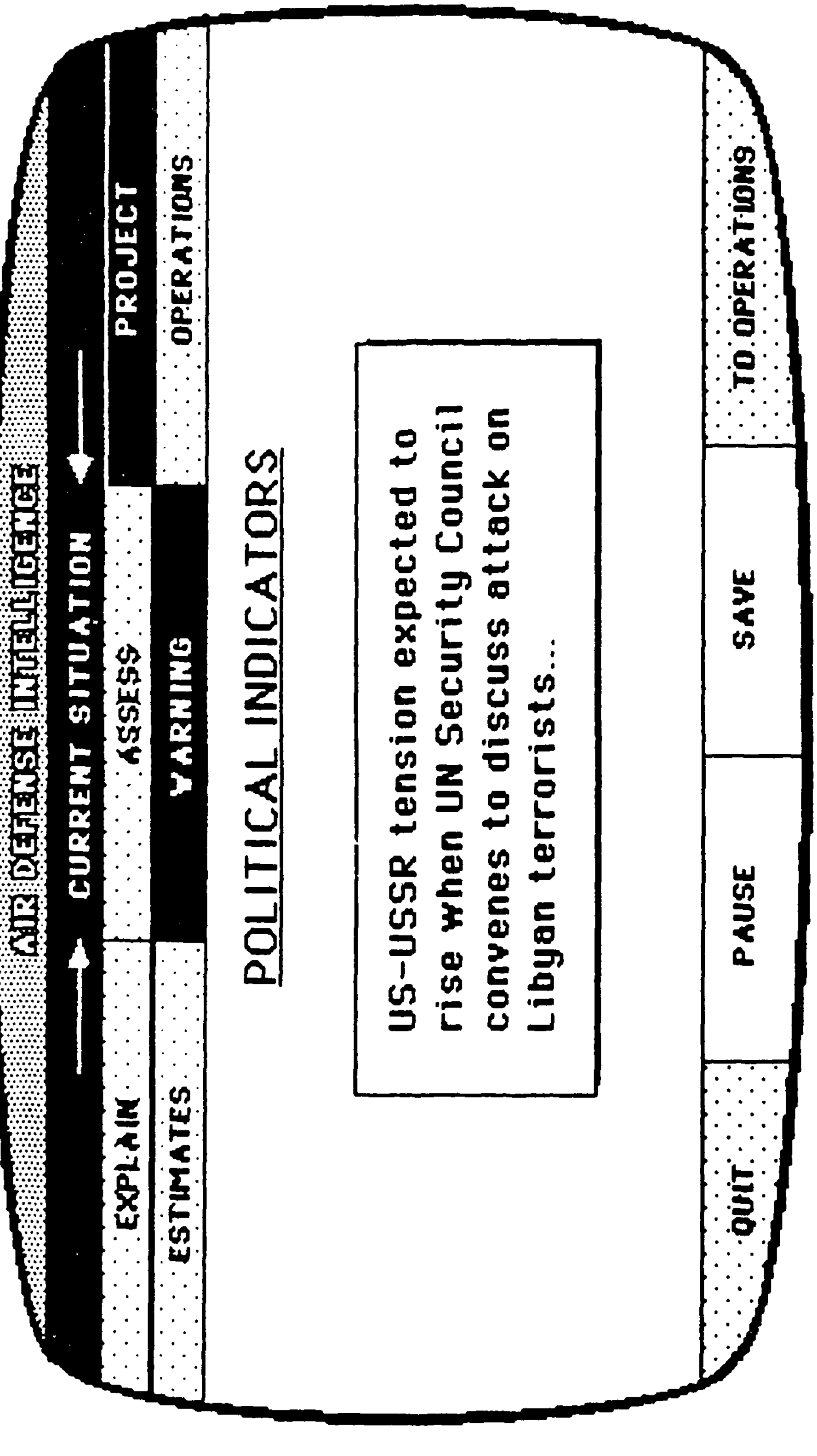


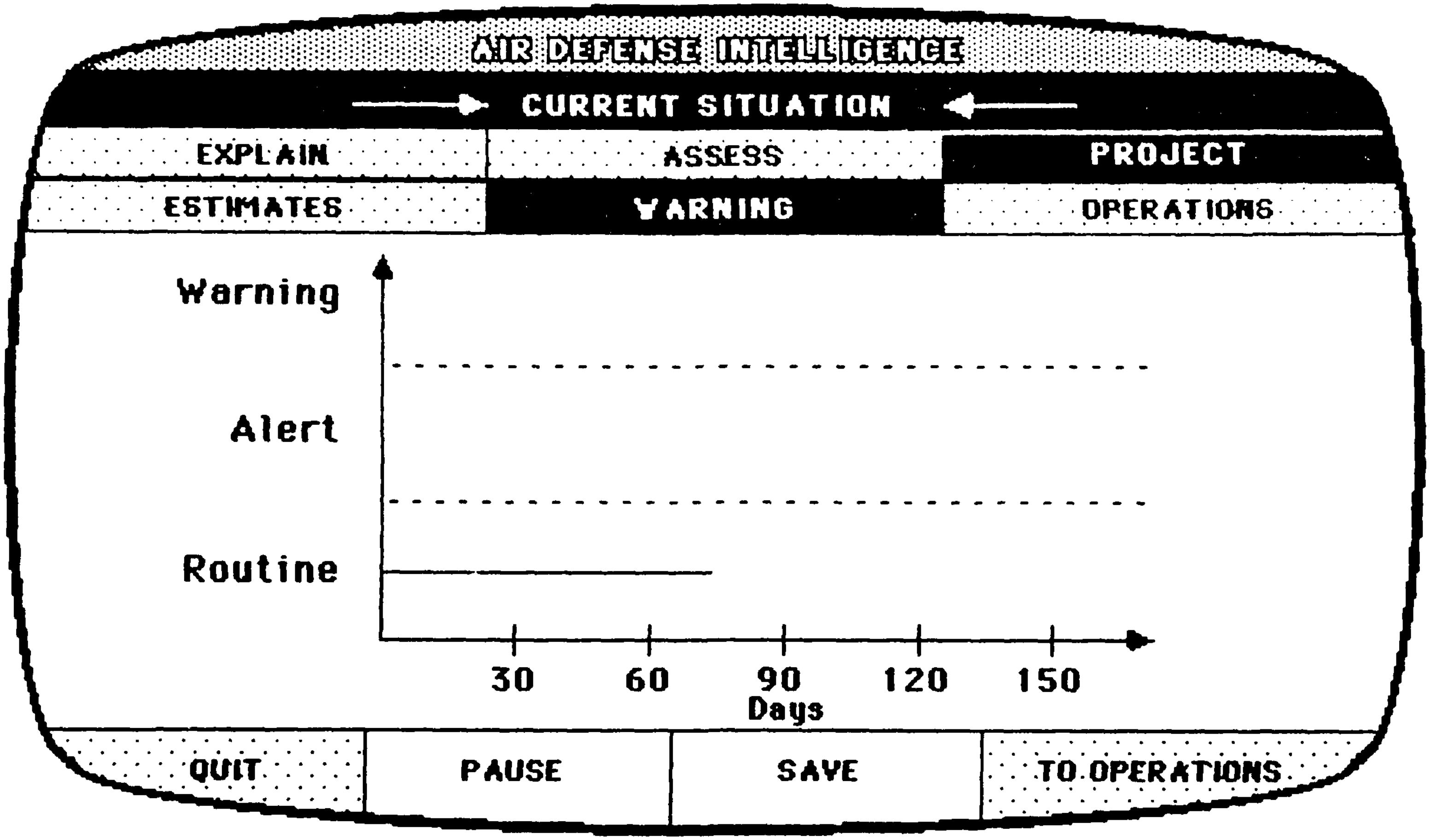
The system explains the expected source of the change in behavior. It suggests that the model-based explanation is split between historical and analytical models, but that the indicator-based explanation can be traced to expected changes in political indicators. The user inspects the political events expected to trigger the change to near-alert status by clicking on **Check?**.


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Routine Estimate Check: T+90 Days
Indicators:
Political
Models:
Analytical
Historical
QUIT
PAUSE
SAVE
TO OPERATIONS

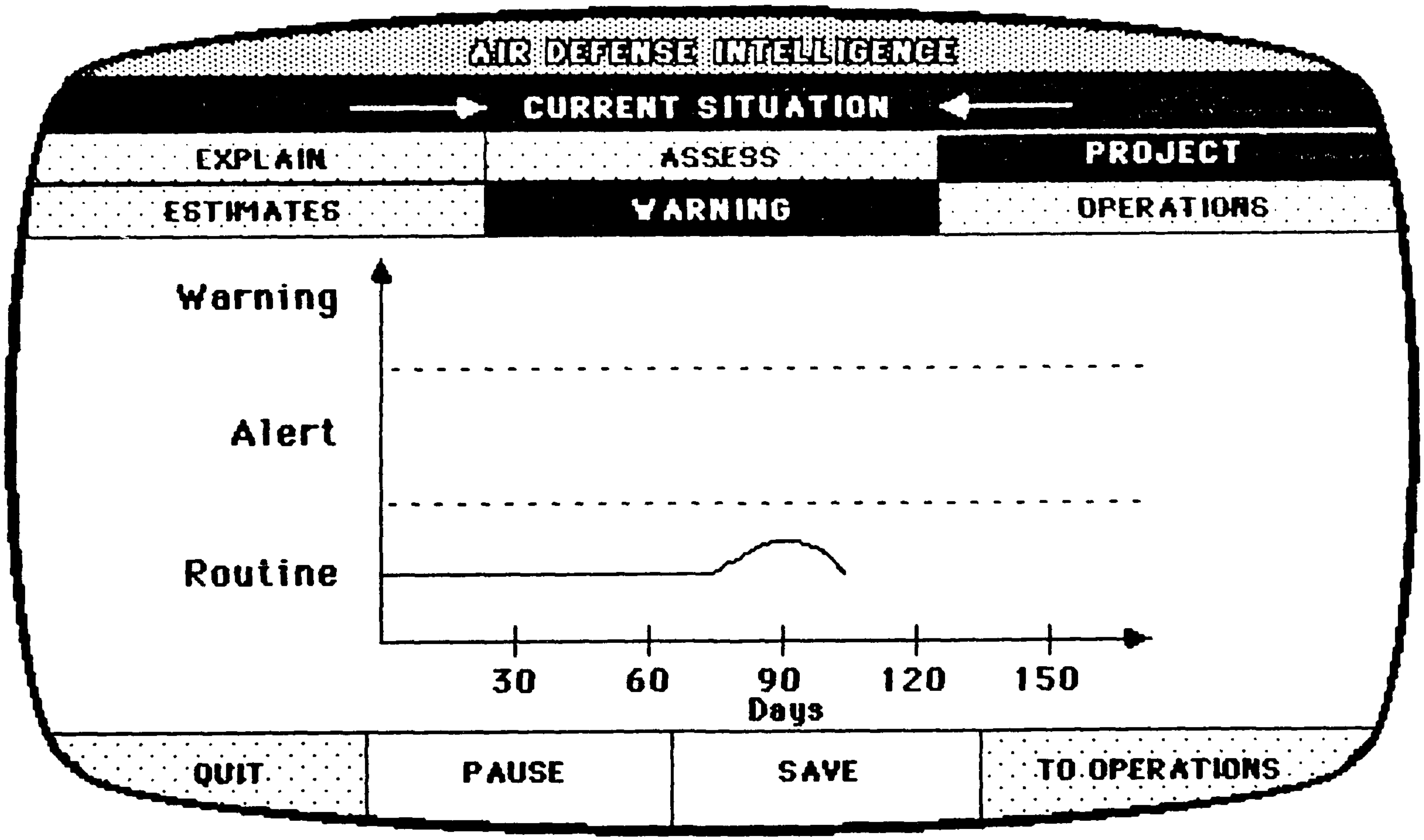


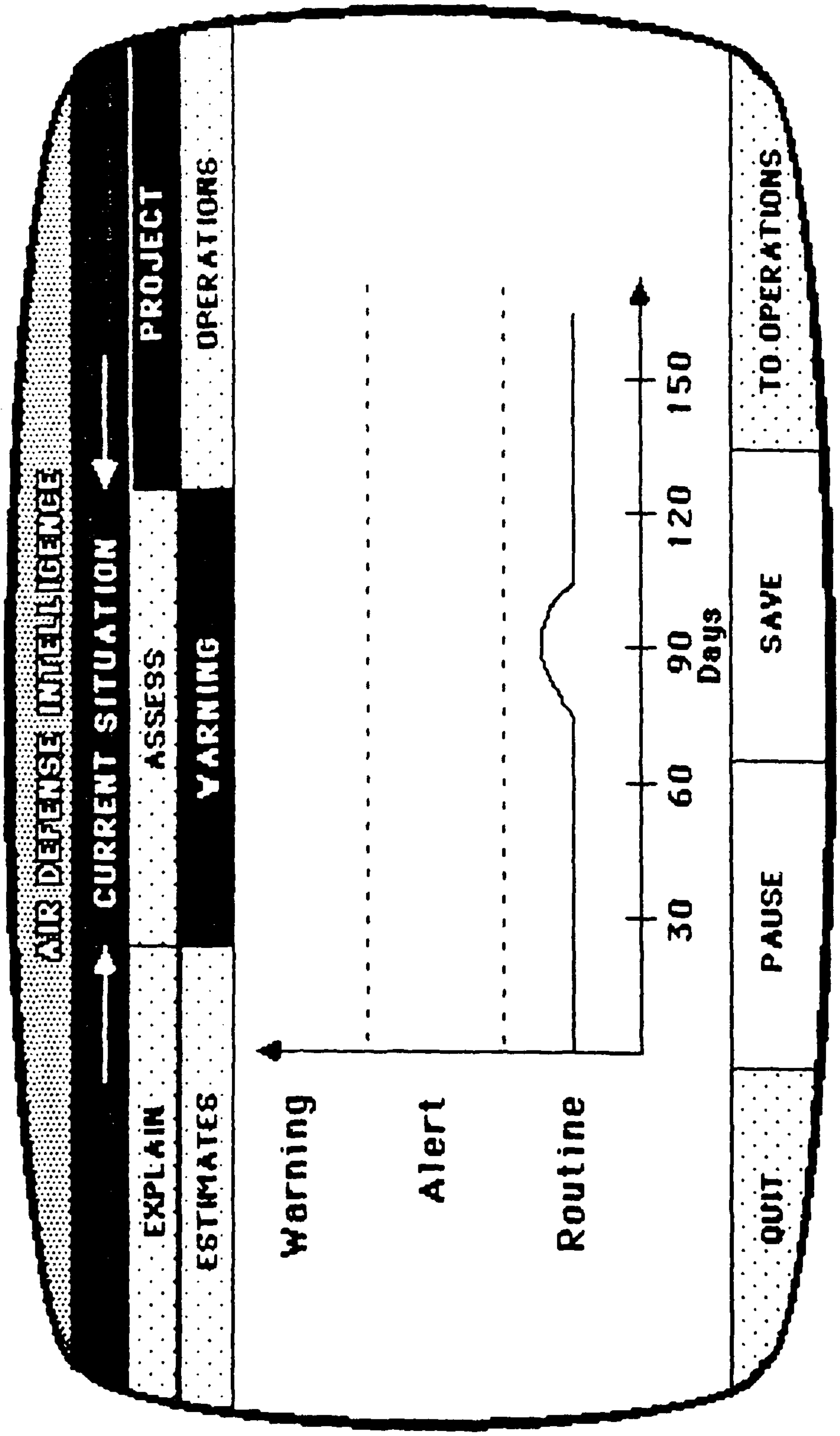
The system explains why the political indicators are expected to trigger a change. The user moves on to **Warning**.

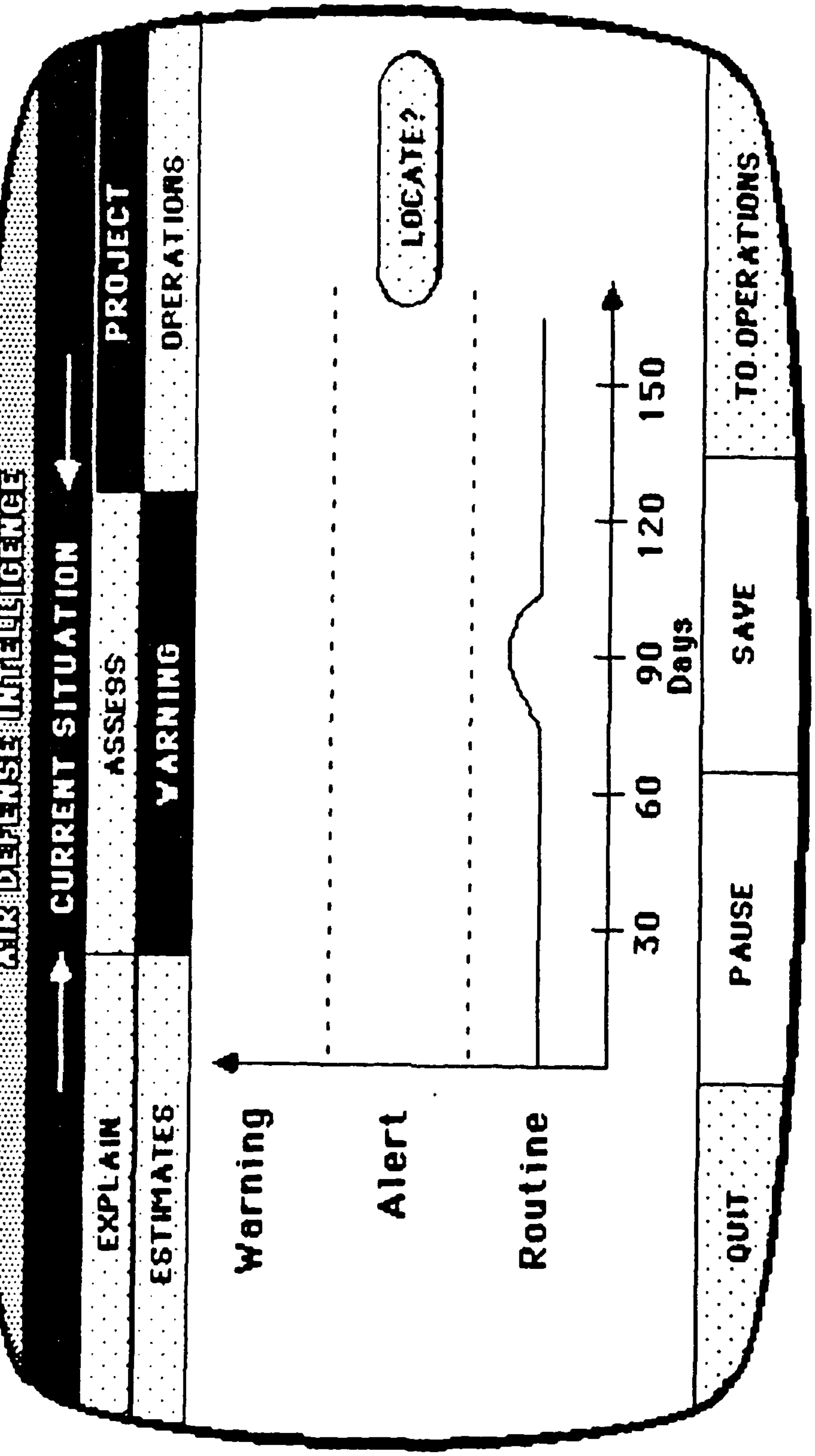

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
POLITICAL INDICATORS
US-USSR tension expected to rise when UN Security Council convenes to discuss attack on Libyan terrorists...
QUIT
PAUSE
SAVE
TO OPERATIONS

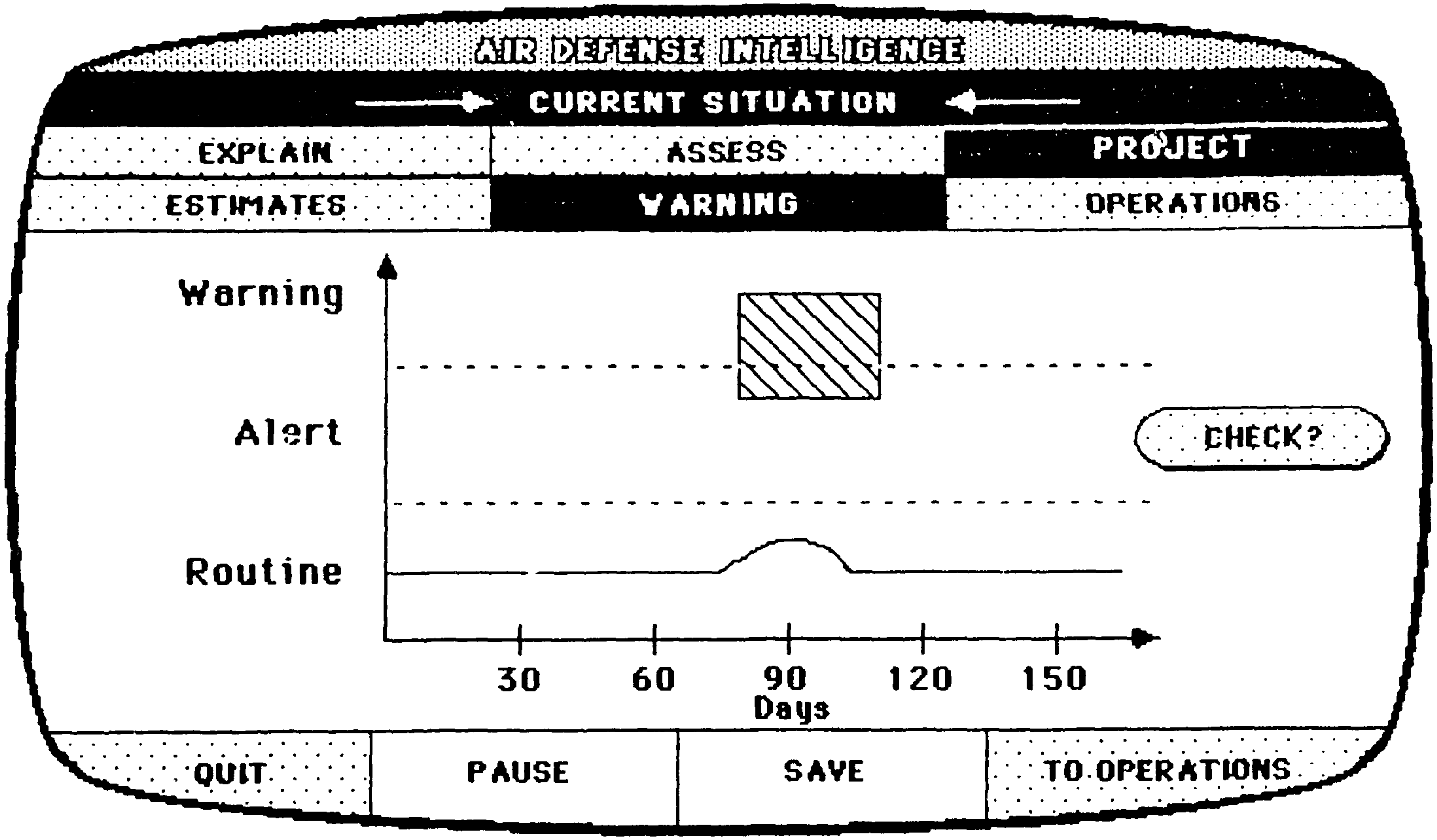


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS

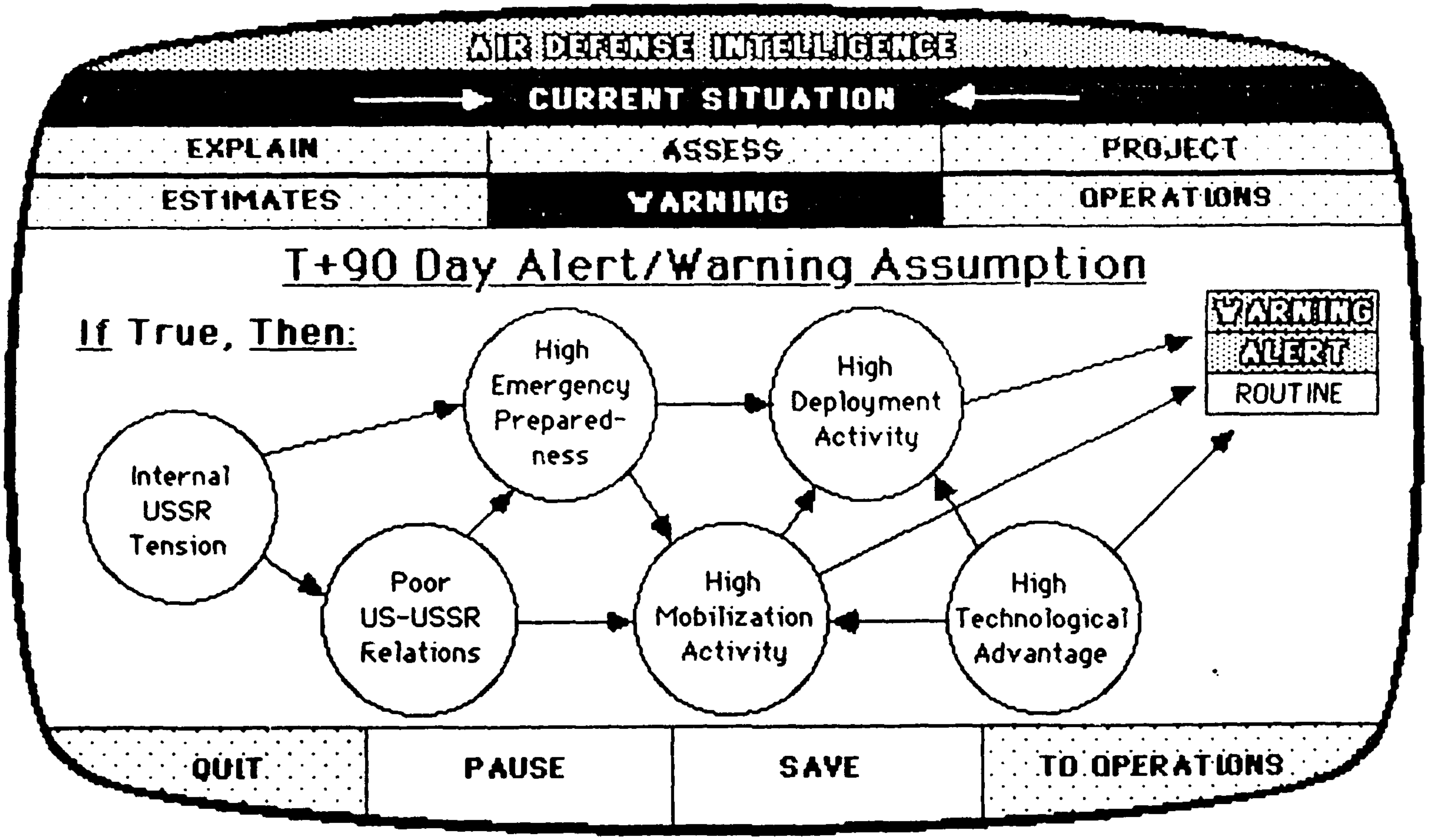

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS

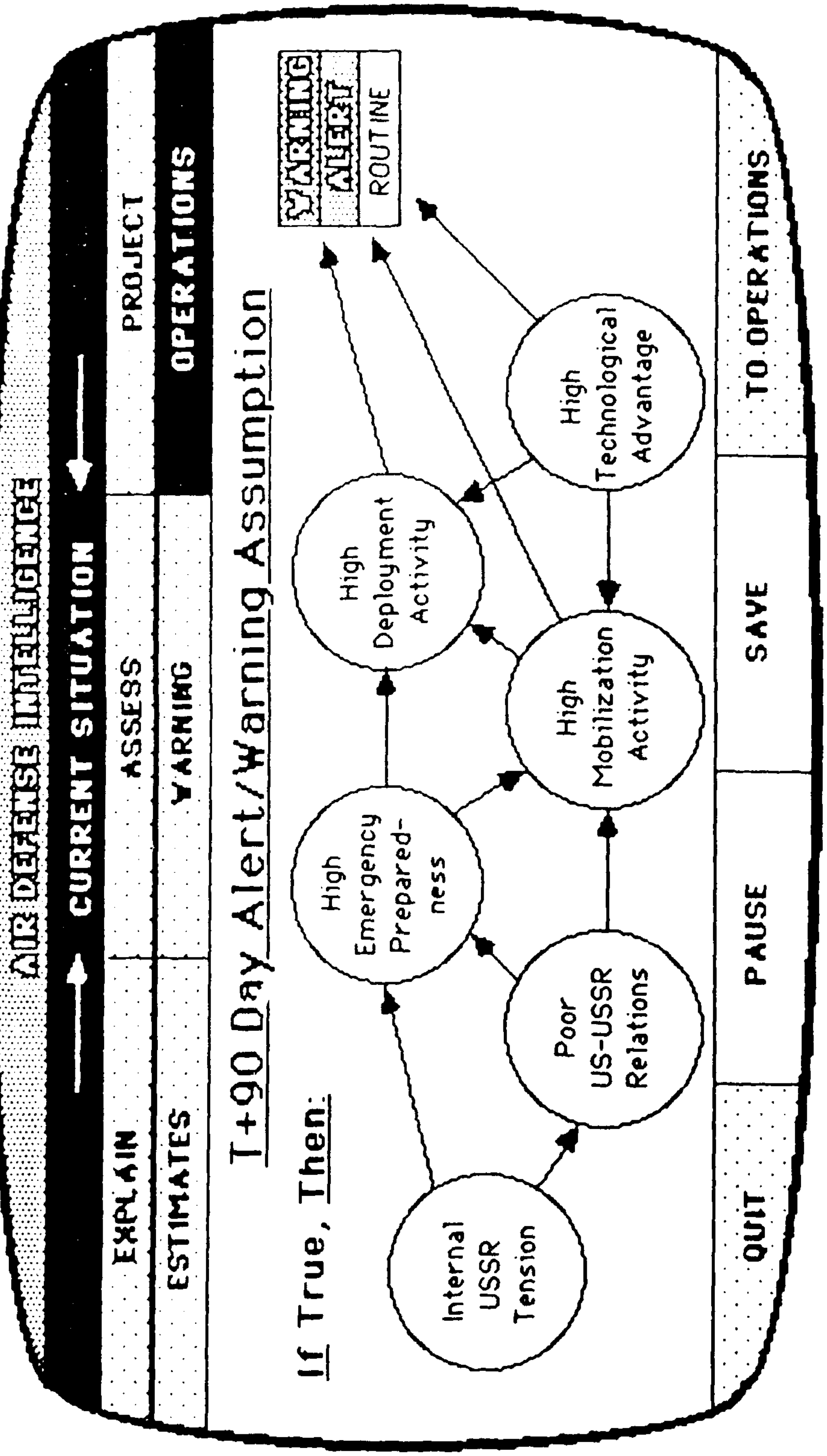

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
LOCATE?
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO OPERATIONS

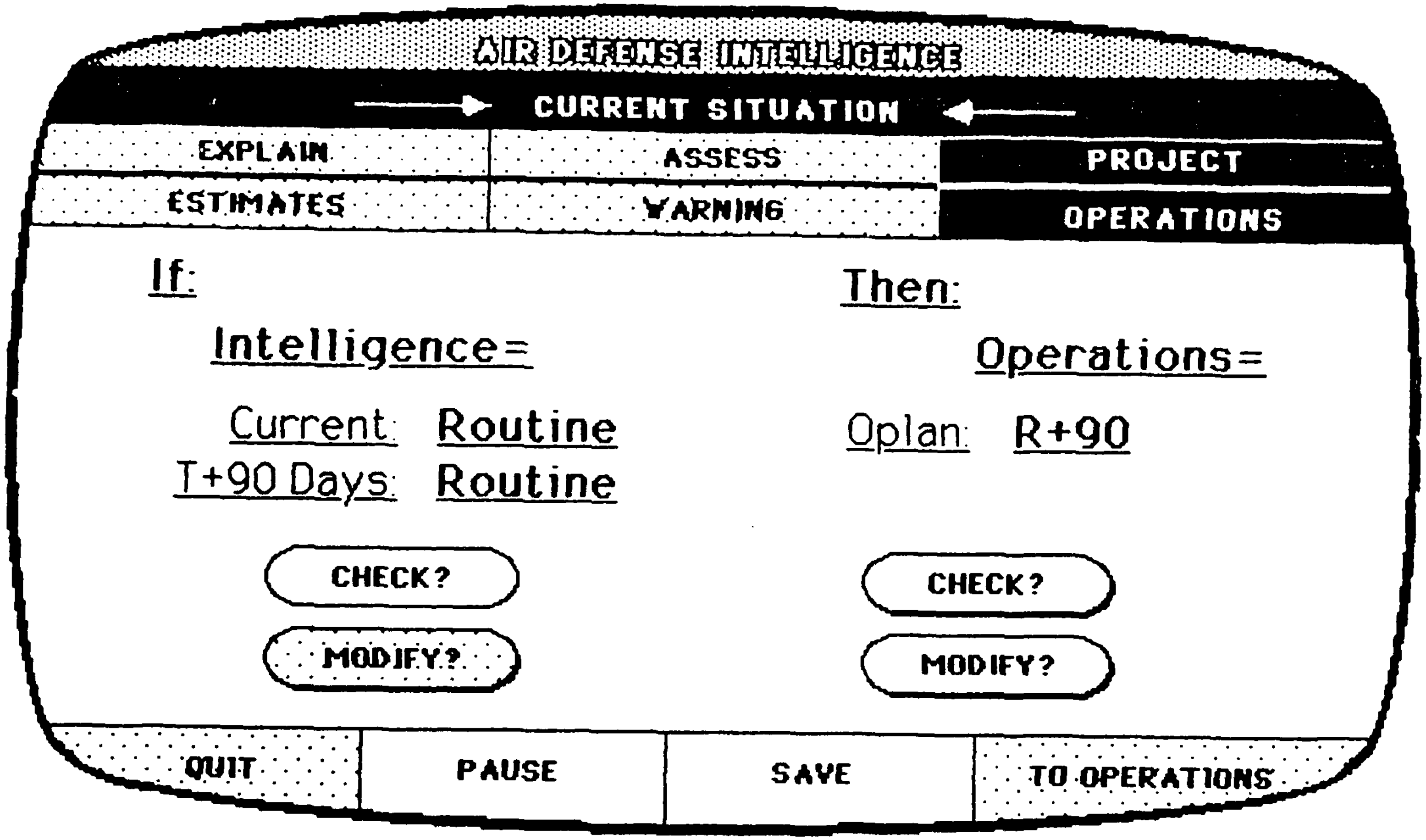


The system now provides the analyst with the capability of testing alternative hypotheses via a deductive inferential process. After clicking on **Check?**, the system presents the analyst with a deduction based on the warning assumption.

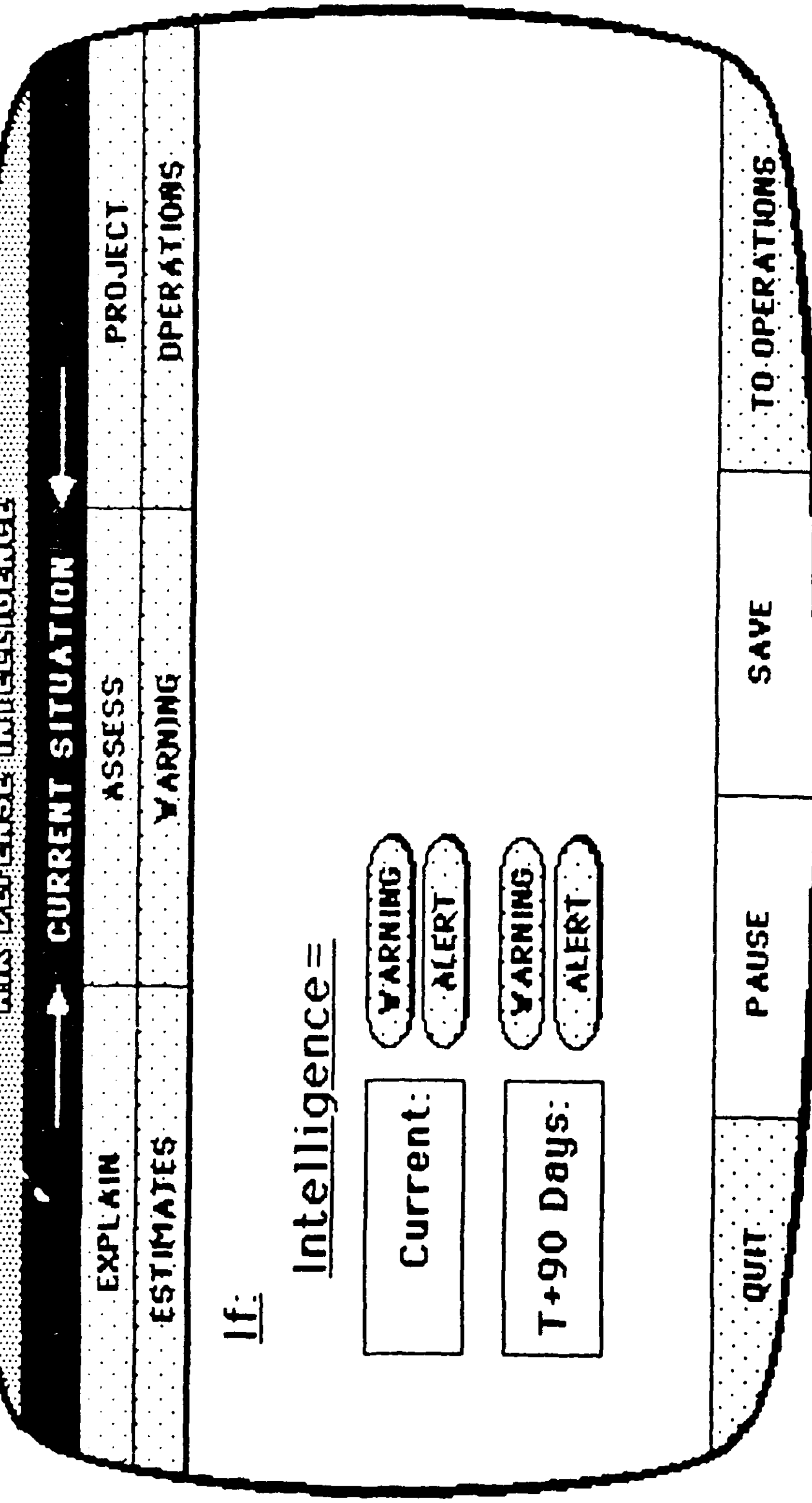


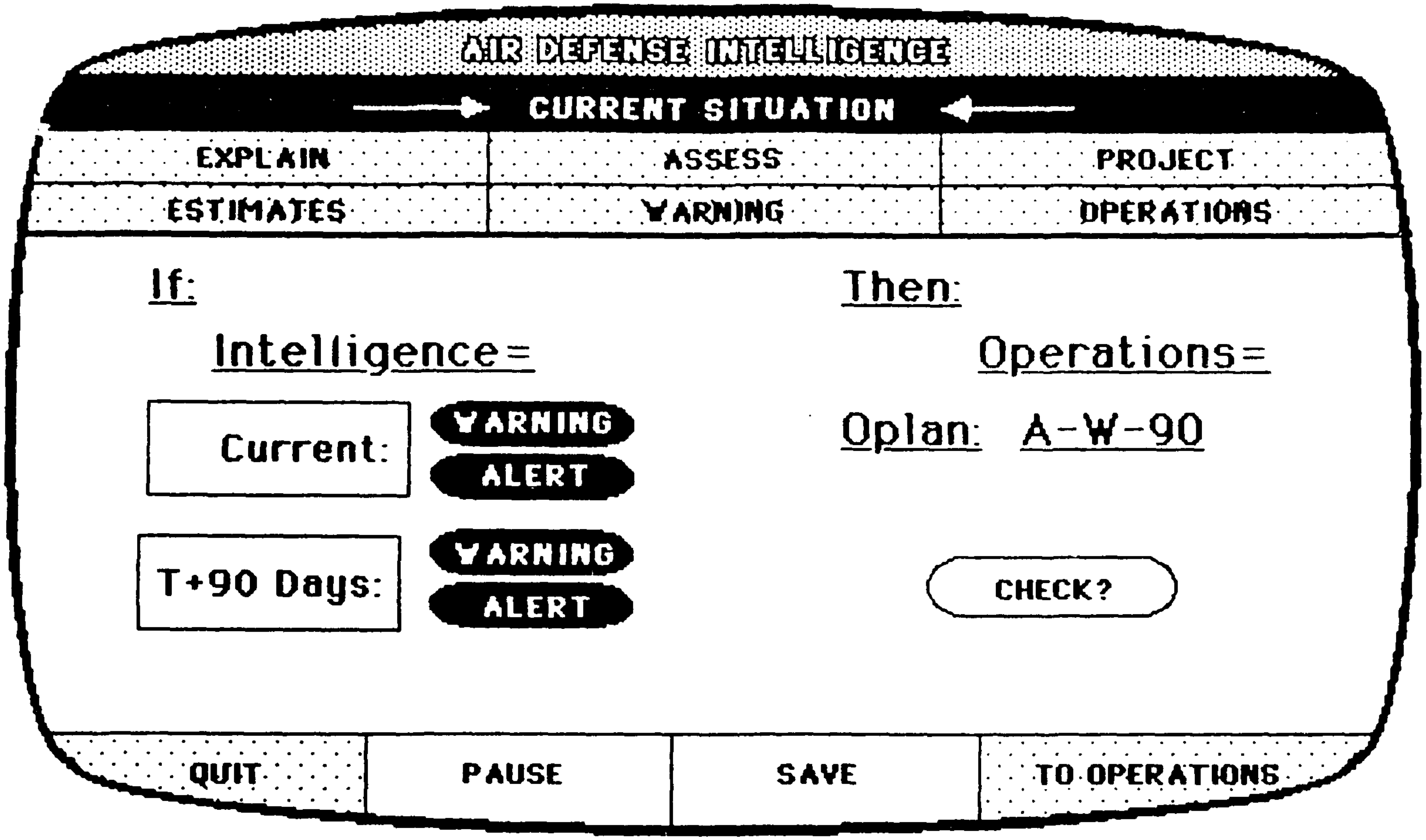
The system suggests that "if warning is true, then . . . " the following inferential relationships will also be true. This capability permits analysts to play "what - if" games with the system, and call the system's knowledge base into question, when appropriate. The capability also helps suggest how intelligence collection assets should be tasked, if the analyst is "looking" for something in the threat environment. The user then clicks on **Operations**.


AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
T+90 Day Alert/Warning Assumption
If True, Then:
Internal USSR Tension
Poor US-USSR Relations
High Emergency Prepared-ness
High Mobilization Activity
High Deployment Activity
High Technological Advantage
WARNING
ALERT
ROUTINE
QUIT
PAUSE
SAVE
TO OPERATIONS



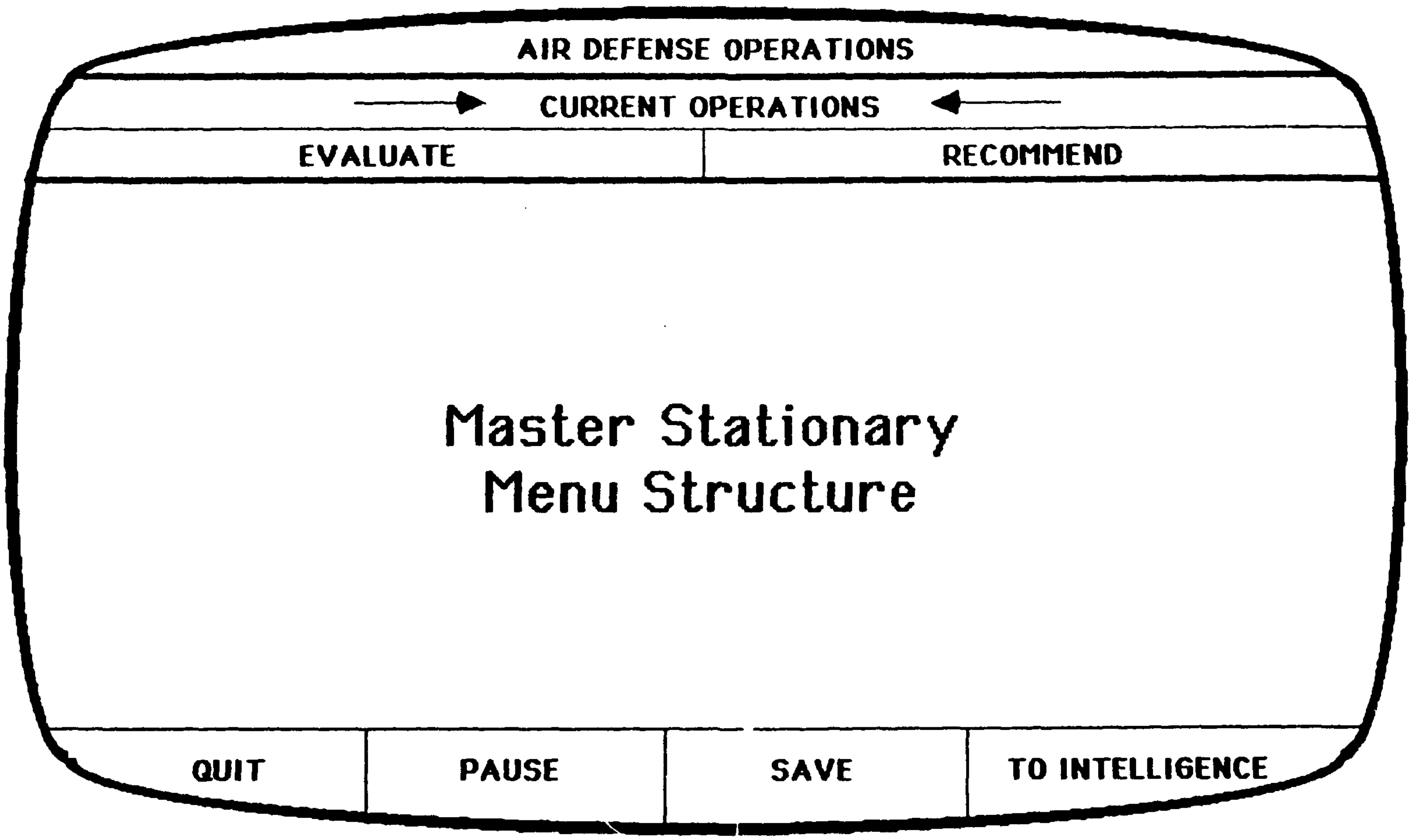
The system provides insight into the "consequences" of the intelligence estimate vis-a-vis operations. This capability is "unconventional" since it assumes that the intelligence analysis process should be influenced somewhat by the OPLANS that will be triggered by estimates. The user clicks on **Modify** since he wants to change the "if" condition of the OPLAN selection process.

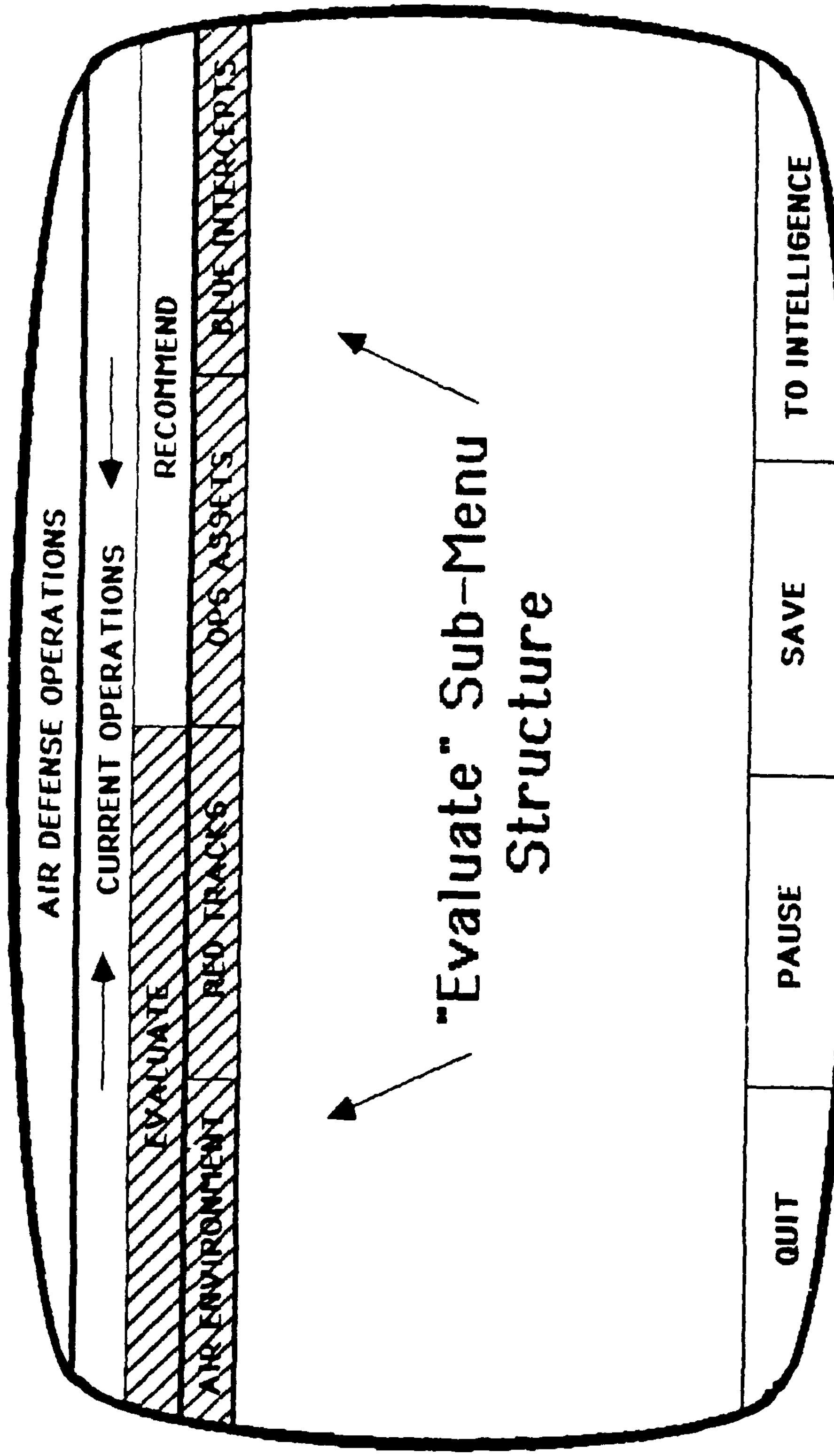

AIR DEFENSE INTELLIGENCE
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
ESTIMATES
WARNING
OPERATIONS
If:
Intelligence=
Current:
WARNING
ALERT
T+90 Days:
WARNING
ALERT
QUIT
PAUSE
SAVE
TO OPERATIONS

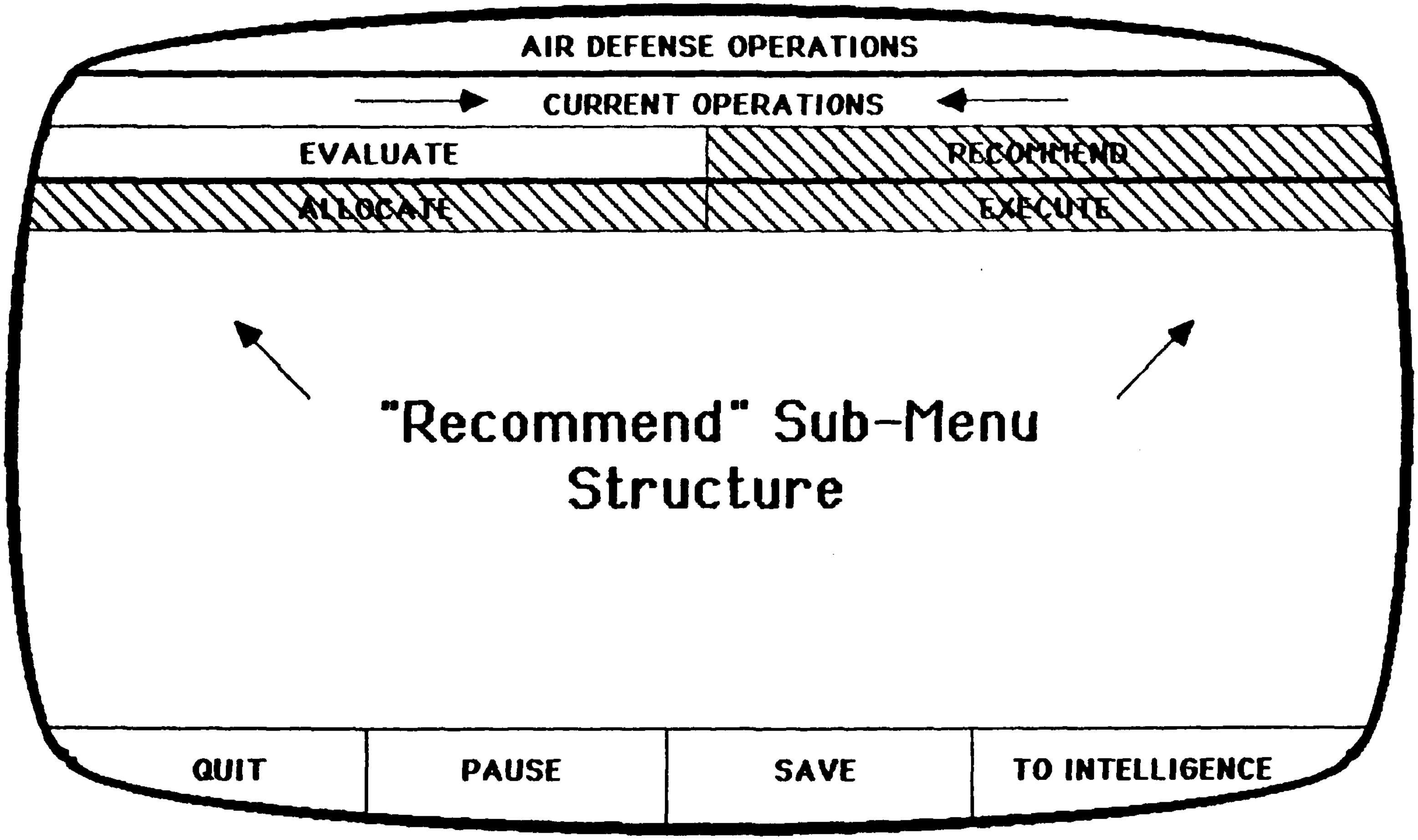


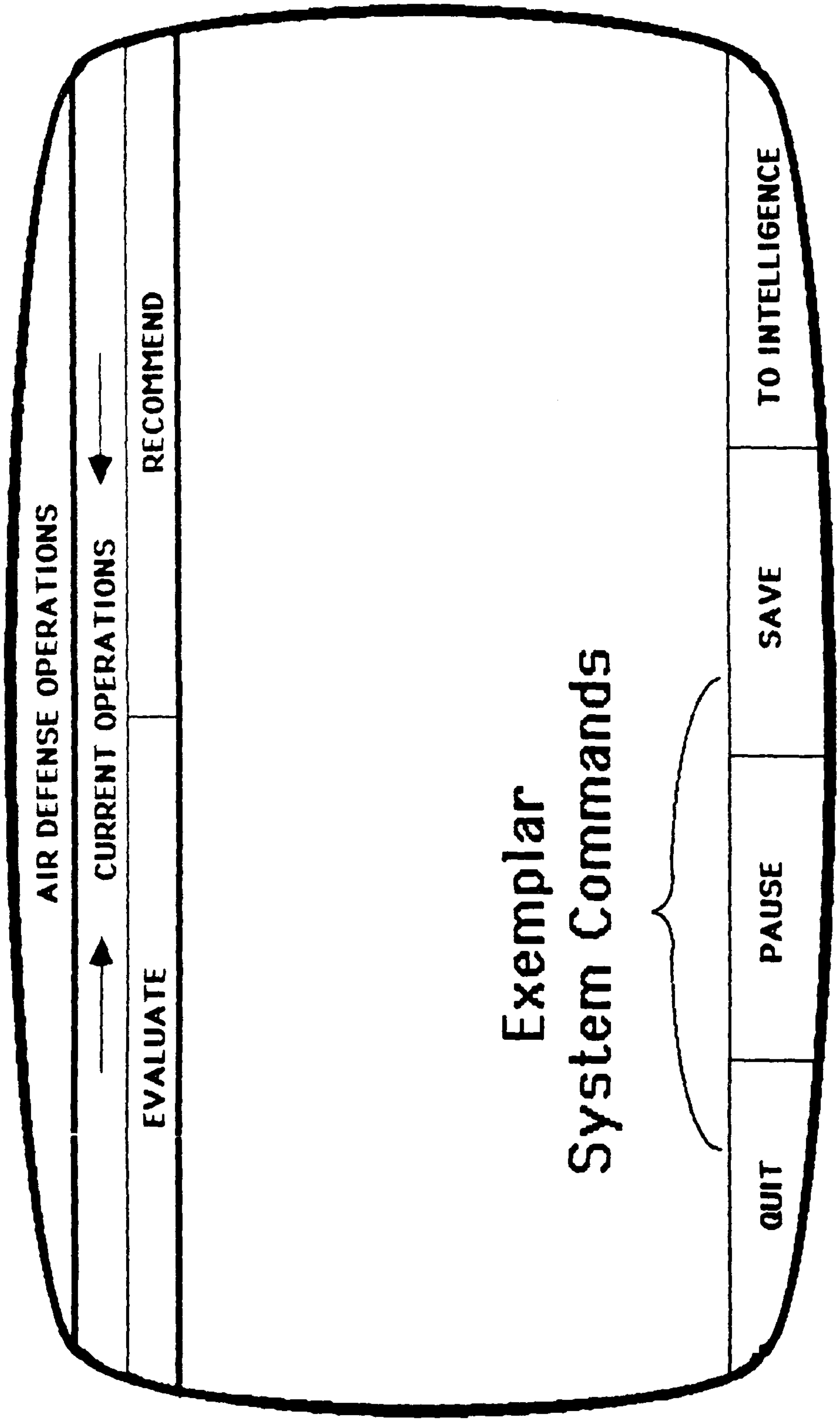
The analyst asks the user what the OPLAN would be if the situation changed from "routine" to "alert/warning." A new OPLAN is identified, suggesting that a slight change in the intelligence estimate could trigger a major operational adjustment. The threshold should be communicated to the intelligence analyst. OPLANS should also be communicated to the intelligence analyst, so that the implications of the estimate can be integrated into the air defense **intelligence** and operations process.

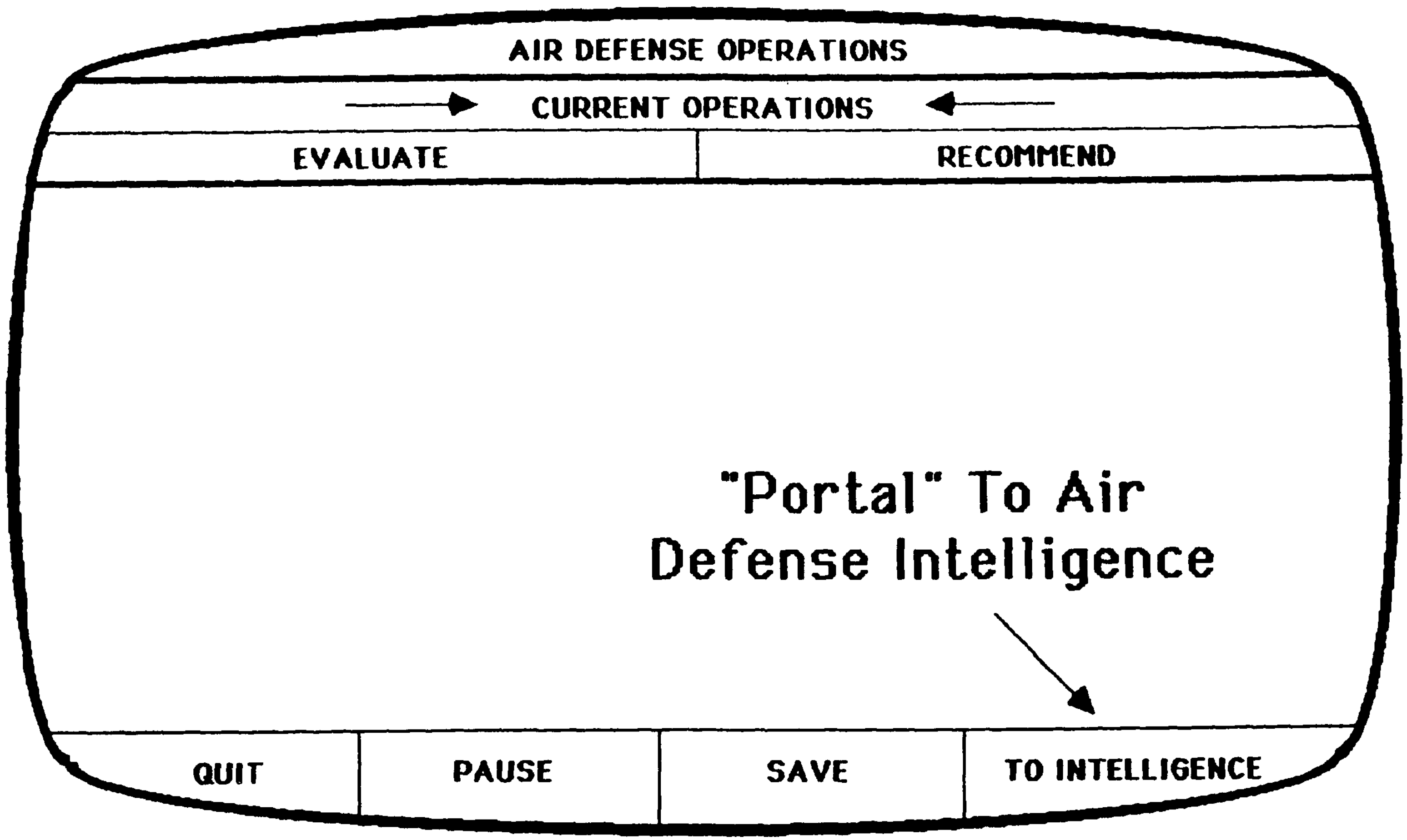
Air Defense Operations Prototype

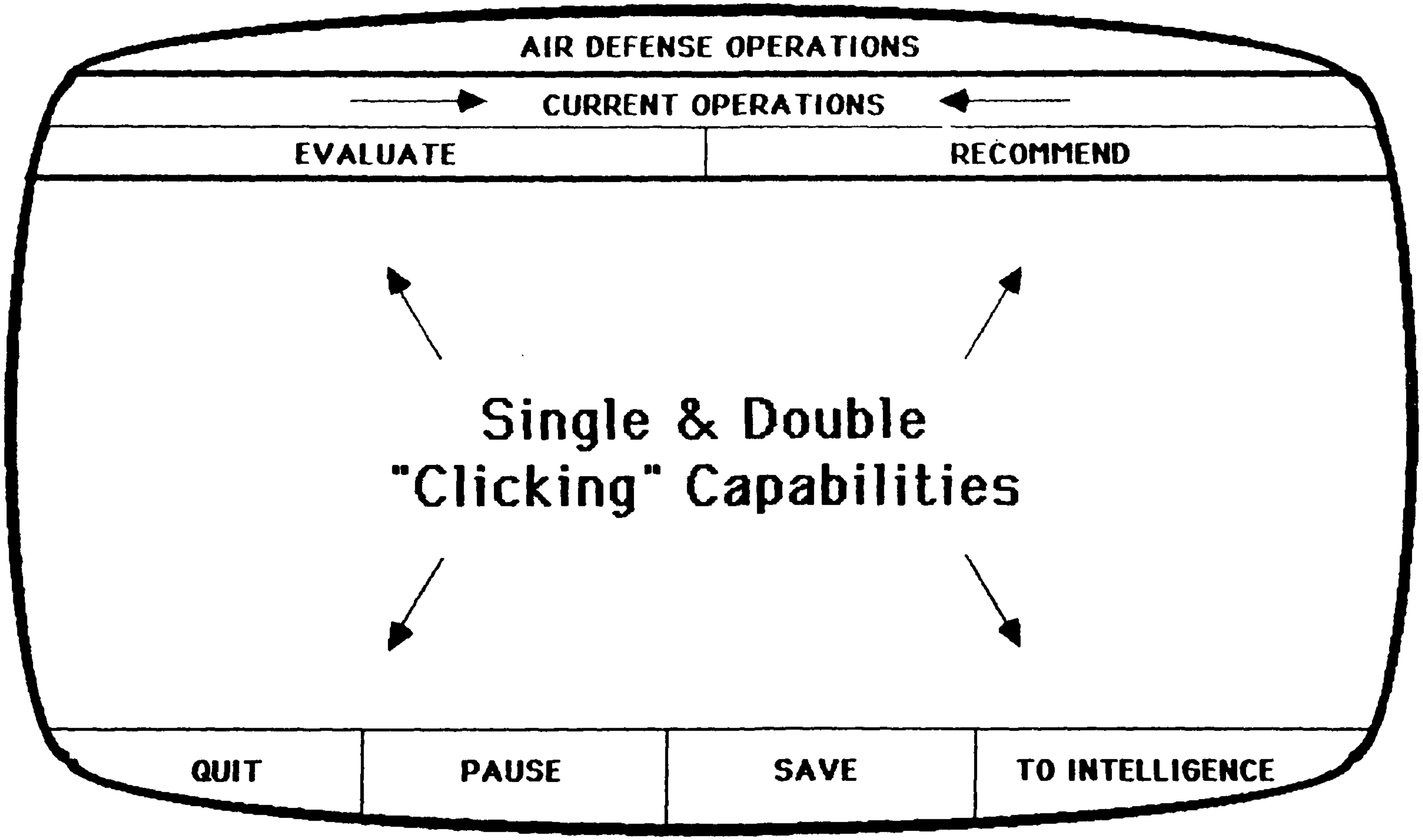

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Master Stationary
Menu Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE

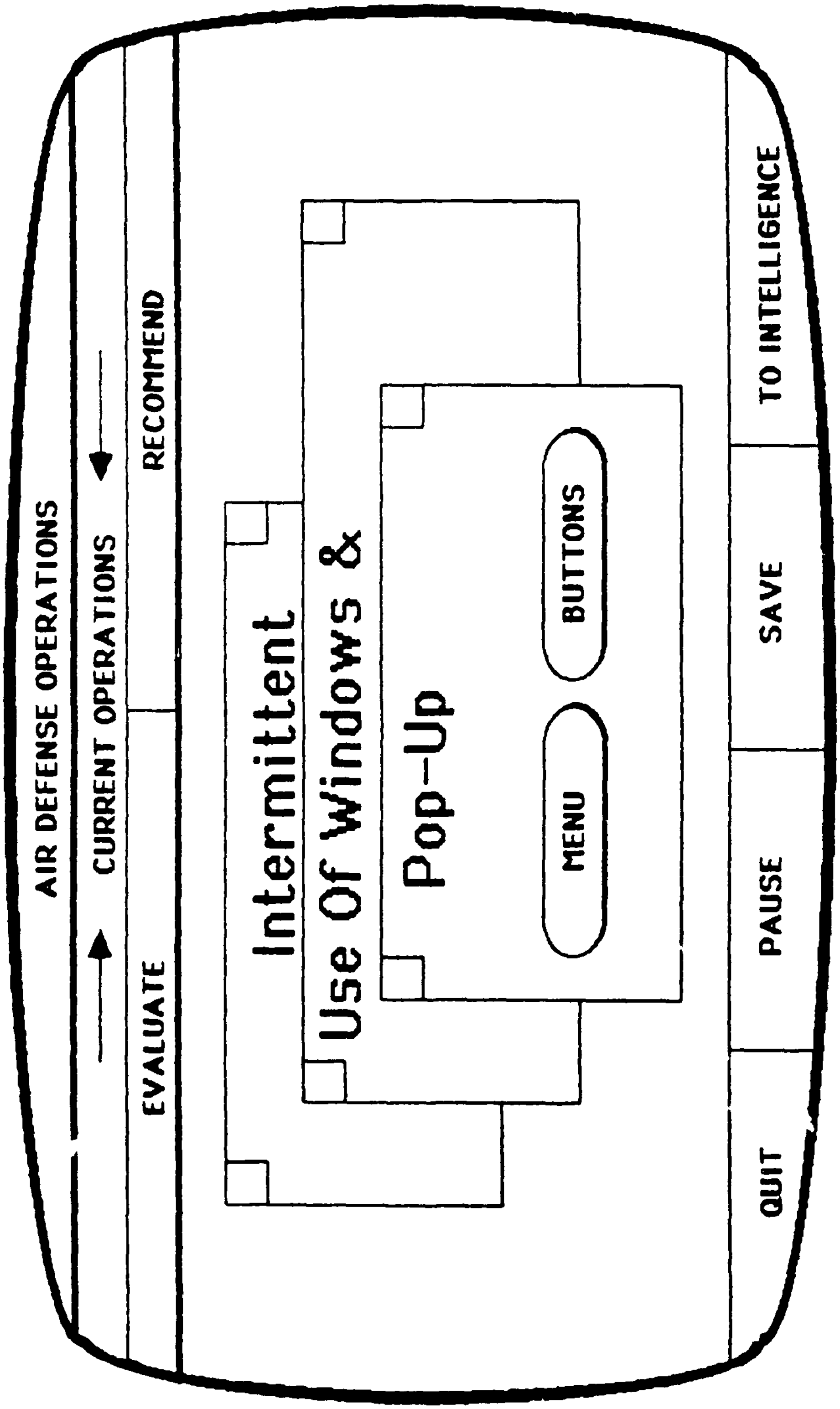

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
"Evaluate" Sub-Menu
Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE

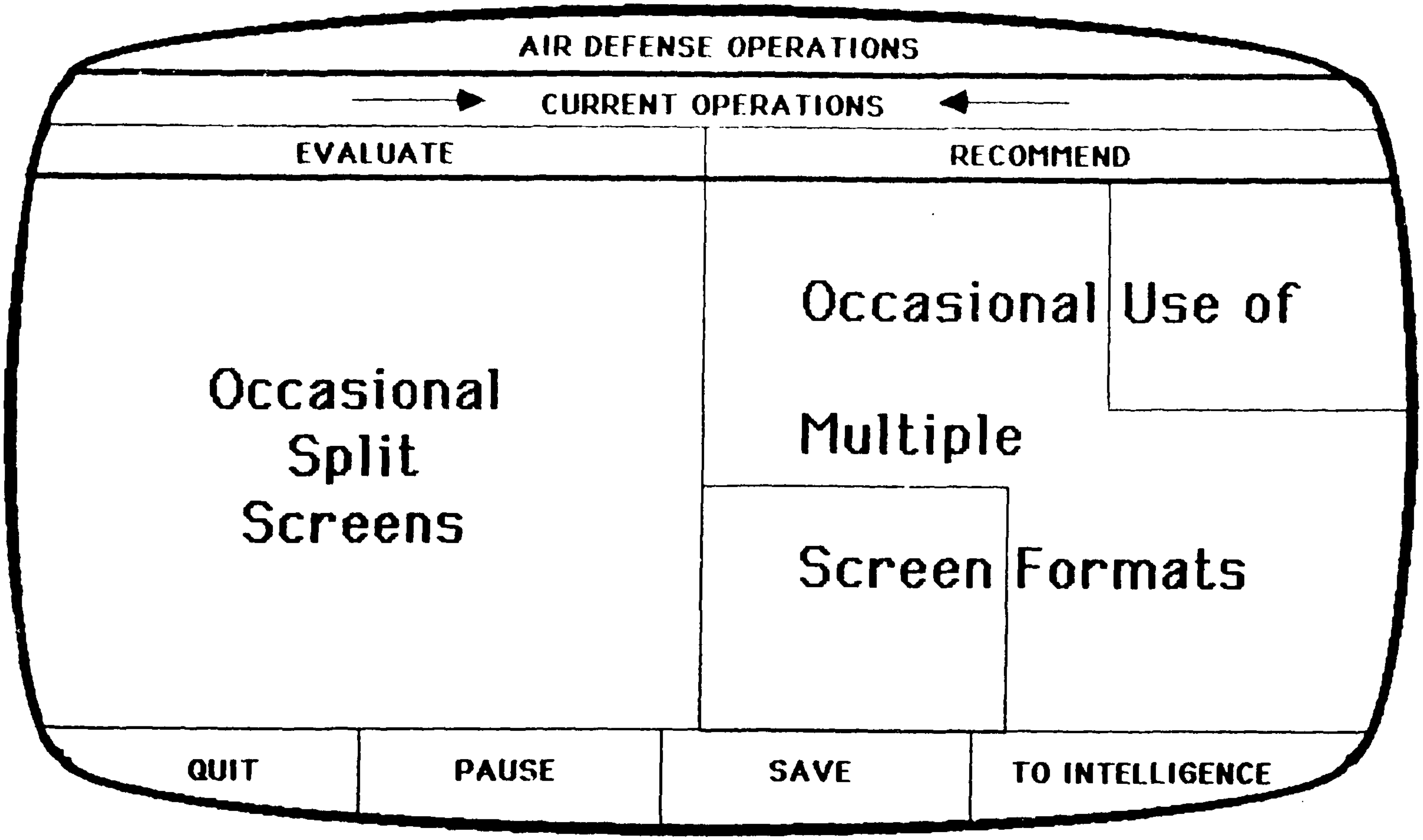

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
"Recommend" Sub-Menu Structure
QUIT
PAUSE
SAVE
TO INTELLIGENCE

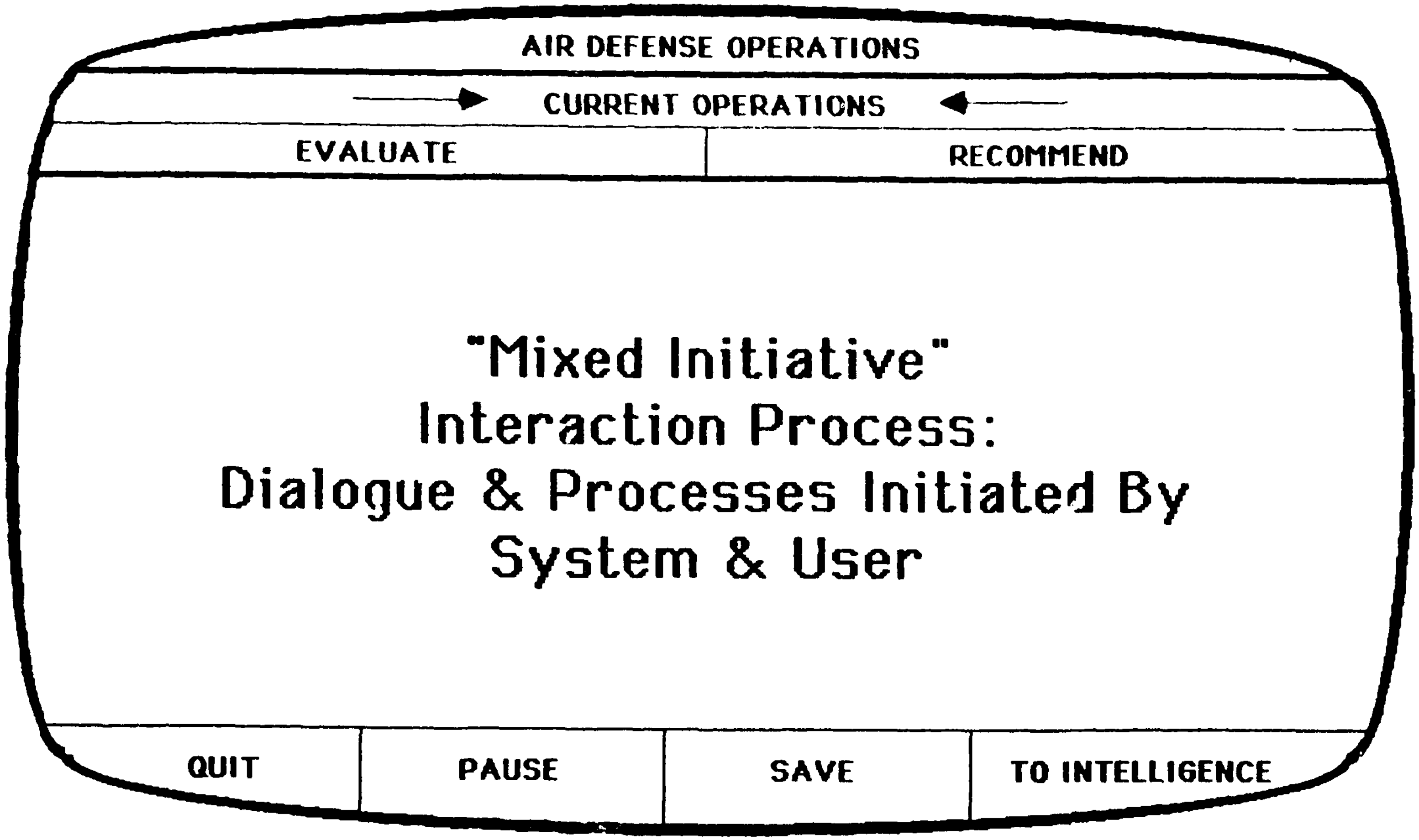

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Exemplar
System Commands
QUIT
PAUSE
SAVE
TO INTELLIGENCE

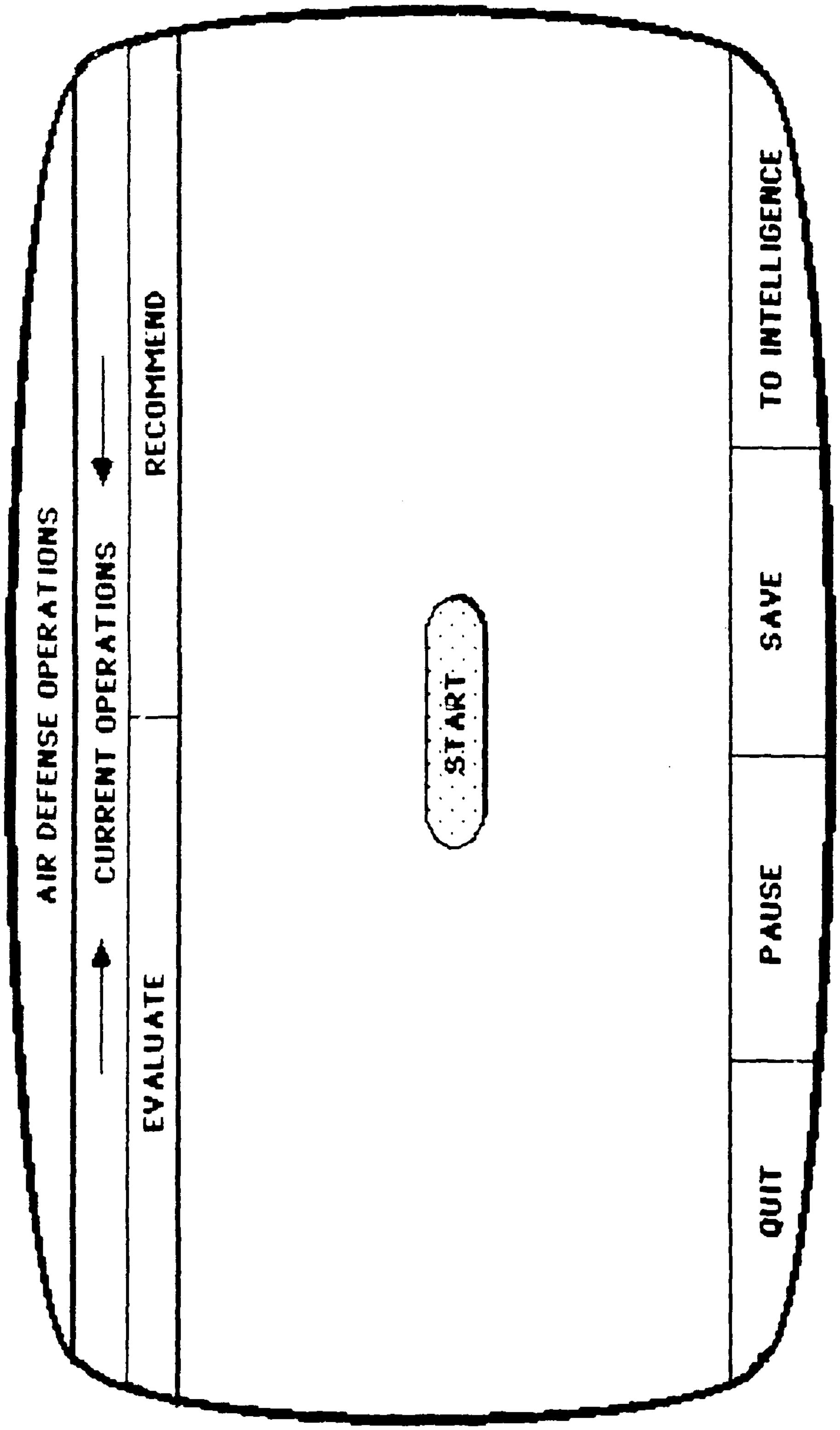

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
"Portal" To Air Defense Intelligence
QUIT
PAUSE
SAVE
TO INTELLIGENCE

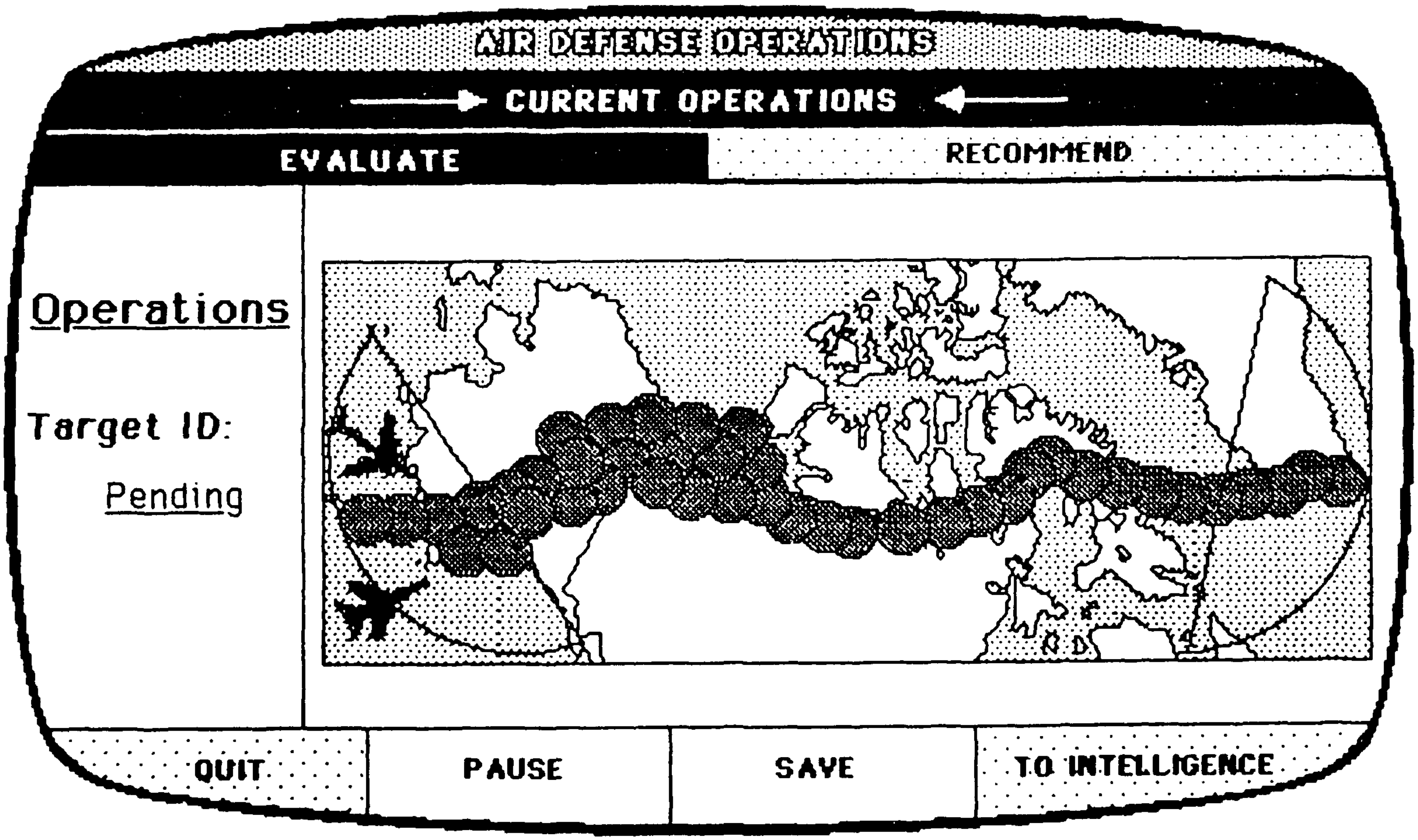

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Single & Double
"Clicking" Capabilities
QUIT
PAUSE
SAVE
TO INTELLIGENCE

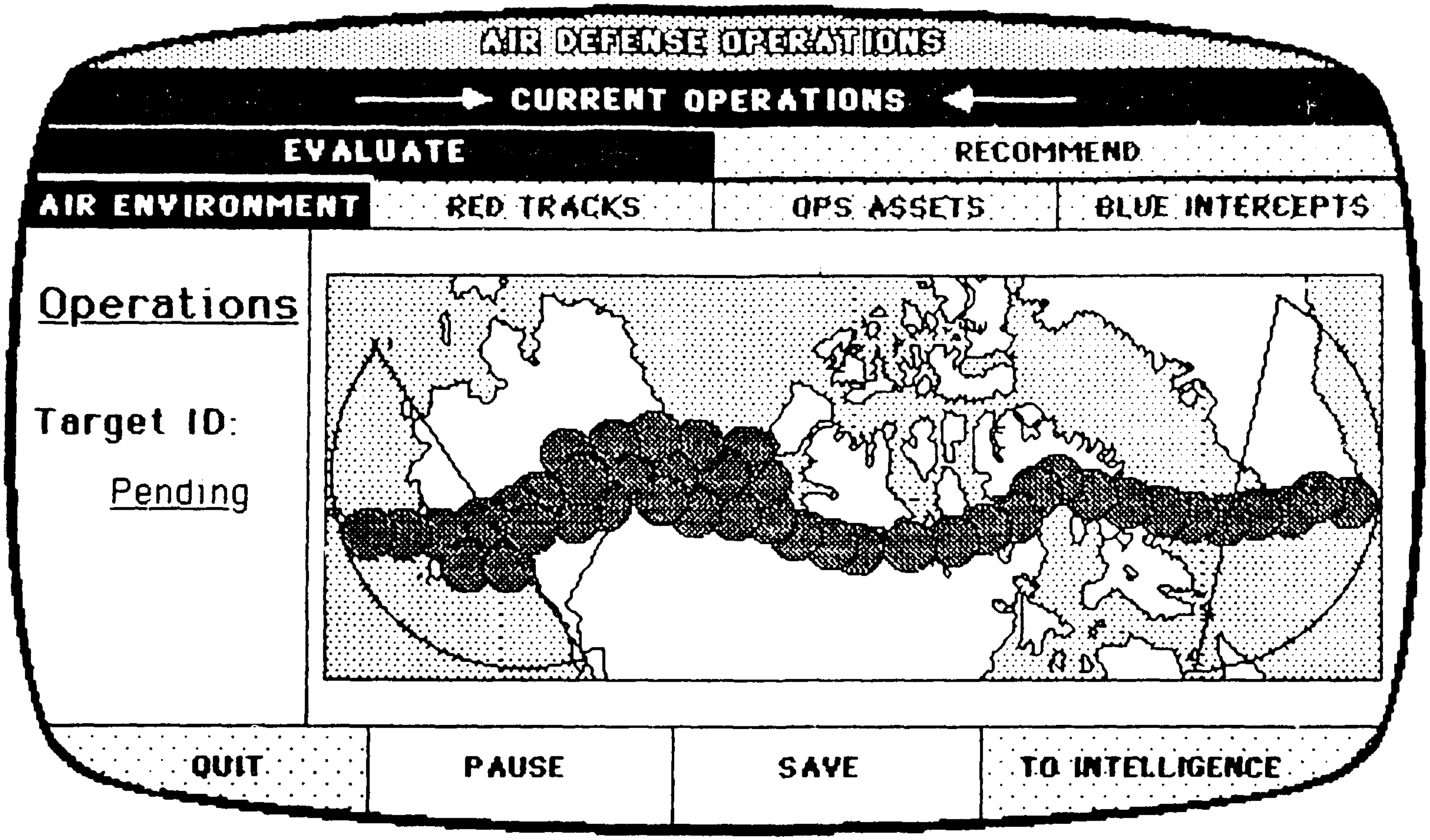

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Intermittent
Use Of Windows &
Pop-Up
MENU
BUTTONS
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Occasional Split Screens
Occasional Use of Multiple Screen Formats
QUIT
PAUSE
SAVE
TO INTELLIGENCE

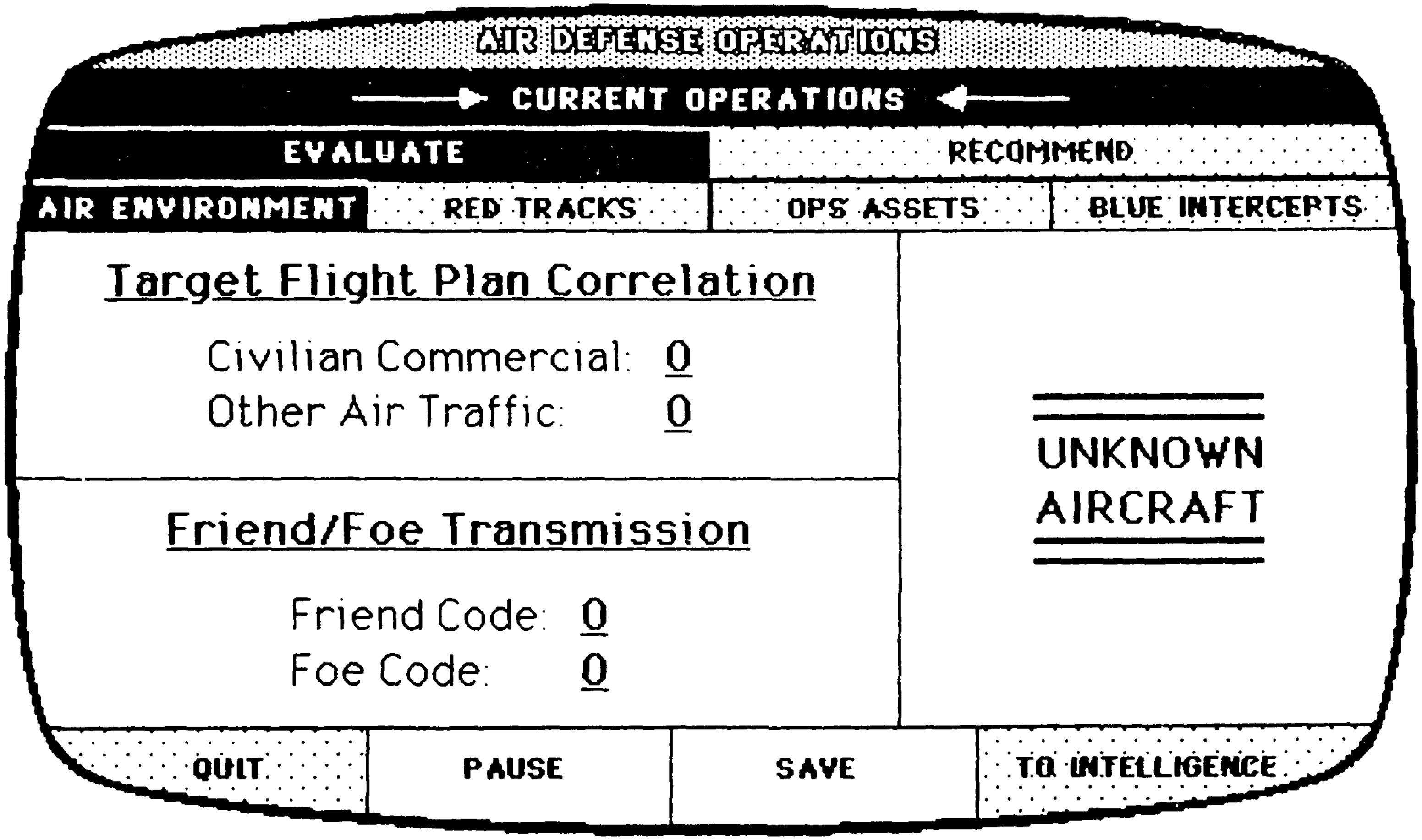

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
"Mixed Initiative"
Interaction Process:
Dialogue & Processes Initiated By
System & User
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
START
QUIT
PAUSE
SAVE
TO INTELLIGENCE

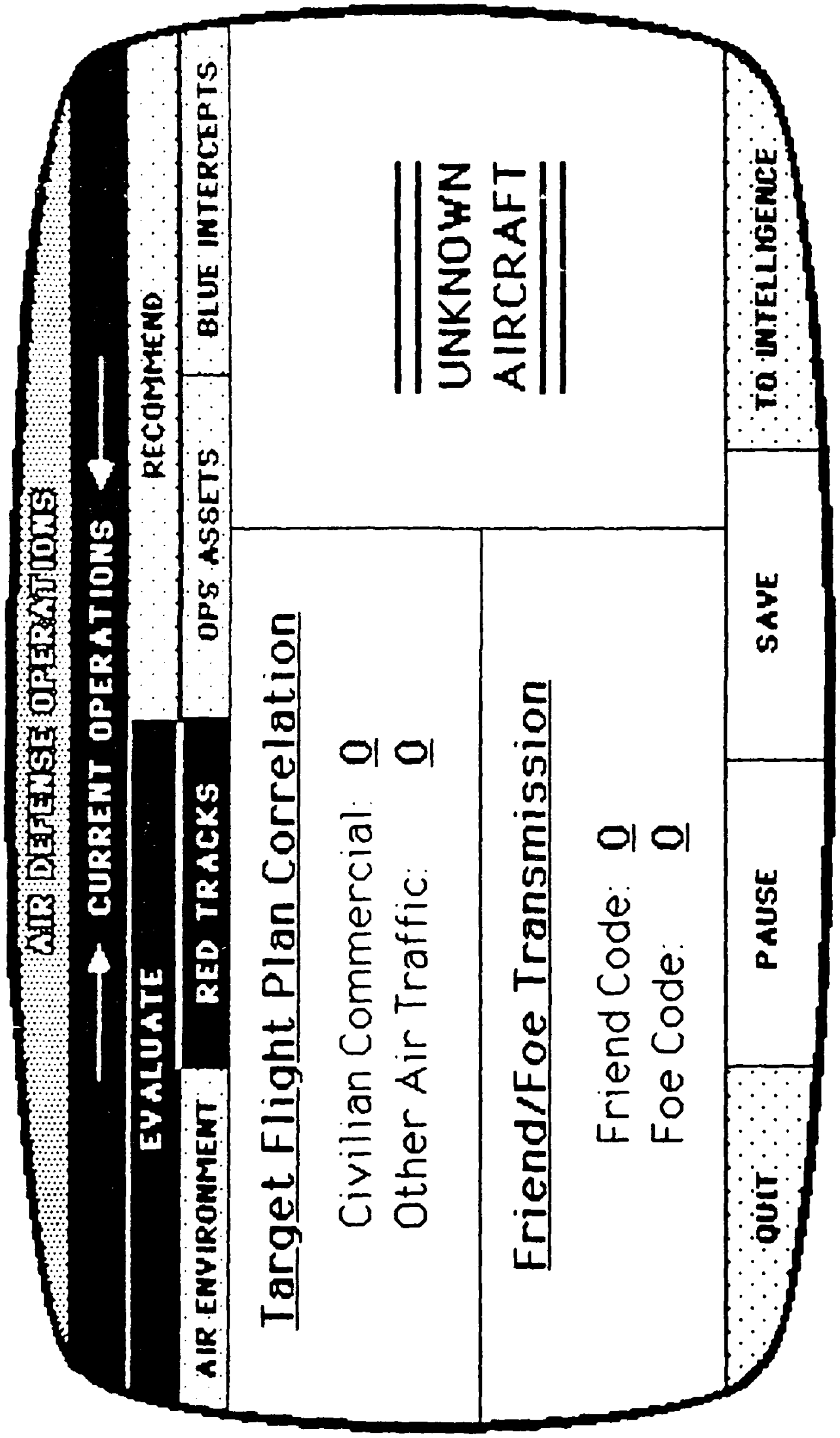

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
Operations
Target ID:
Pending
QUIT
PAUSE
SAVE
TO INTELLIGENCE

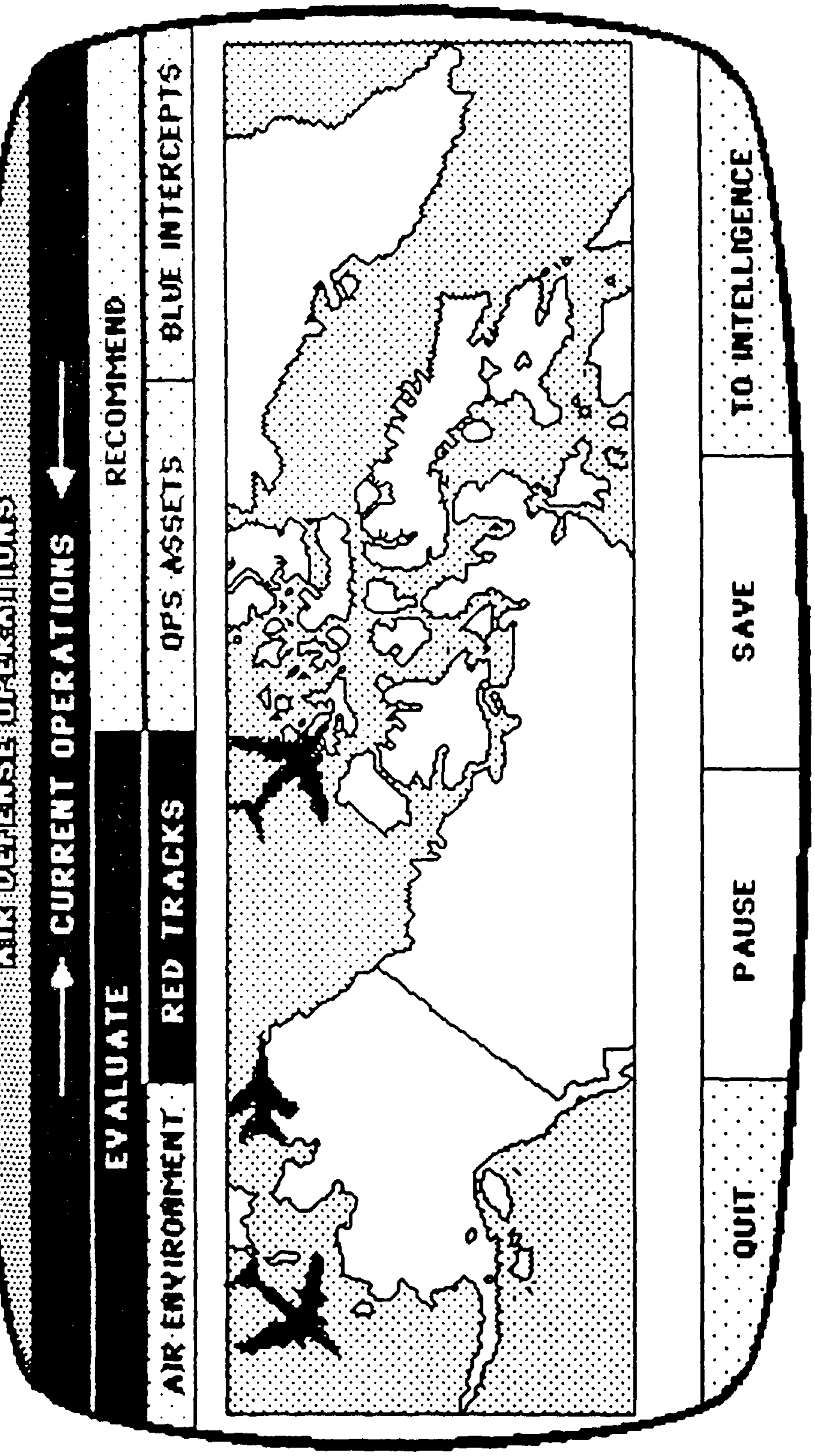


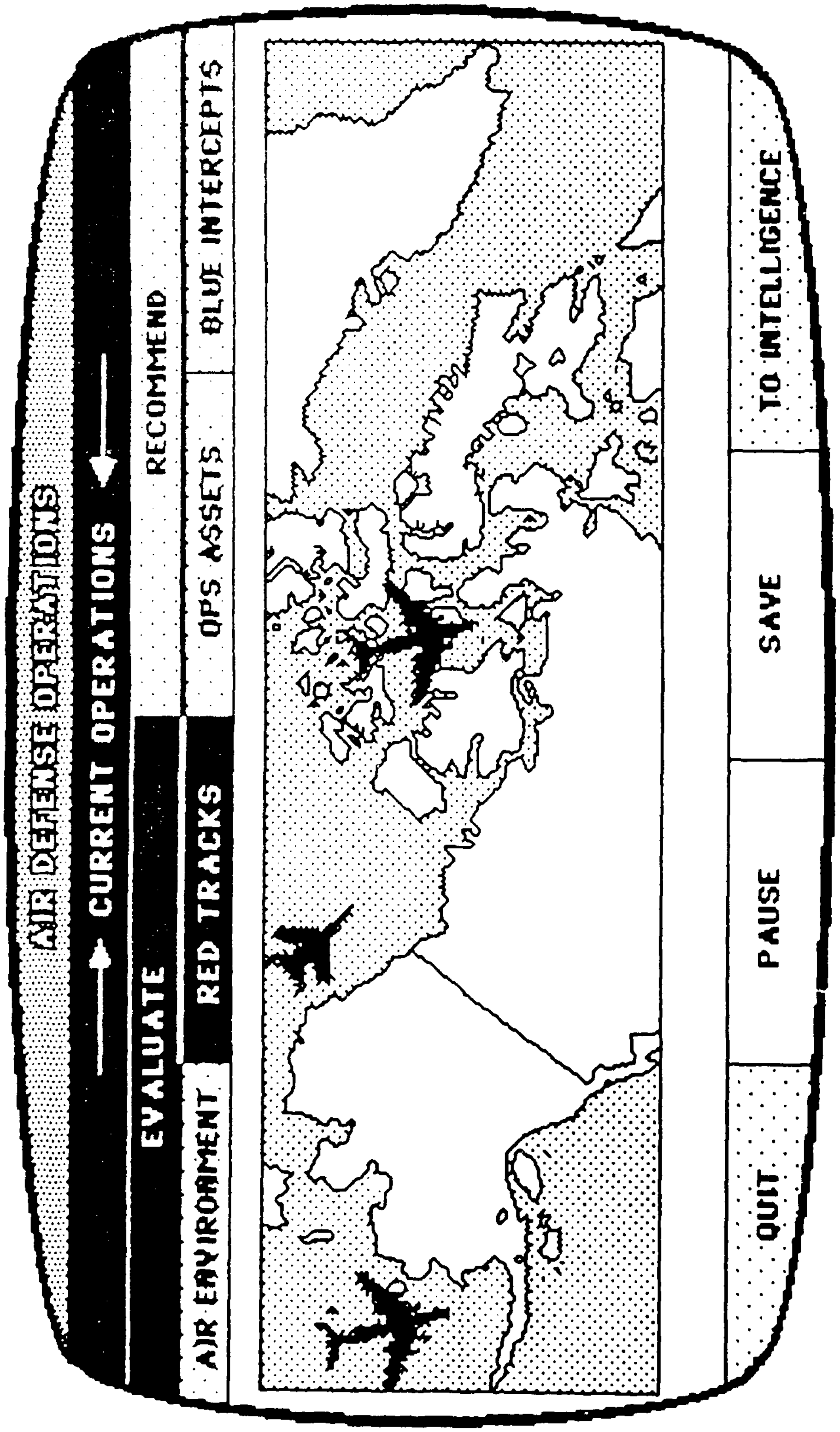
This display presents the current situation at the "Top ROCC," NORAD's Region Operations Control Center at Elmendorf AFB near Anchorage, Alaska. Surveillance has detected several aircraft in the zones of coverage that surround North America. The target ID is designated as "pending," consistent with ROCC operations. The user clicks on **Evaluate Air Environment** to get more information about the situation.

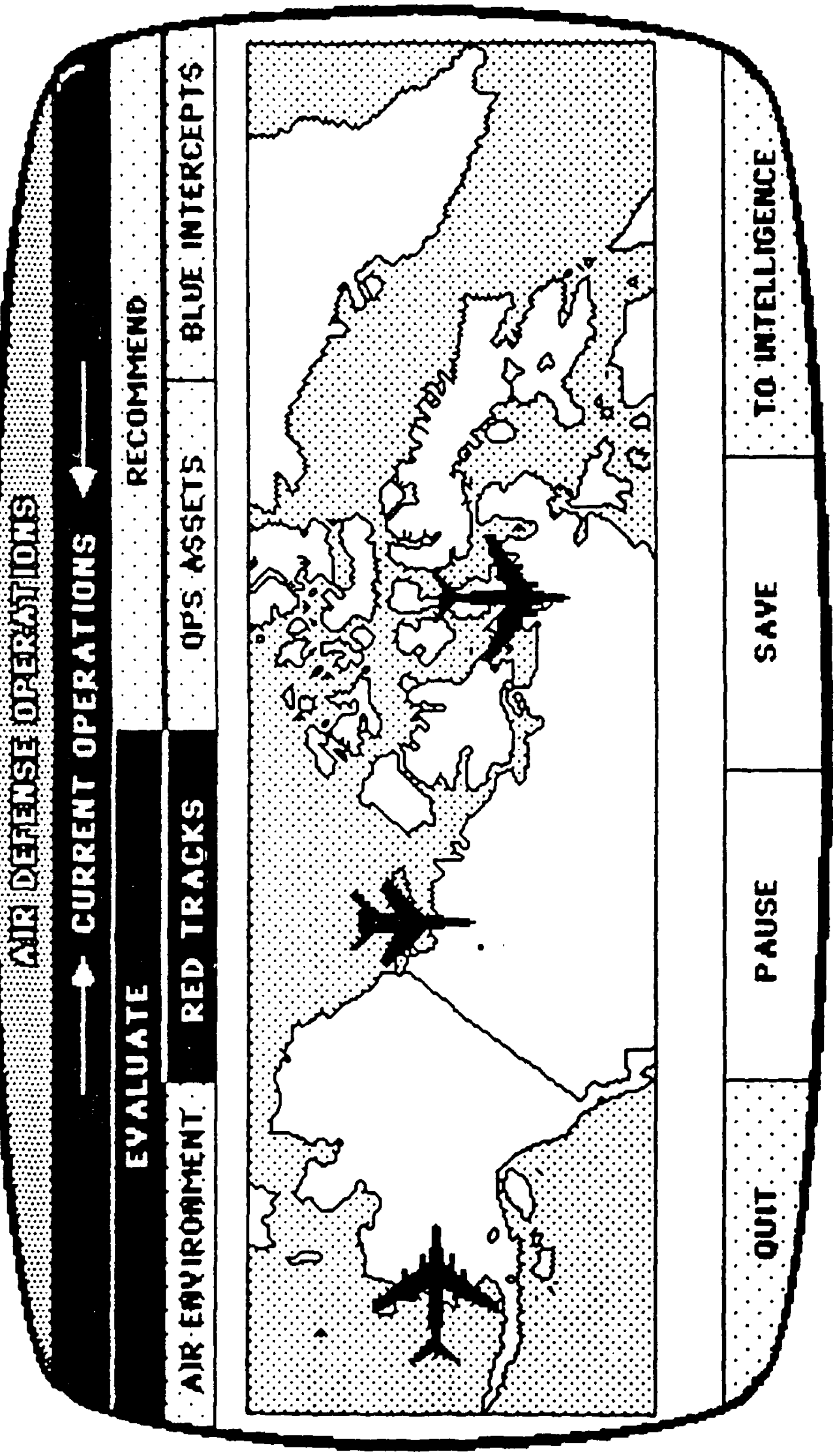


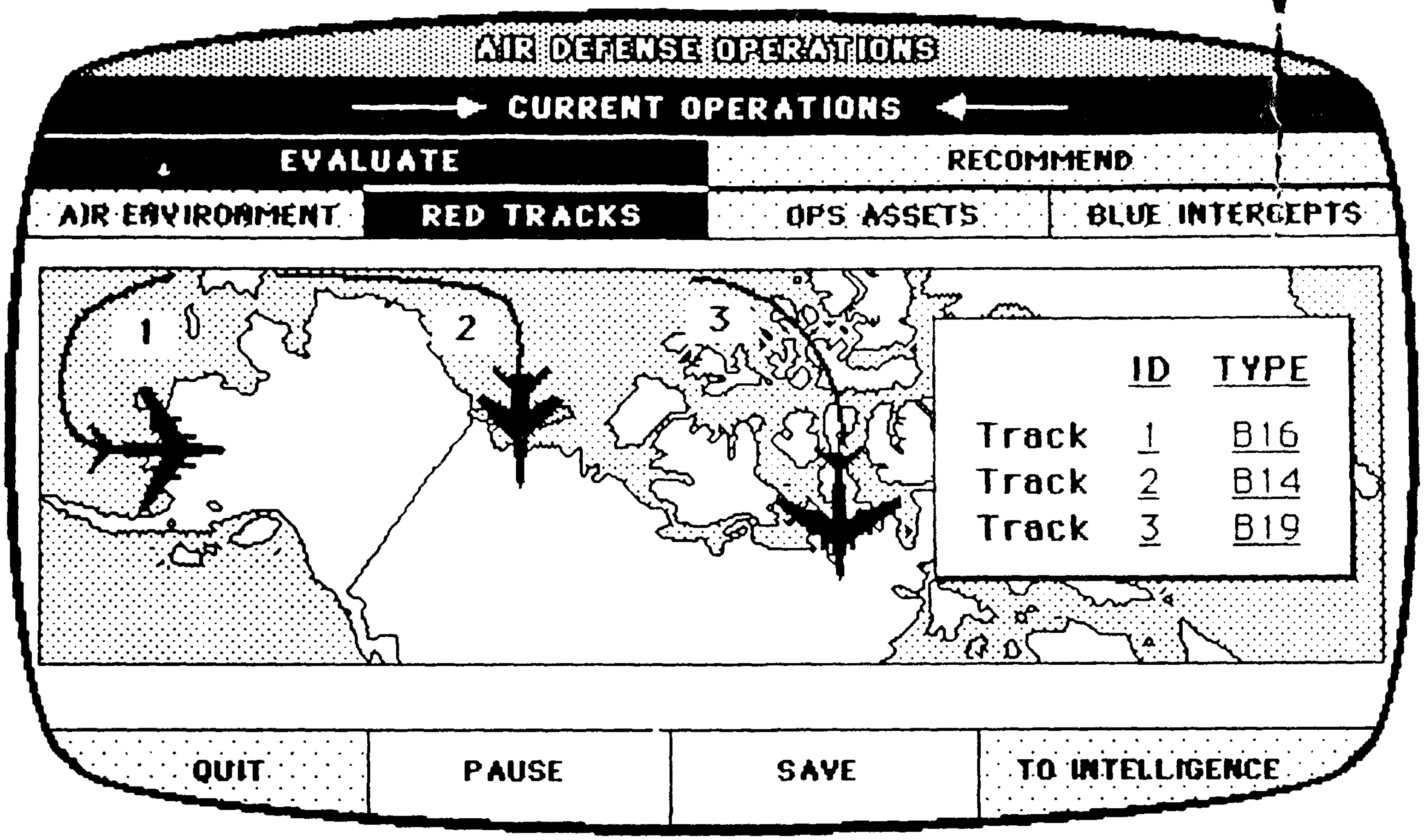
Normal procedure calls for aircraft identification via checks against commercial flights and other civilian aircraft expected to be in the area. The system determines that it is not likely that it is commerical or civilian, and that no IFF transmission has been received. It concludes that the aircraft is unknown. The user then clicks on **Red Tracks**.


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
Target Flight Plan Correlation
Civilian Commercial: 0
Other Air Traffic: 0
Friend/Foe Transmission
Friend Code: 0
Foe Code: 0
UNKNOWN AIRCRAFT
QUIT
PAUSE
SAVE
TO INTELLIGENCE

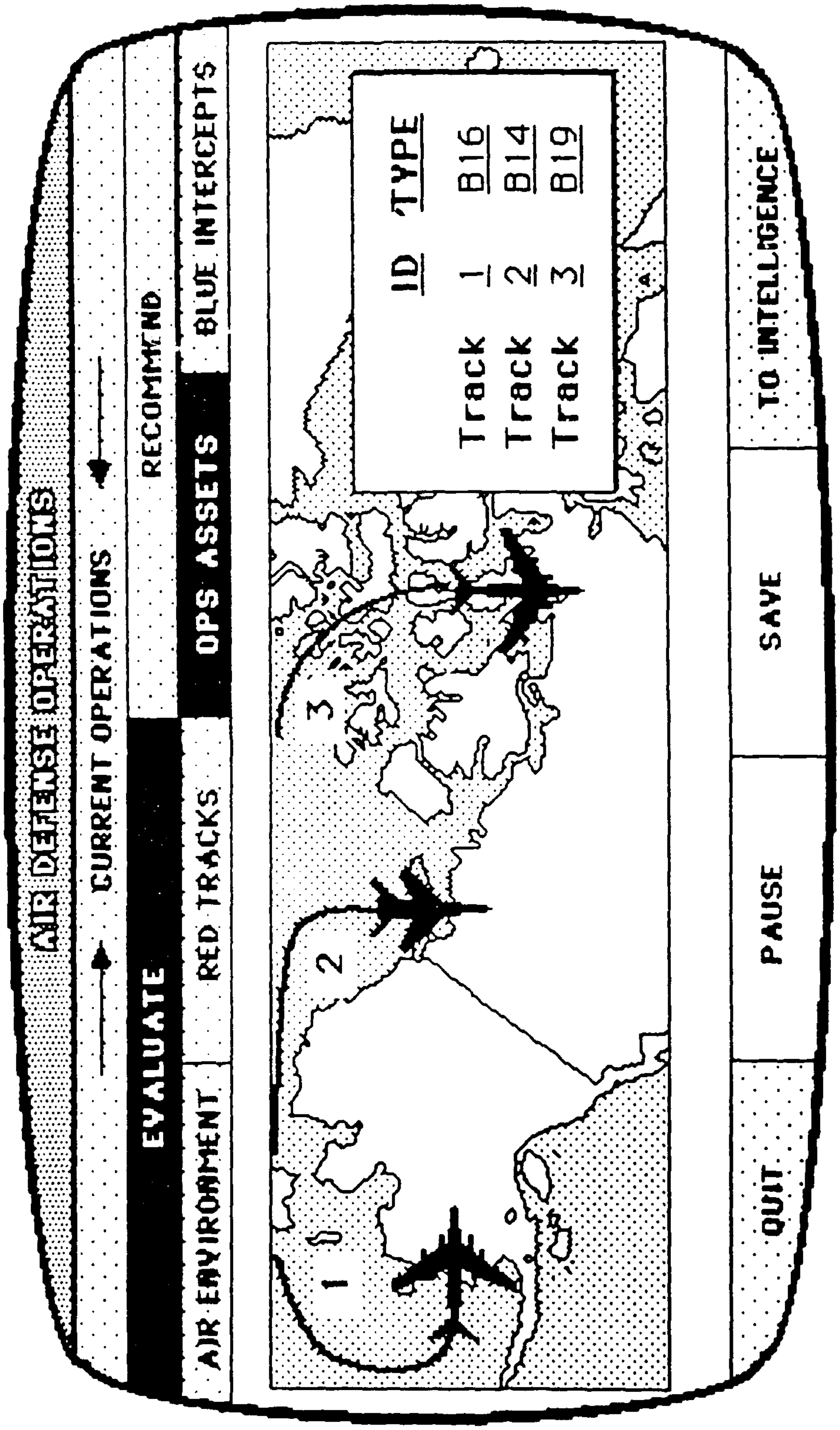

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE

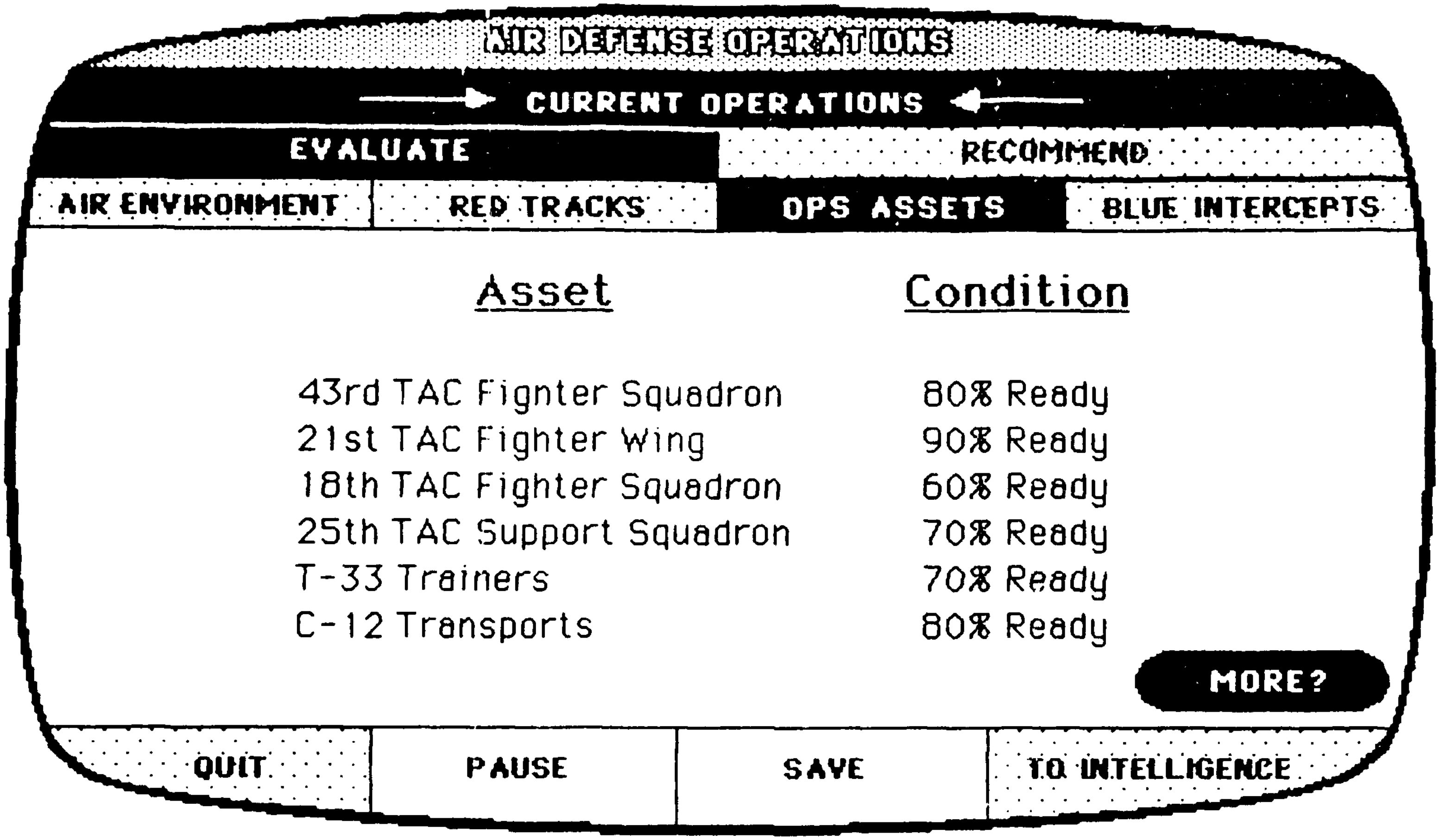

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE

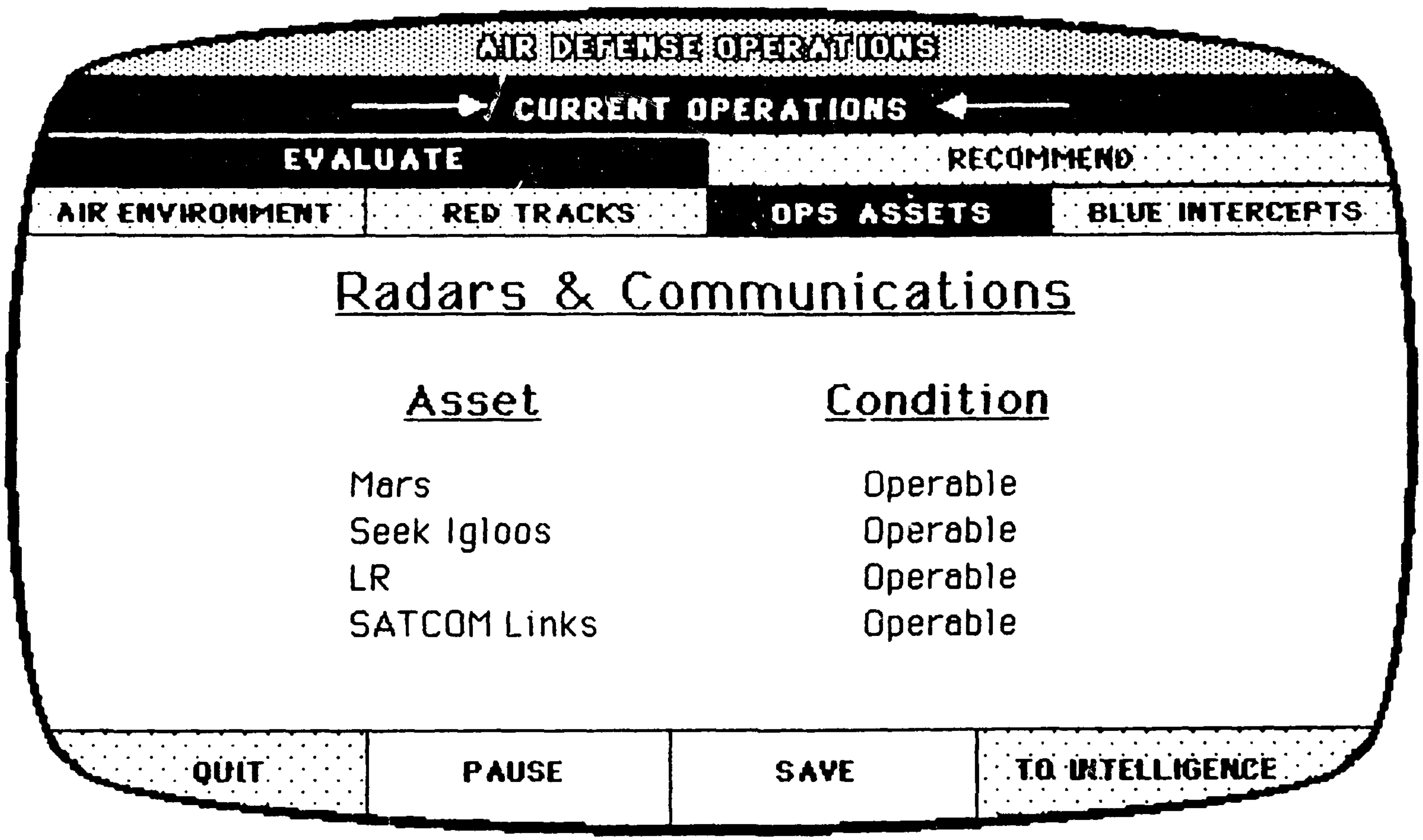


The system calculates likely flight paths for the unknown aircraft based on models of previous Red behavior and known capabilities of the (small) range of possible aircraft. The system animates the tracks and then labels them. The user then clicks on **Assets**, since it is likely that a scramble will occur.

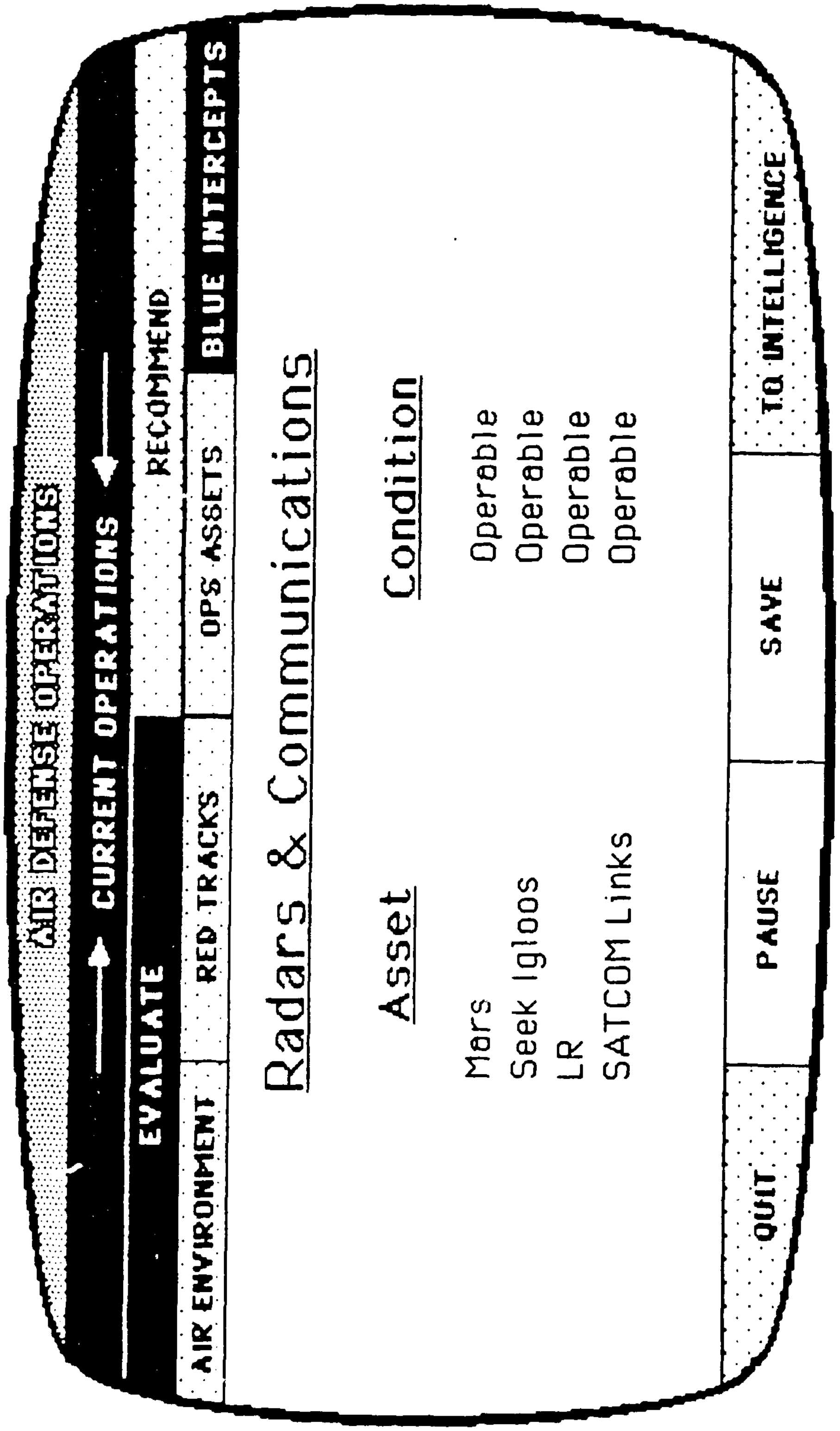

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
ID TYPE
Track 1 B16
Track 2 B14
Track 3 B19
1
2
3
QUIT
PAUSE
SAVE
TO INTELLIGENCE

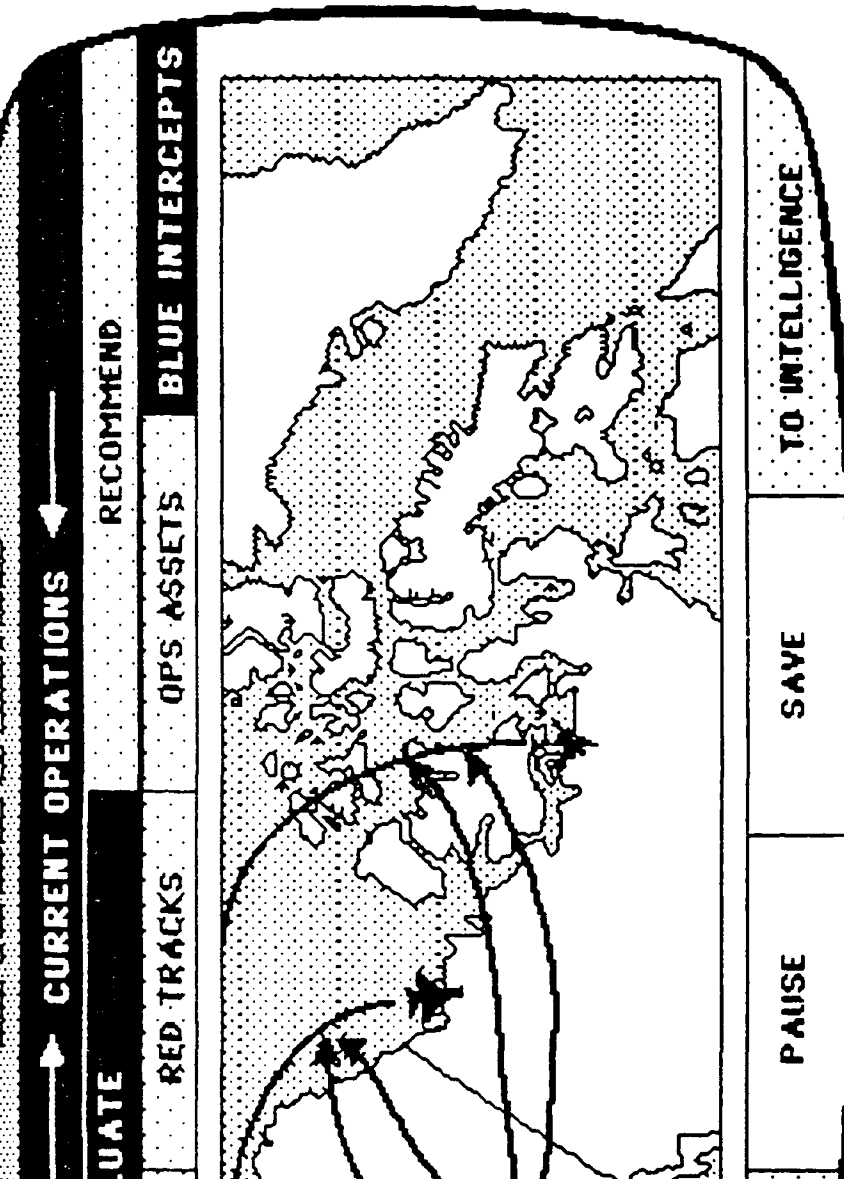


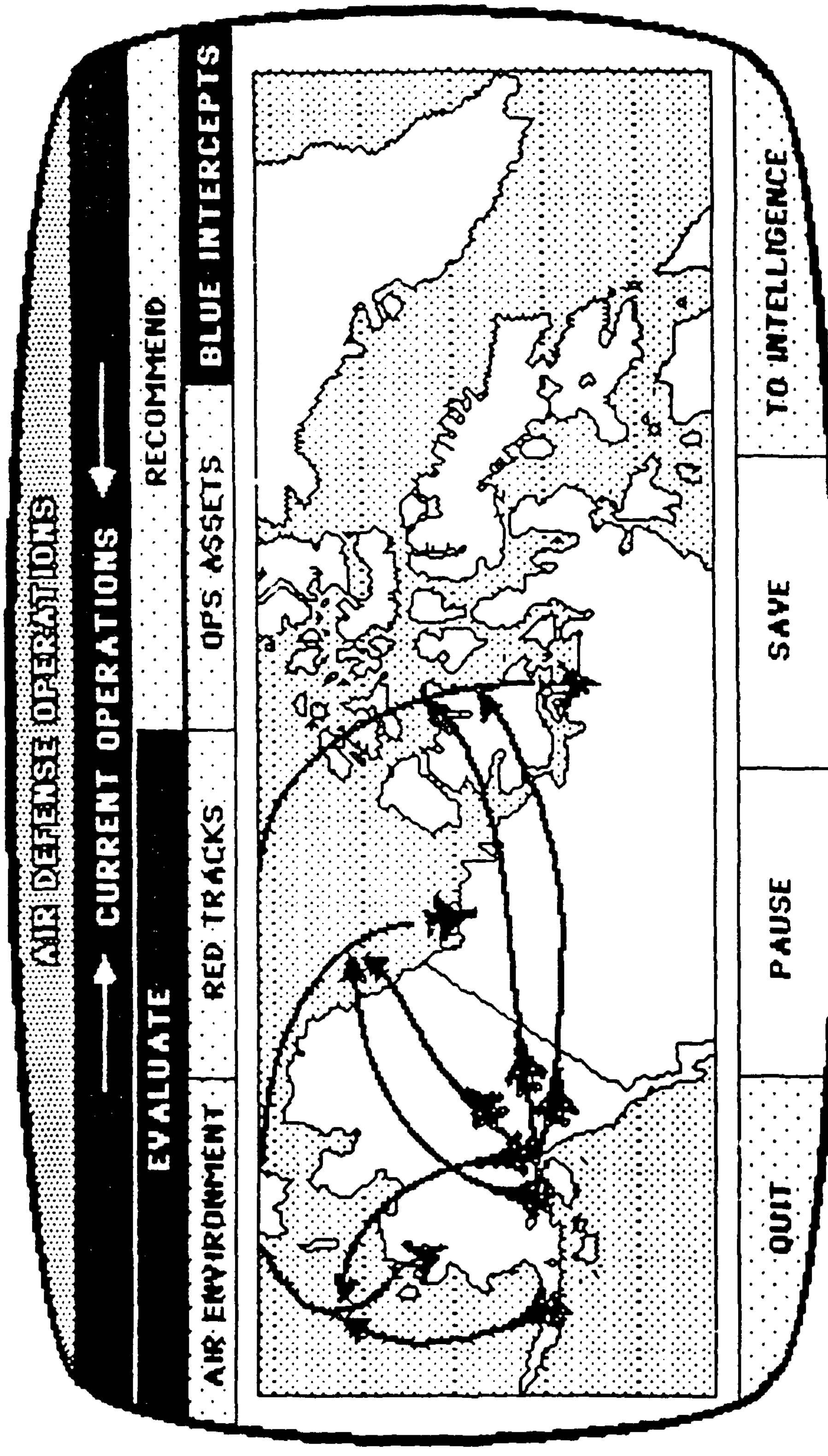
The system recalls the assets available to the Alaskan Air Command (AAC) and the Top ROCC. It also assesses the readiness levels of the assets. In an actual system application of the concept, the user would have the capability of searching through assets for a specific set (like F-15s and NORAD transferred AWACS). The user requests additional information about his assets.

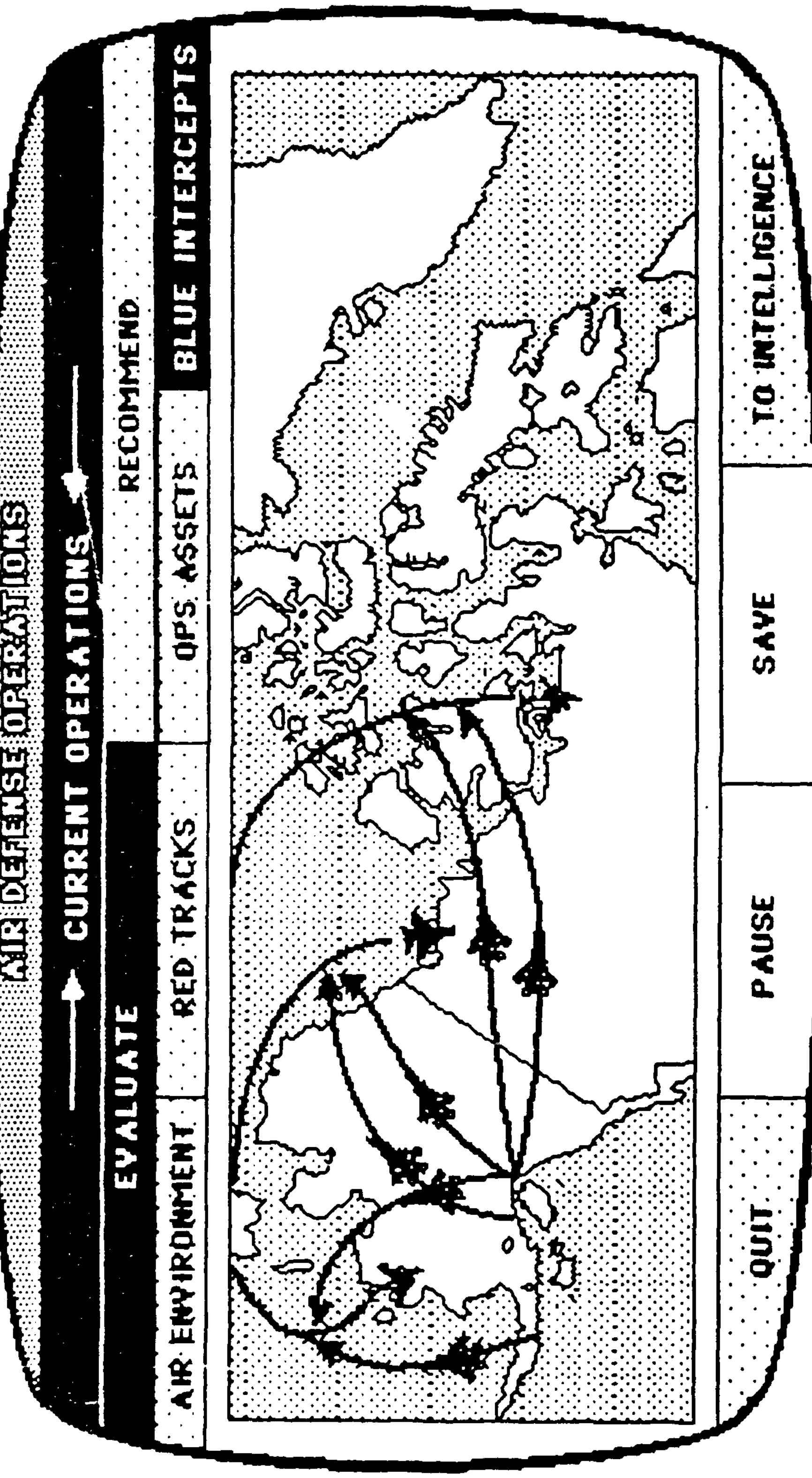


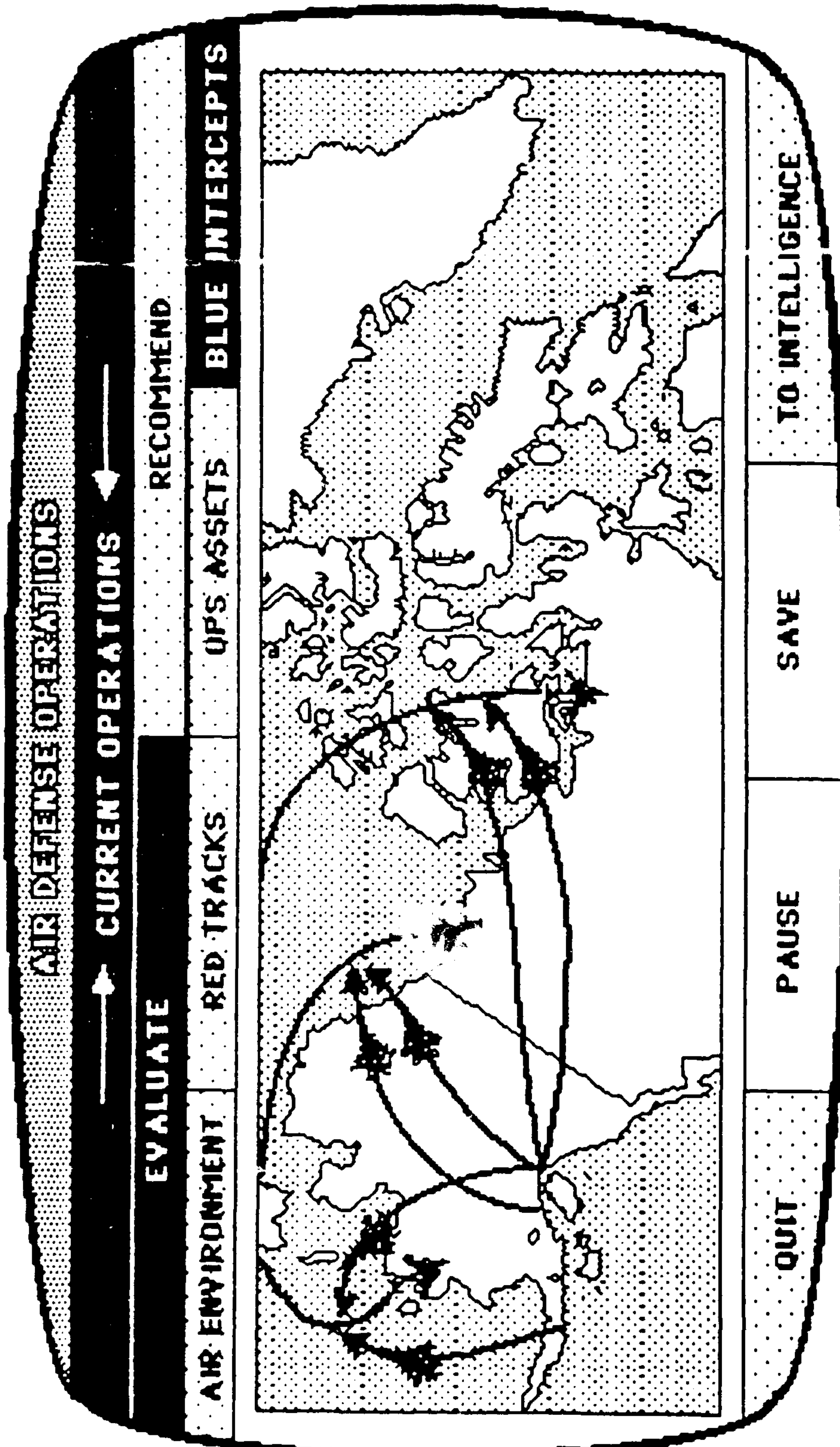
This display suggests that all radars and communications systems are operable; the user then clicks on **Blue Intercepts**.

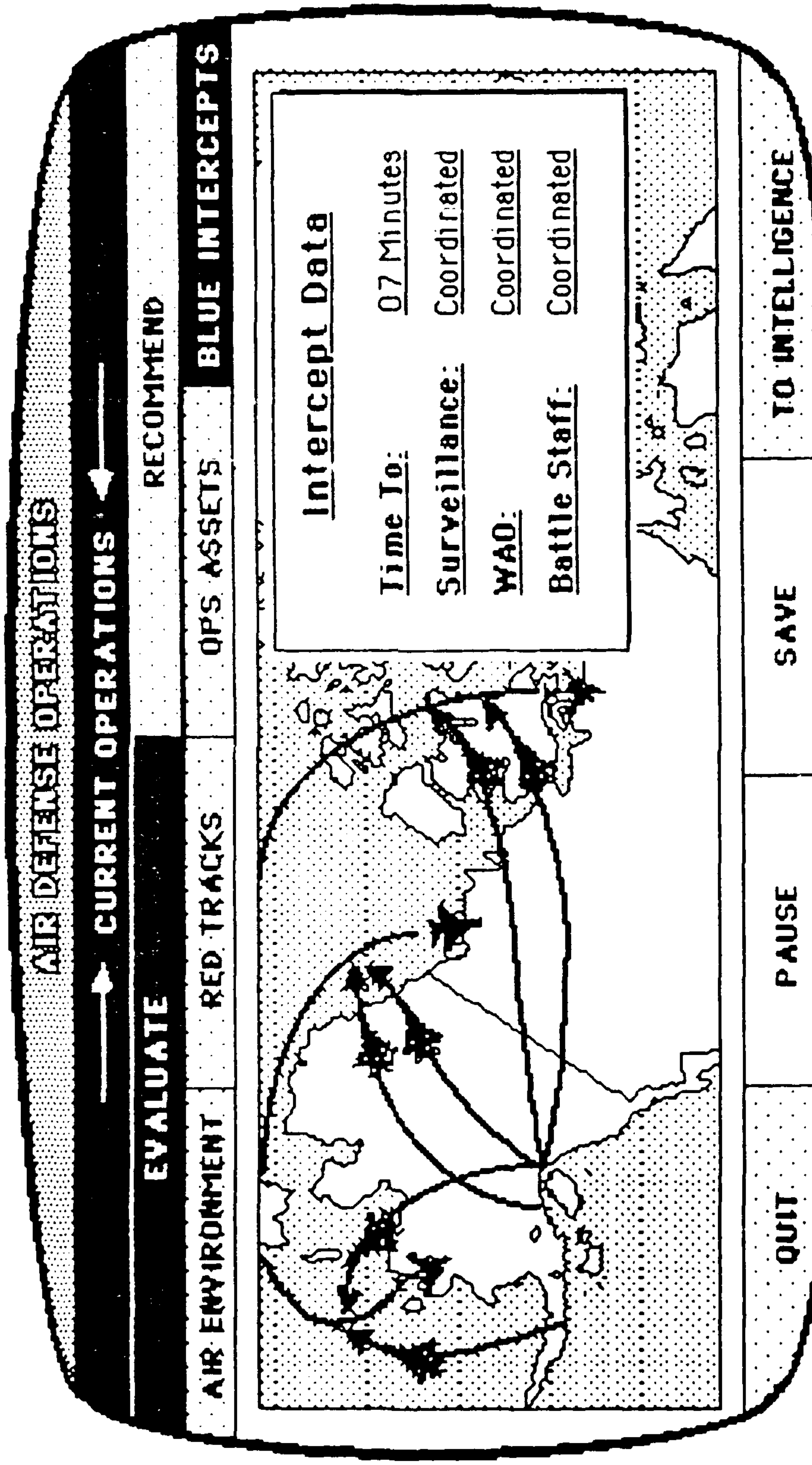

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
Radars & Communications
Asset
Condition
Mars
Operable
Seek Igloos
Operable
LR
Operable
SATCOM Links
Operable
QUIT
PAUSE
SAVE
TO INTELLIGENCE

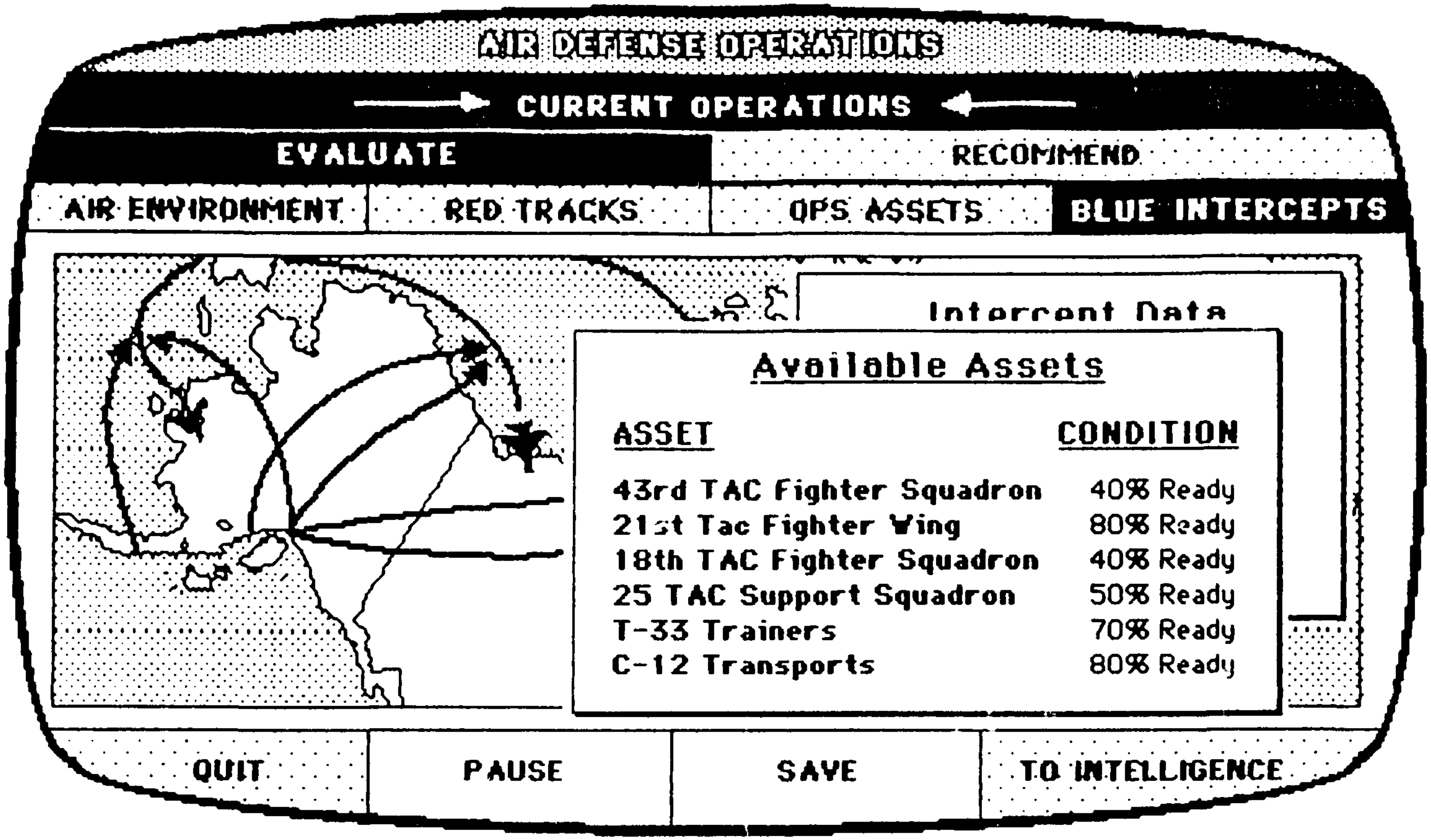

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE

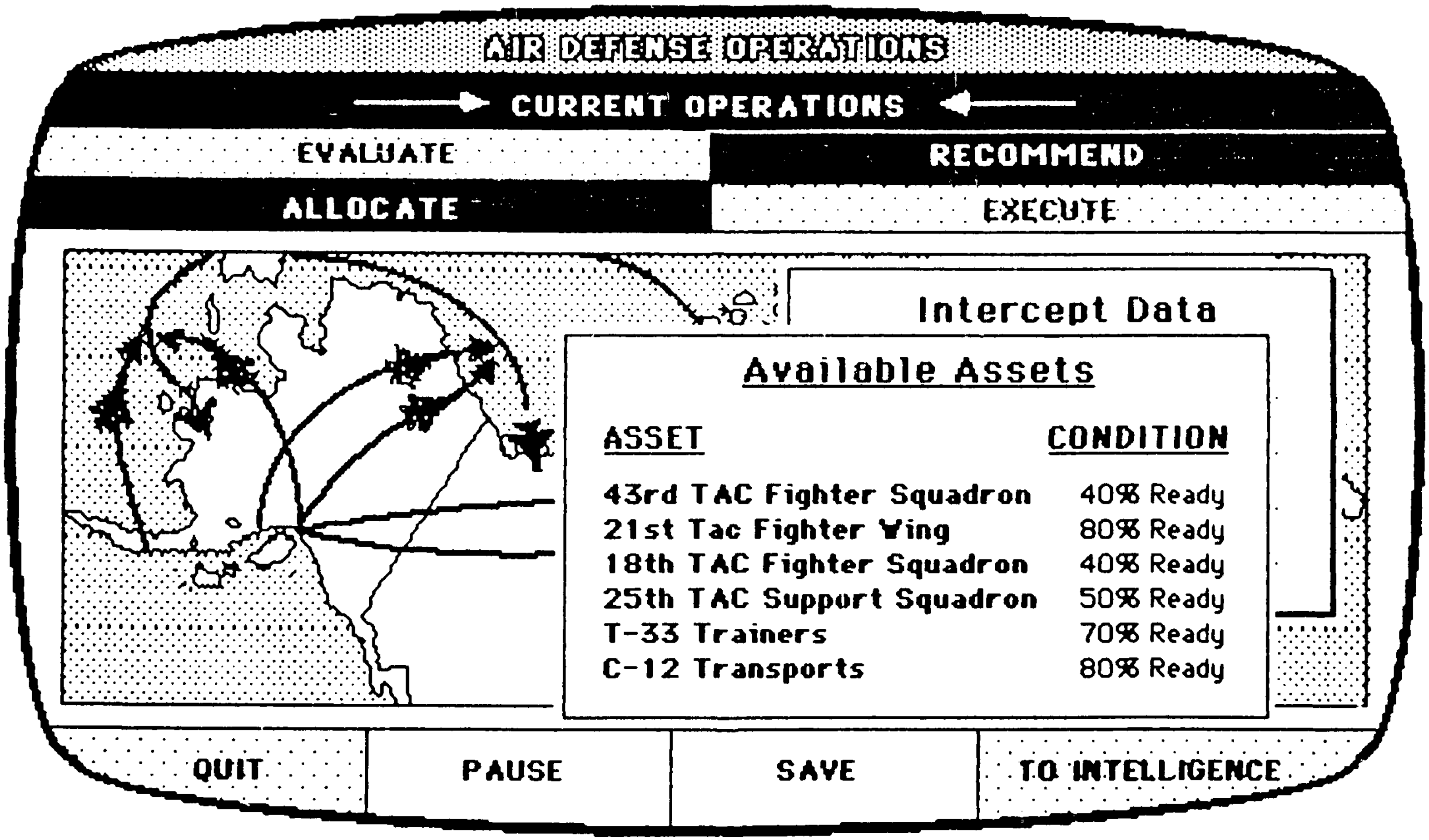

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE

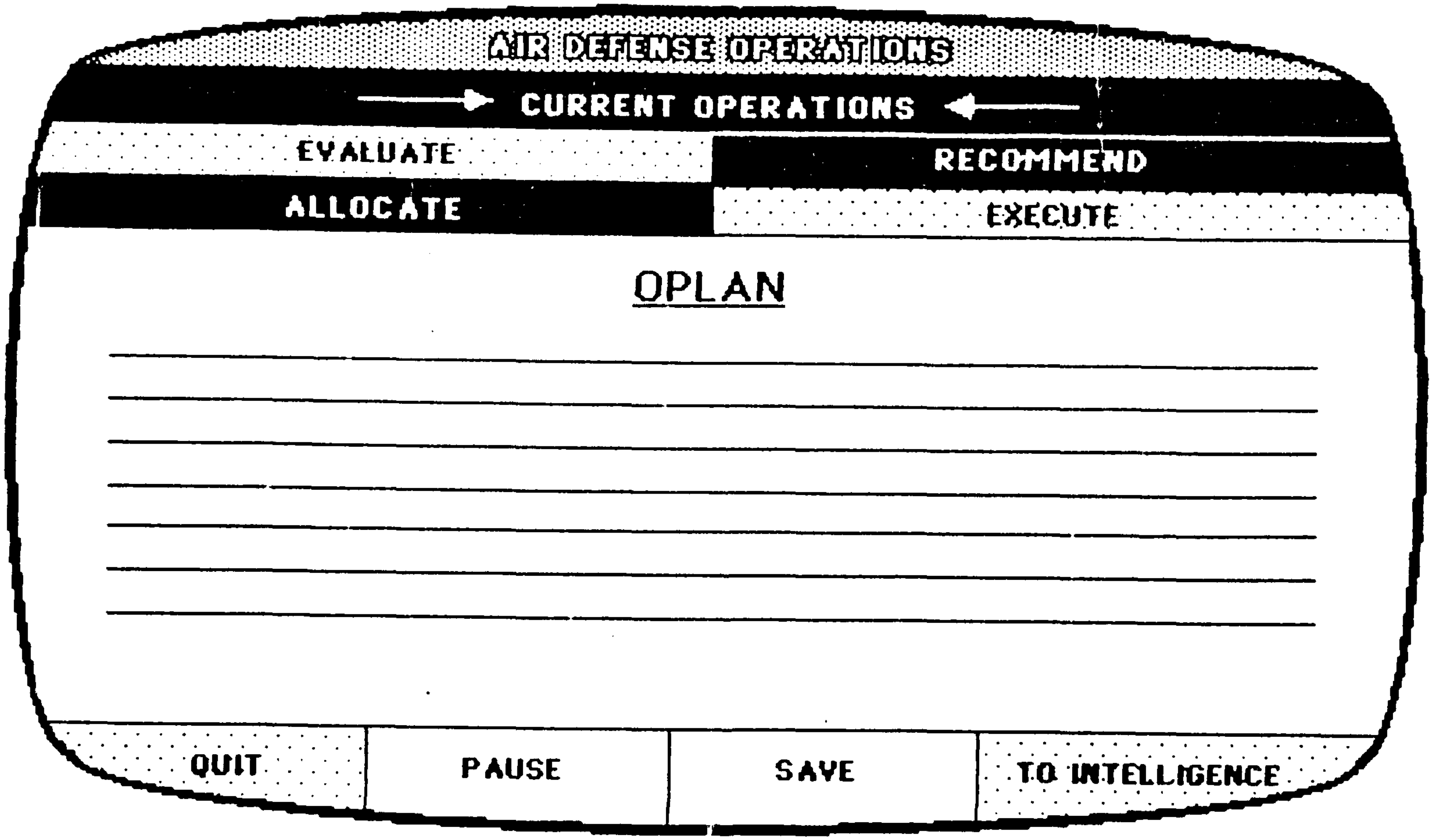

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
QUIT
PAUSE
SAVE
TO INTELLIGENCE

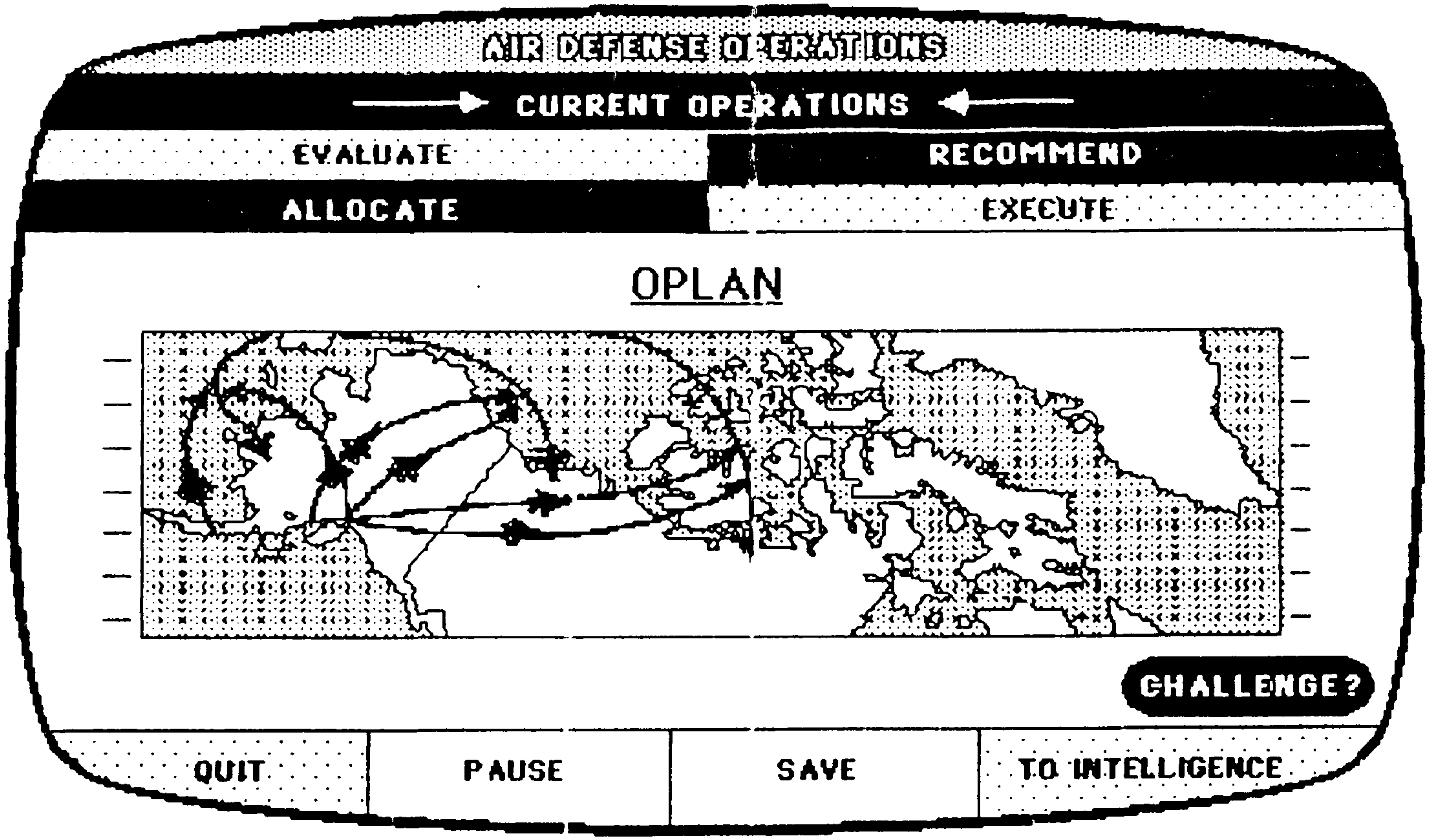

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
AIR ENVIRONMENT
RED TRACKS
OPS ASSETS
BLUE INTERCEPTS
Intercept Data
Time To:
07 Minutes
Surveillance:
Coordinated
WAO:
Coordinated
Battle Staff:
Coordinated
QUIT
PAUSE
SAVE
TO INTELLIGENCE



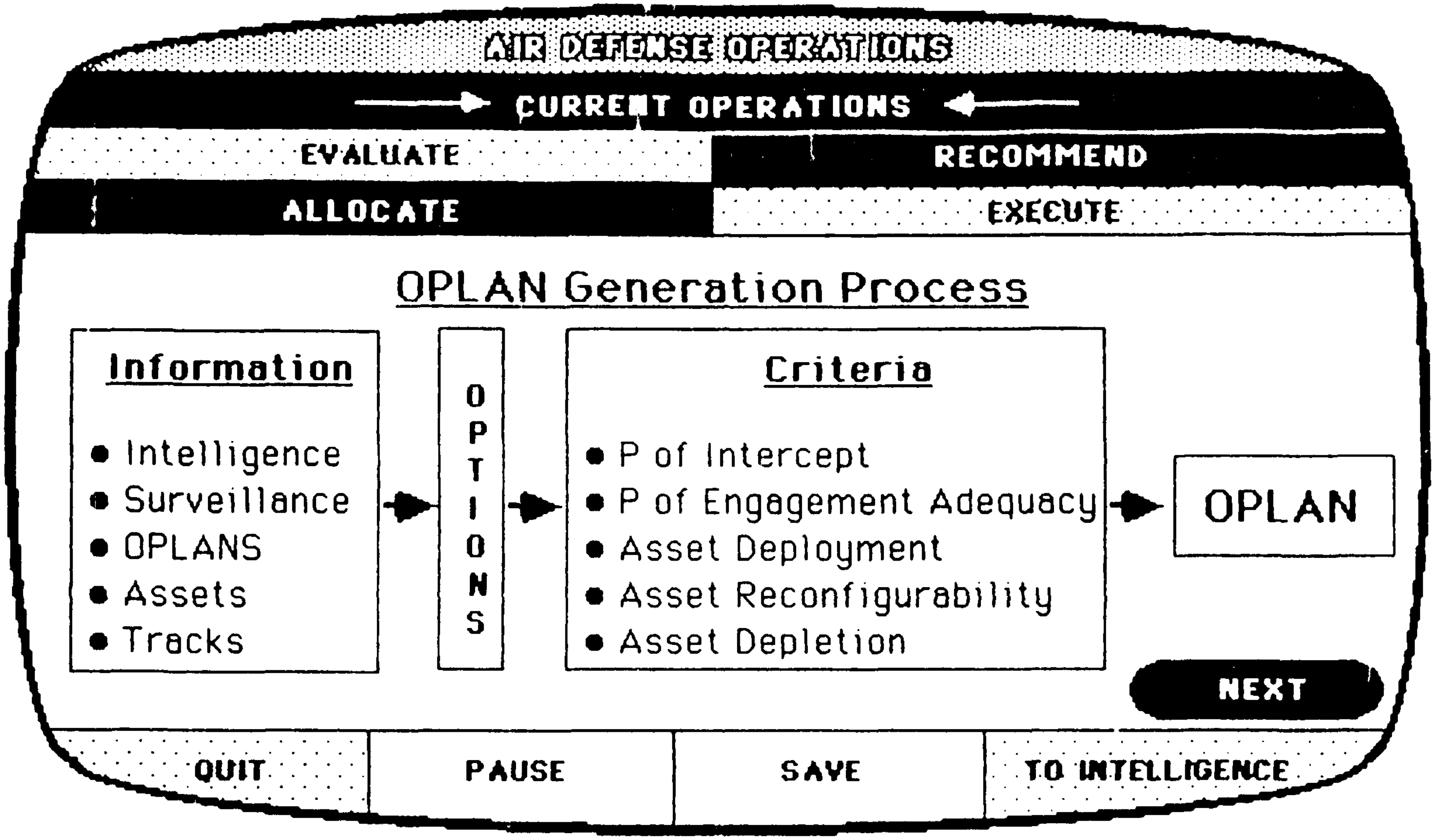
The system calculates possible Blue intercept tracks to determine which aircraft mix is necessary to intercept the unknown aircraft as soon as possible with no loss to the operation. It uses animation to communicate the movement of assets over time and space. It calculates the time it will take for intercept and assesses the coordination of surveillance, the Weapons Assignment Officer (WAO), and the ROCC Battle Staff. Finally, it calculates the impact of the operation on the readiness of available assets. Windows are used to display these real-time calculations. The user then shifts from gathering information to option generation and **evaluation**. He clicks on **Recommend/Allocate**.


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Intercept Data
Available Assets
ASSET
CONDITION
43rd TAC Fighter Squadron 40% Ready
21st Tac Fighter Wing 80% Ready
18th TAC Fighter Squadron 40% Ready
25th TAC Support Squadron 50% Ready
T-33 Trainers 70% Ready
C-12 Transports 80% Ready
QUIT
PAUSE
SAVE
TO INTELLIGENCE

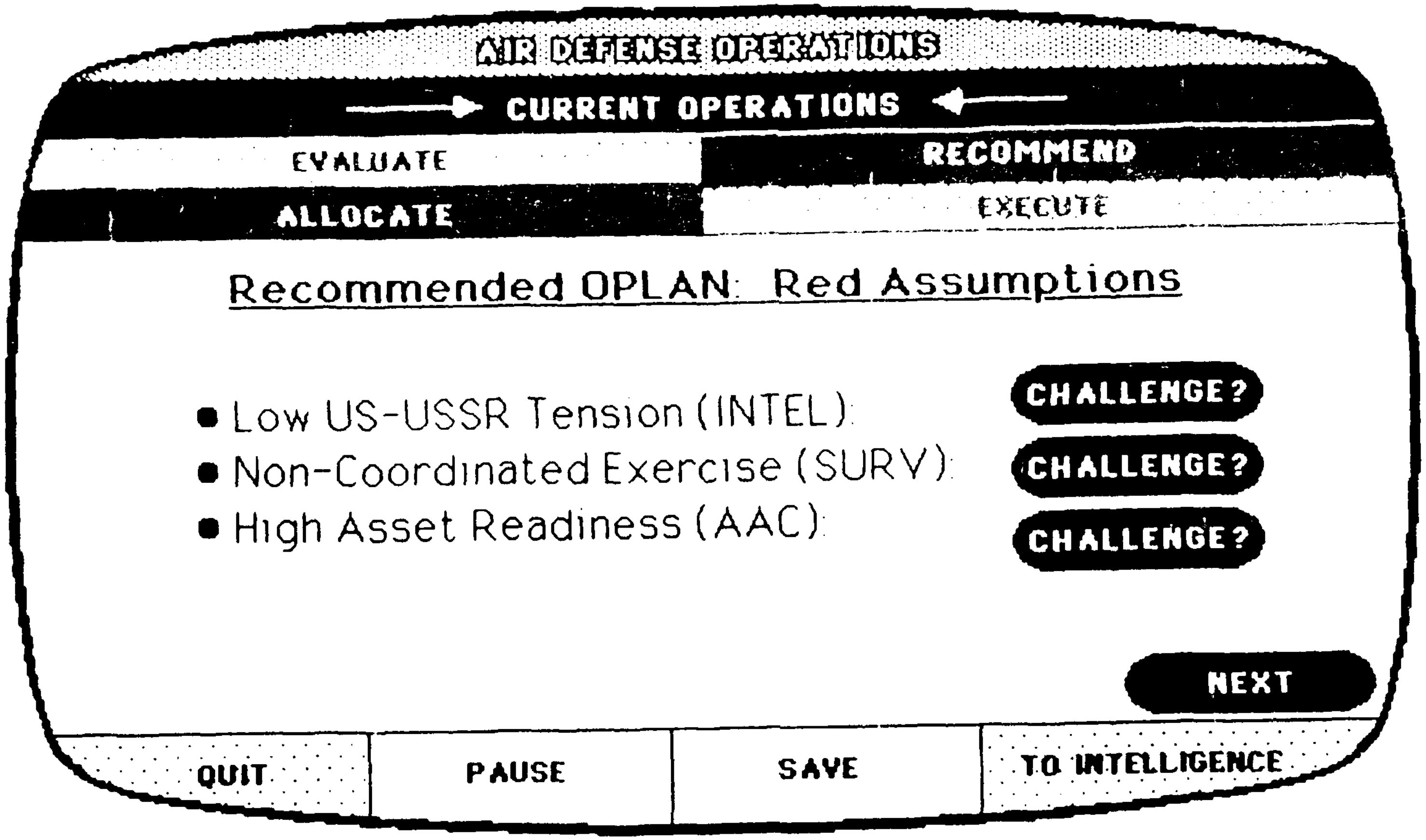

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN
QUIT
PAUSE
SAVE
TO INTELLIGENCE



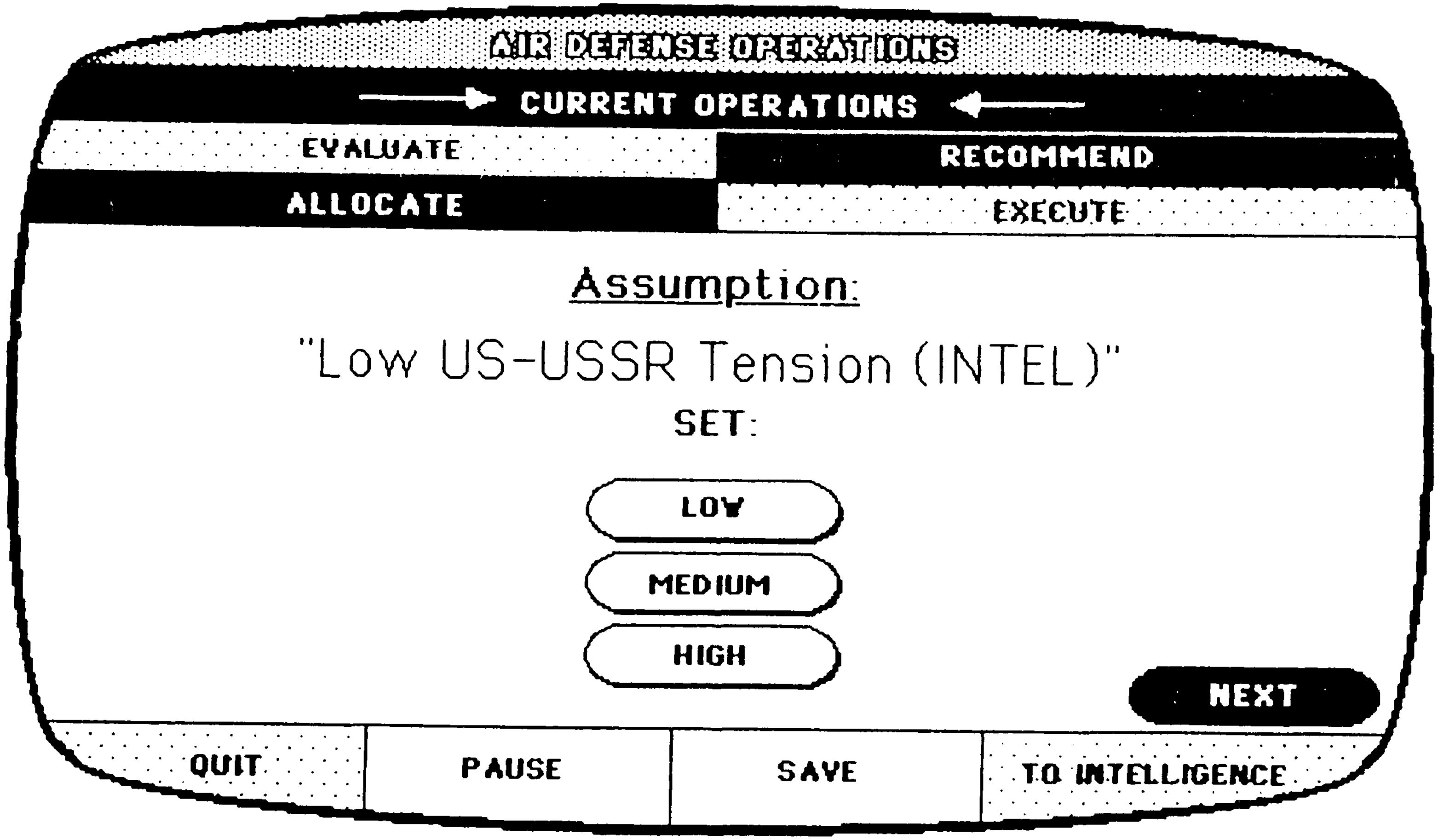
The system then generates a strawman scramble OPLAN. It presents the plan in narrative form and then immediately in graphic form. The intention here is to deliberately change the perspective of the user; that is, to permit him to see the same plan in at least two different "forms." The system also permits the user to **Challenge?** the plan, which he does. The **Challenge?** capability is designed to evoke alternative hypotheses from the user, and to encourage the user to critique the system-generated OPLAN.



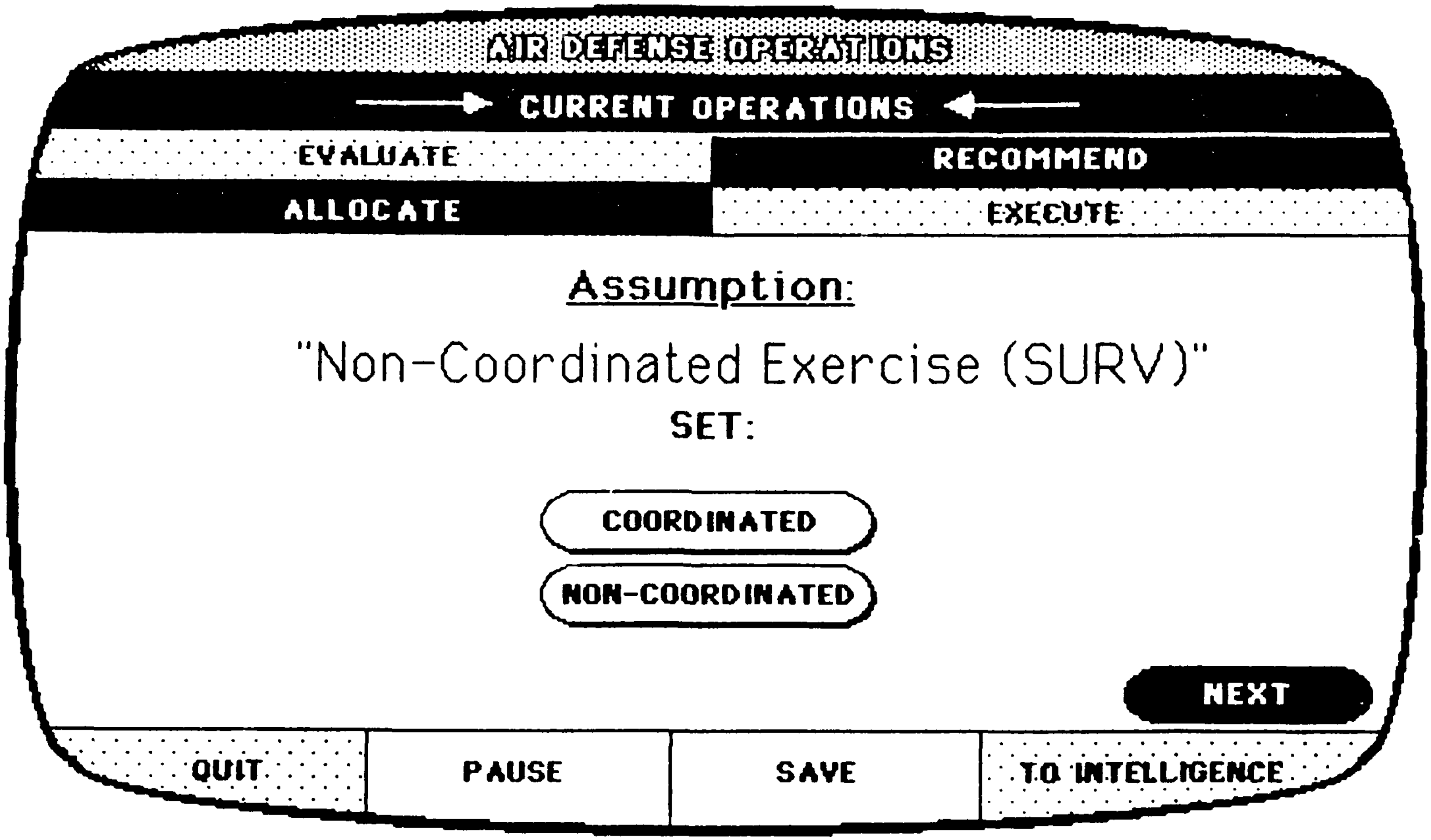
After the user challenges the system, the system presents its "internal (decision-making)logic" to the user. Here the system is actually displaying its option generation/selection process to the user. Users are better able to understand system output if they understand the model from which it came. The system suggests that it processes information, then looks to a set of correlated candidate OPLANS, and then scrutinizes them vis-a-vis a set of normative criteria. The user clicks on **Next**.



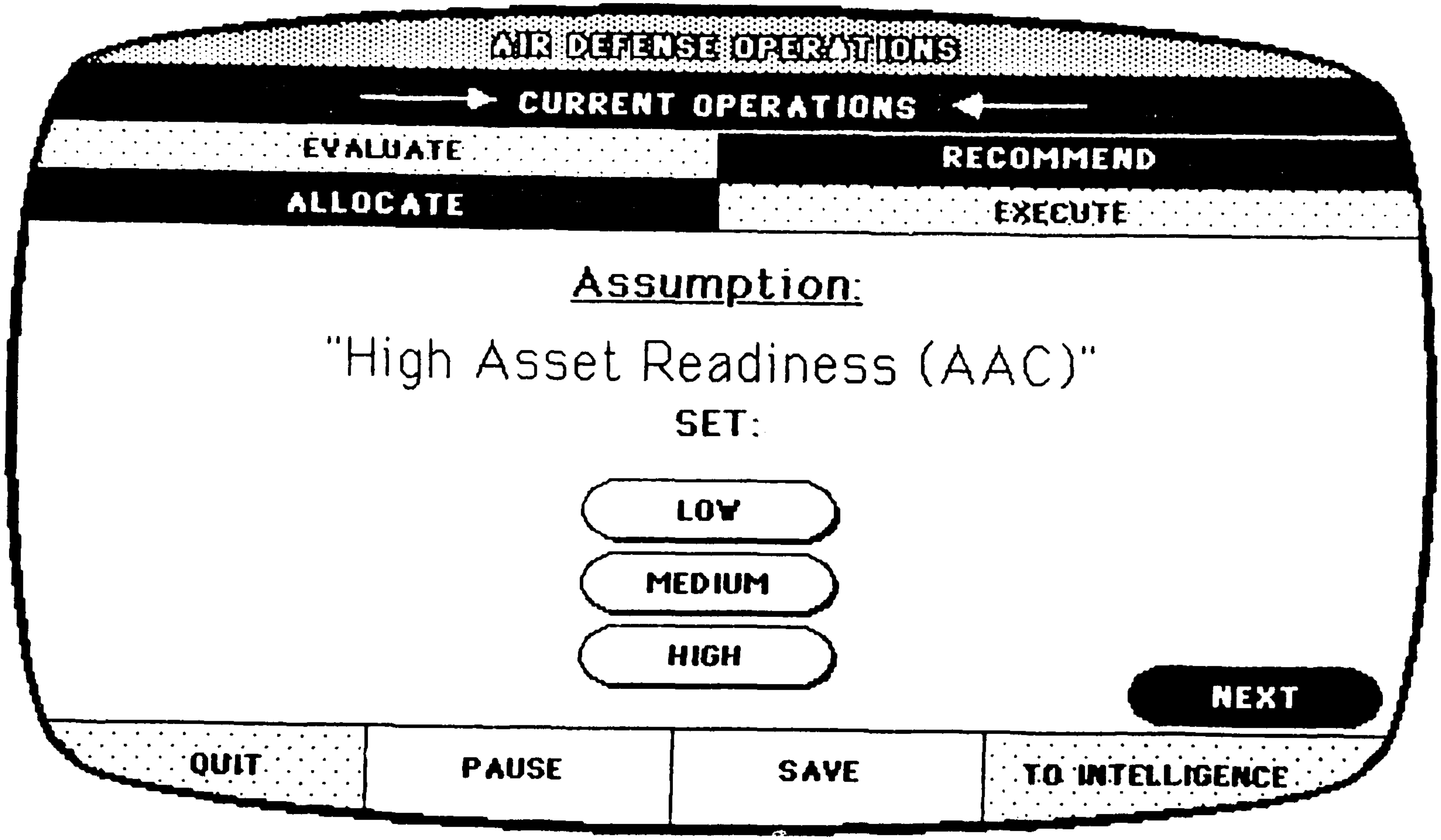
The system then displays the key assumptions it made during the OPLAN calculation. The user can override the system's assumptions by **Challenging** them. In effect, this capability permits users to alter the facts (conditions; stimuli) that trigger the system's knowledge base about optimal OPLANS given certain (pre-specified) sets of conditions. This additional insight into the system's decision-making process provides users with a deep understanding of the option generation/selection process and, therefore, into their own decision-making processes (via their agreement or disagreement with the system). He clicks on **Next**.



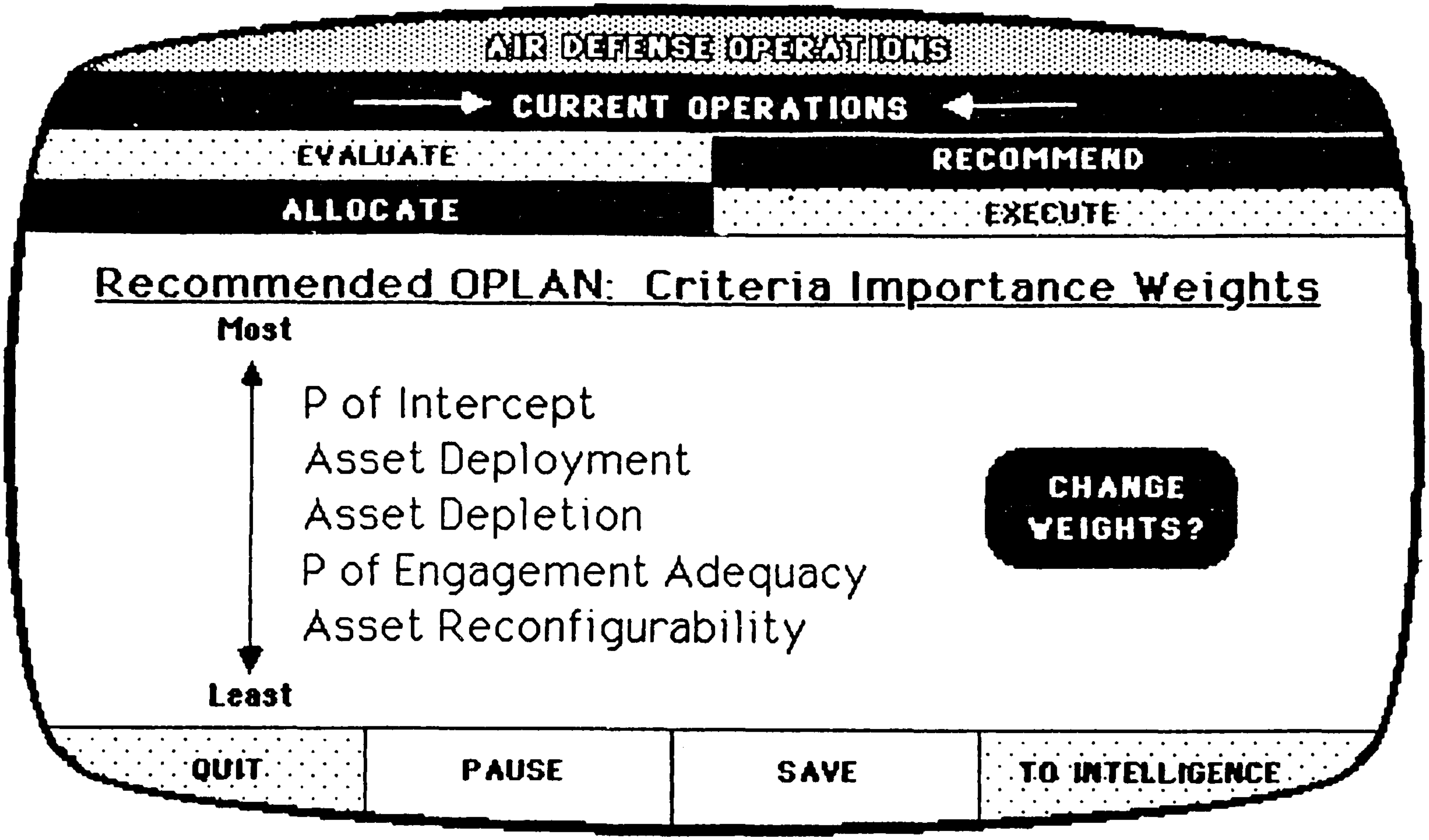
The system permits the user to change the planning assumption. He clicks on **Next**.



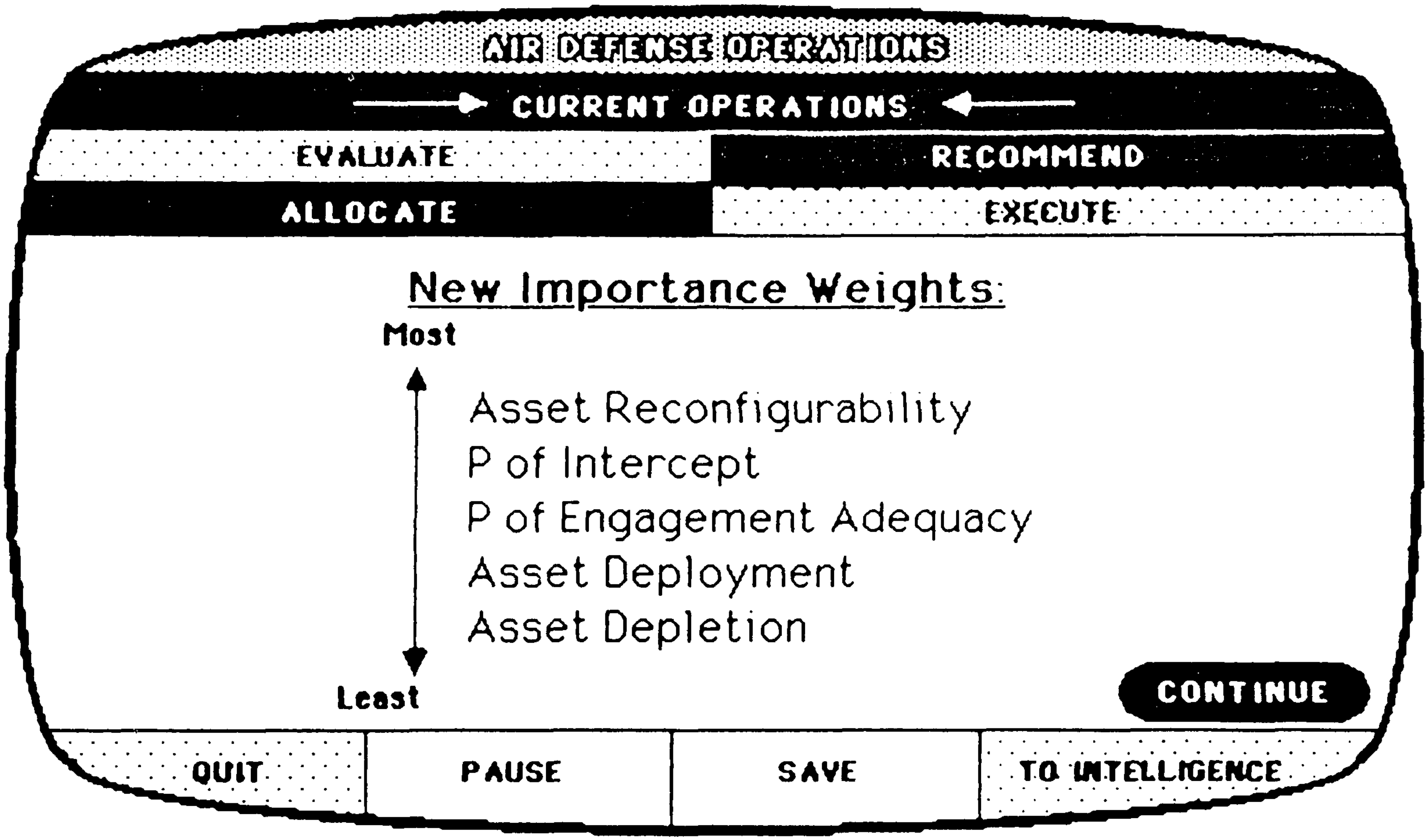
The system permits the user to change the second planning assumption. He clicks on **Next**.



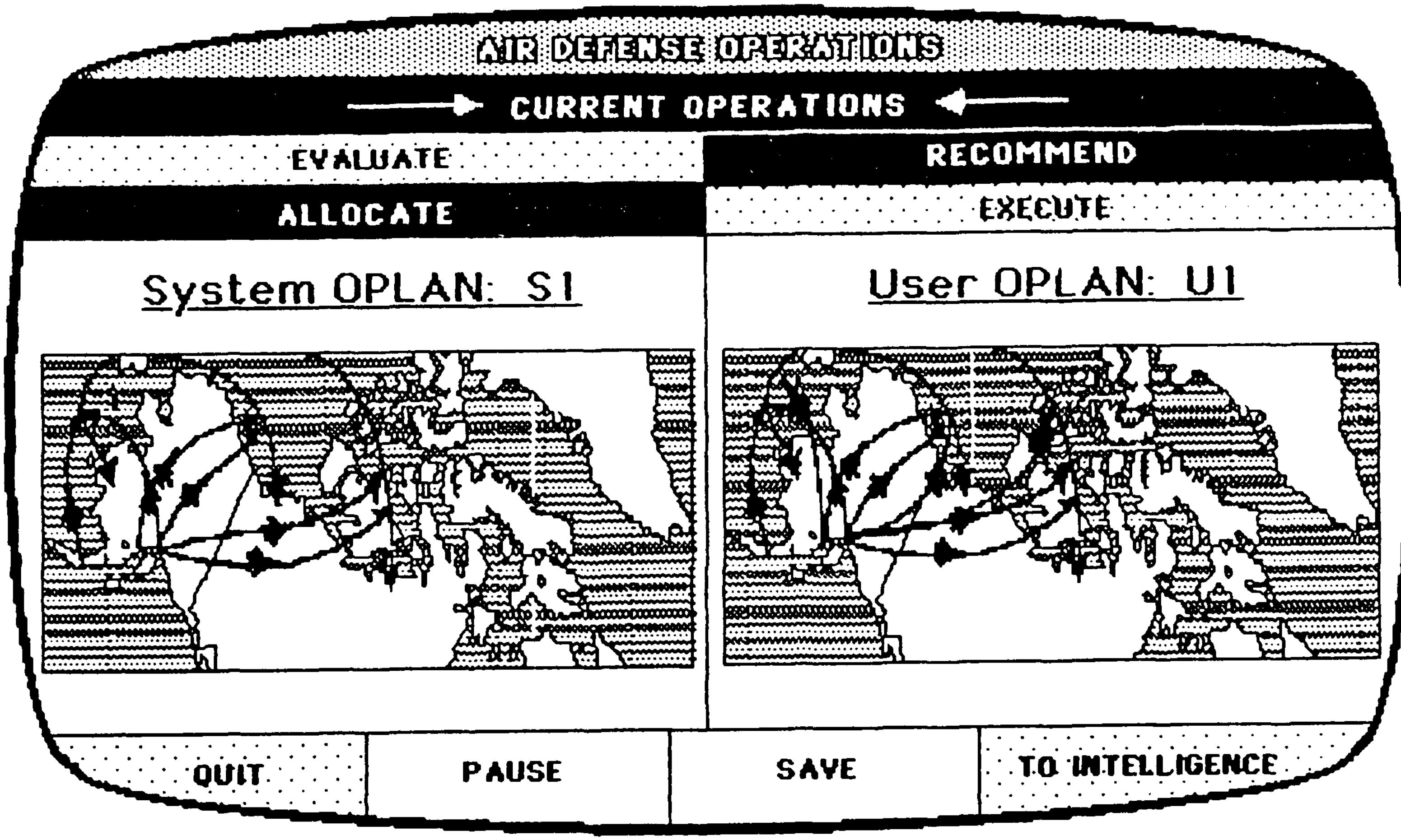
The system invites the user to change the third assumption. He then clicks on **Next**.



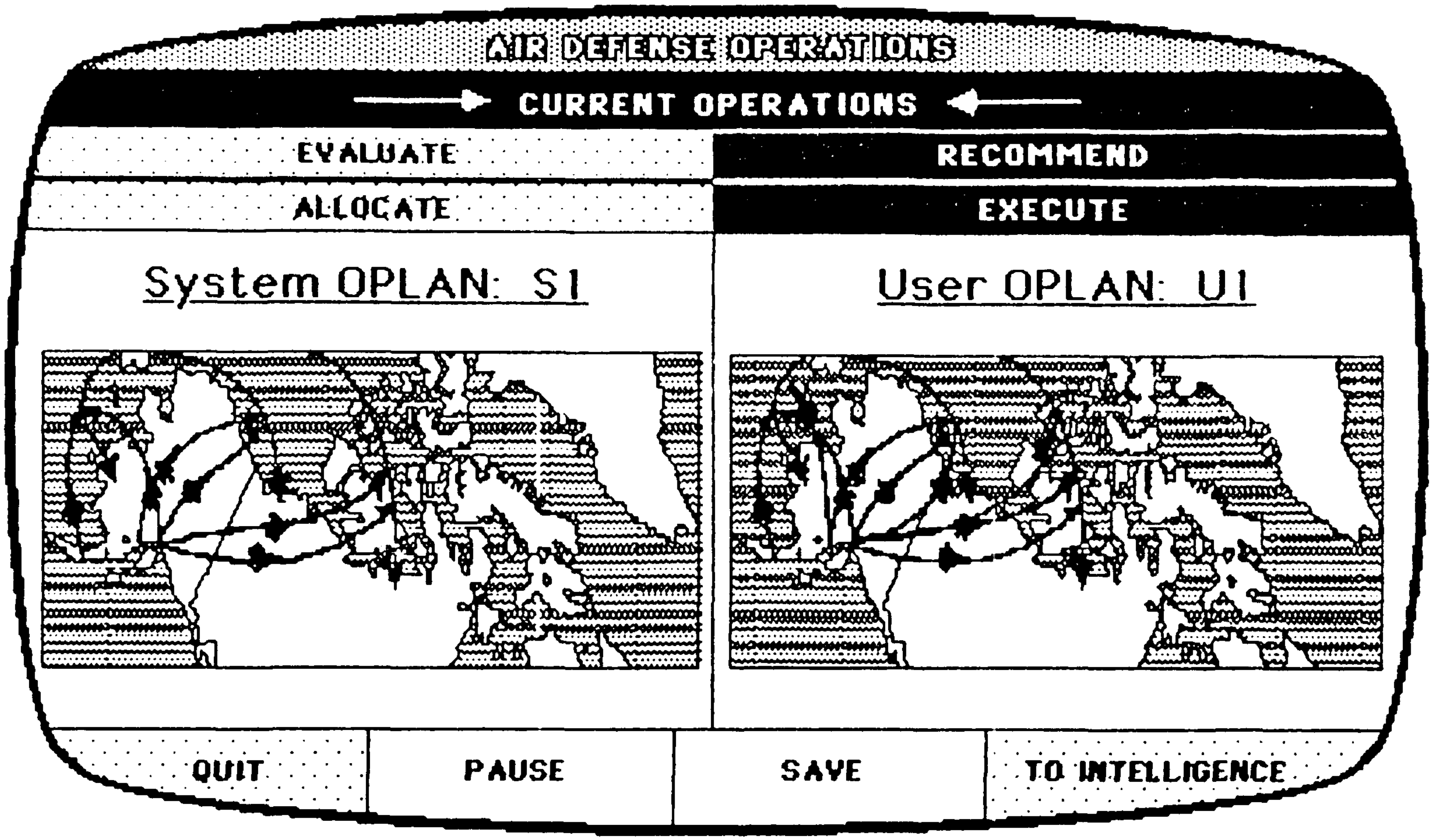
The system then displays the criteria it used to generate the OPLAN, as well as each criterion's importance vis-a-vis the others. The user inspects the weights and decides to change them (by clicking on **Change Weights?**). Here the system is providing insight into how the option evaluation process was structured.

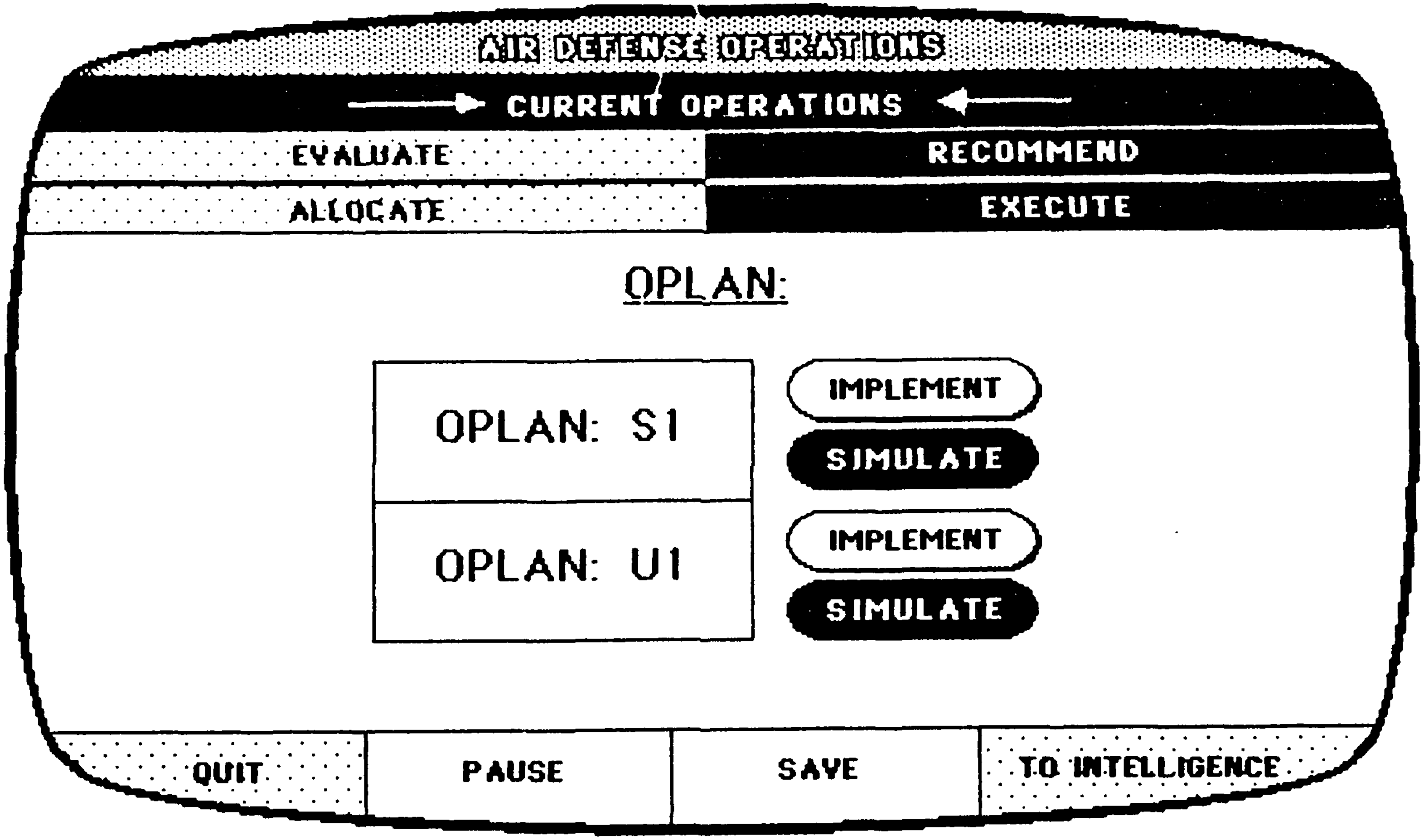


The user re-arranges the weights. By so doing, the user is reacting to the strawman option and suggesting how his own decision-making process is organized. It would then be possible for the system to react to his strawman, and so on, until the iteration yields an "acceptable" outcome. The user clicks on **Continue**.

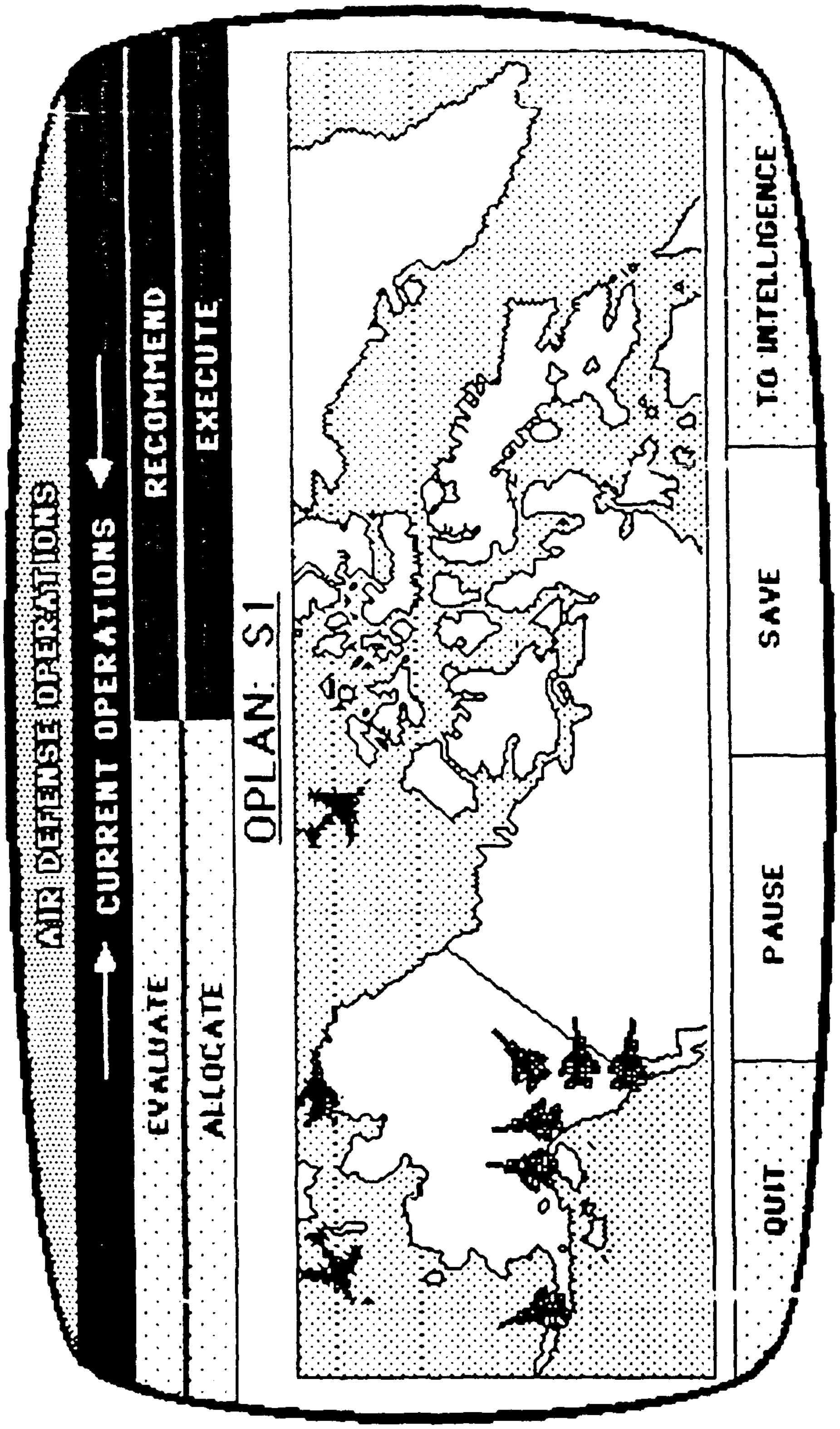


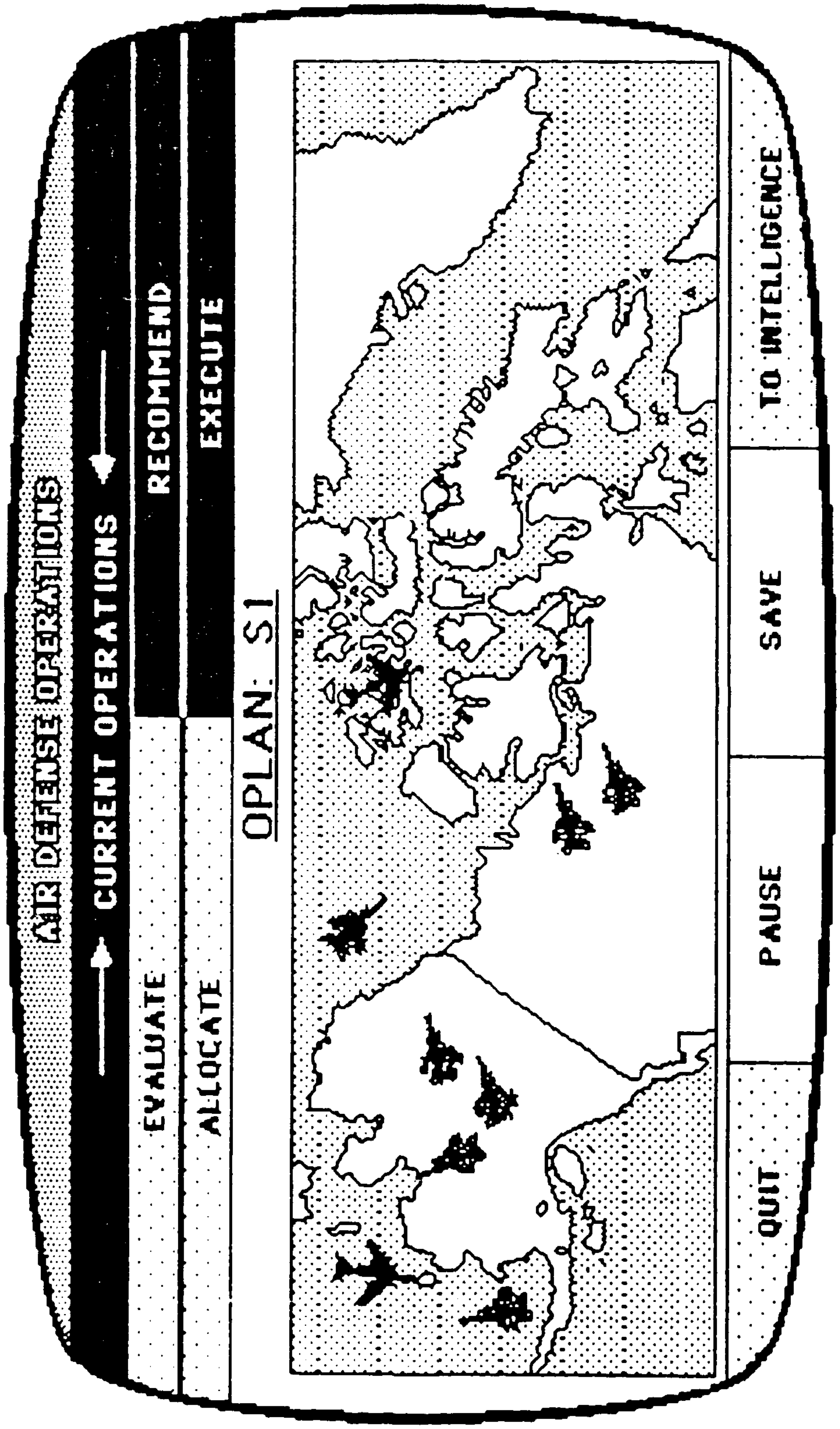
The system presents a new OPLAN based on the user's challenges to the system-generated one. It also presents the system-generated OPLAN right alongside, so the user can visually inspect each plan and the two plans together. He then selects the **Execute** option.

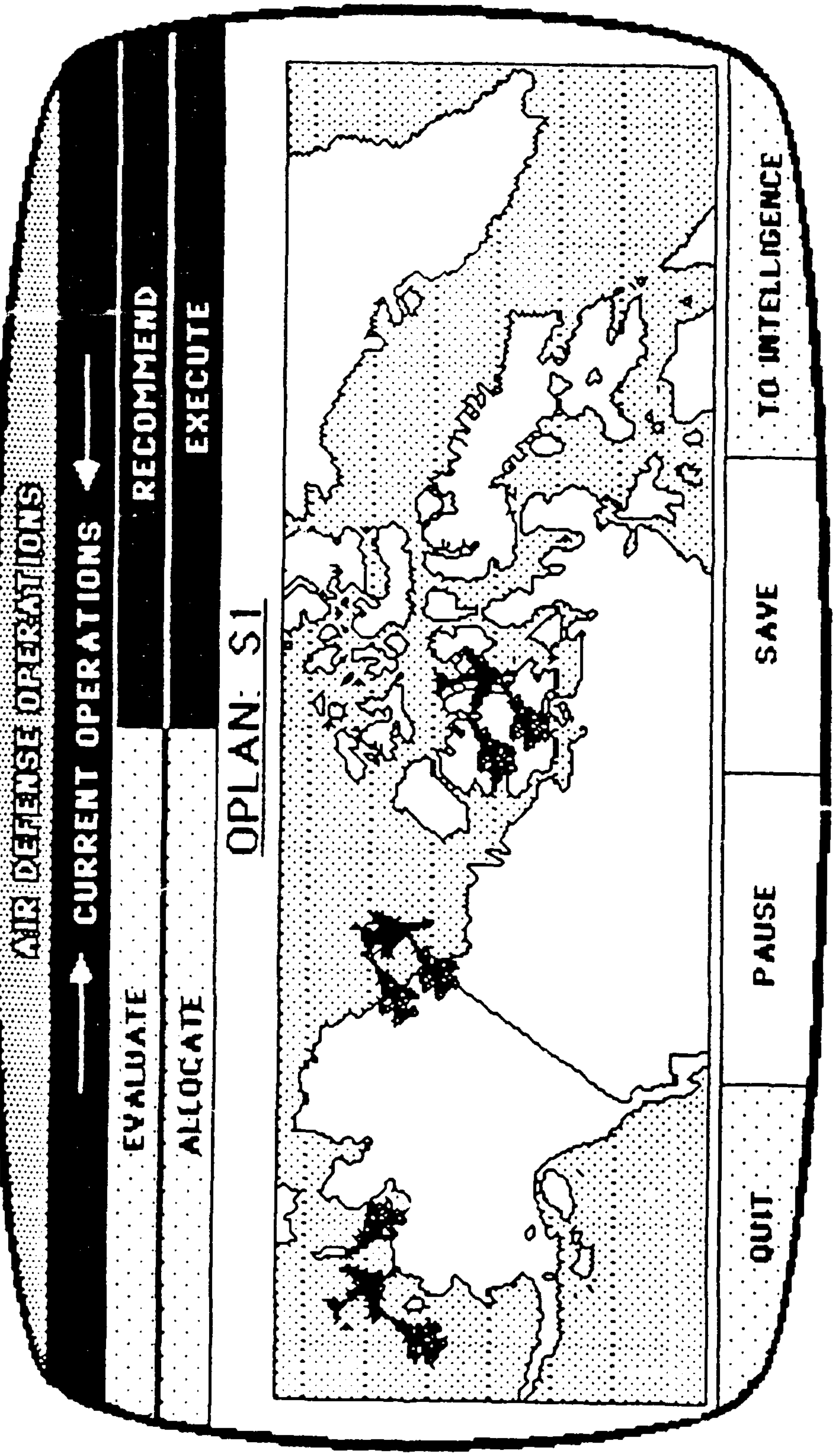

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
System OPLAN: S1
User OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

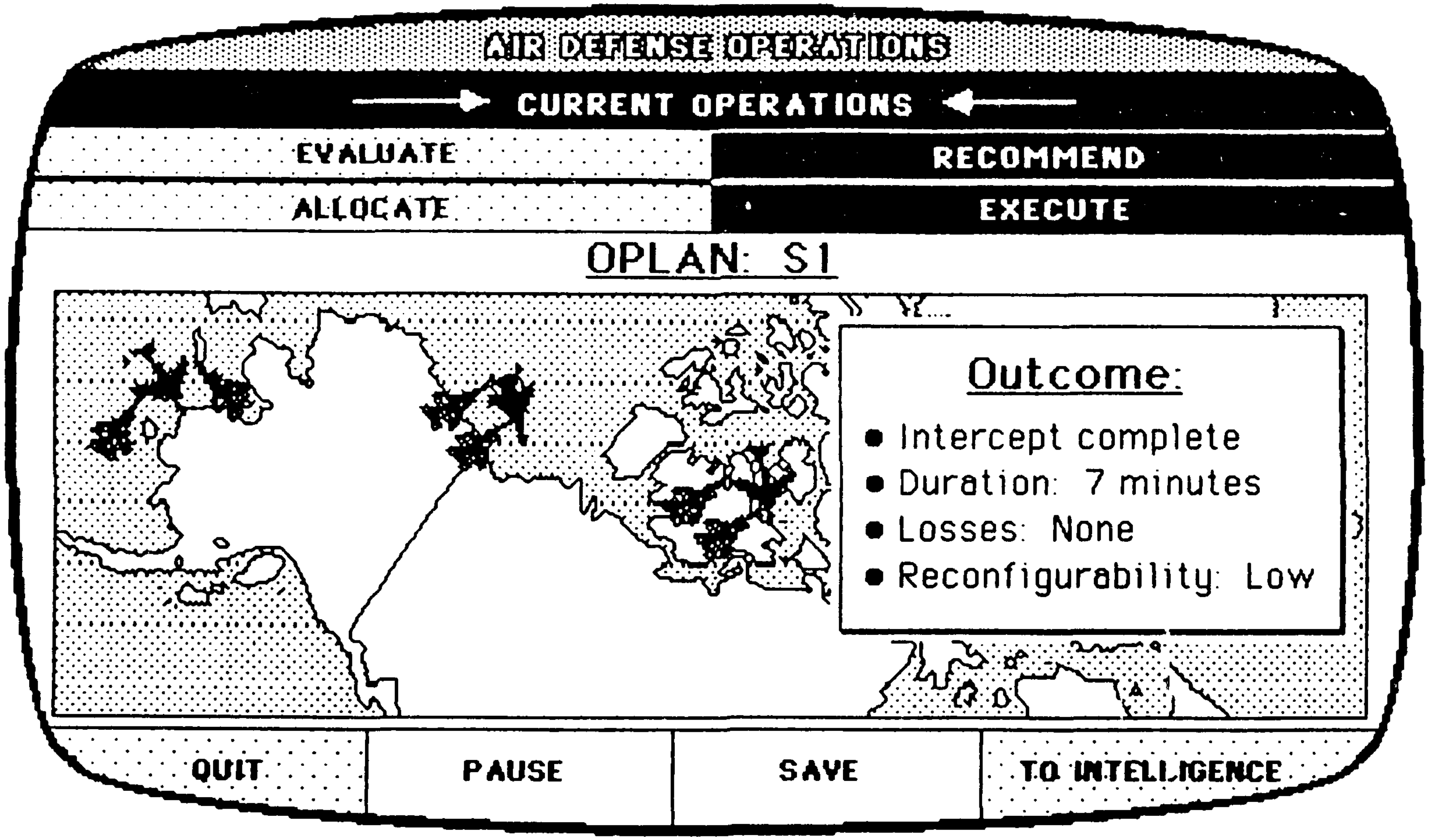


The system asks him what he wants to simulate. He selects OPLAN S1, the system's plan, first and then his plan, OPLAN U1.

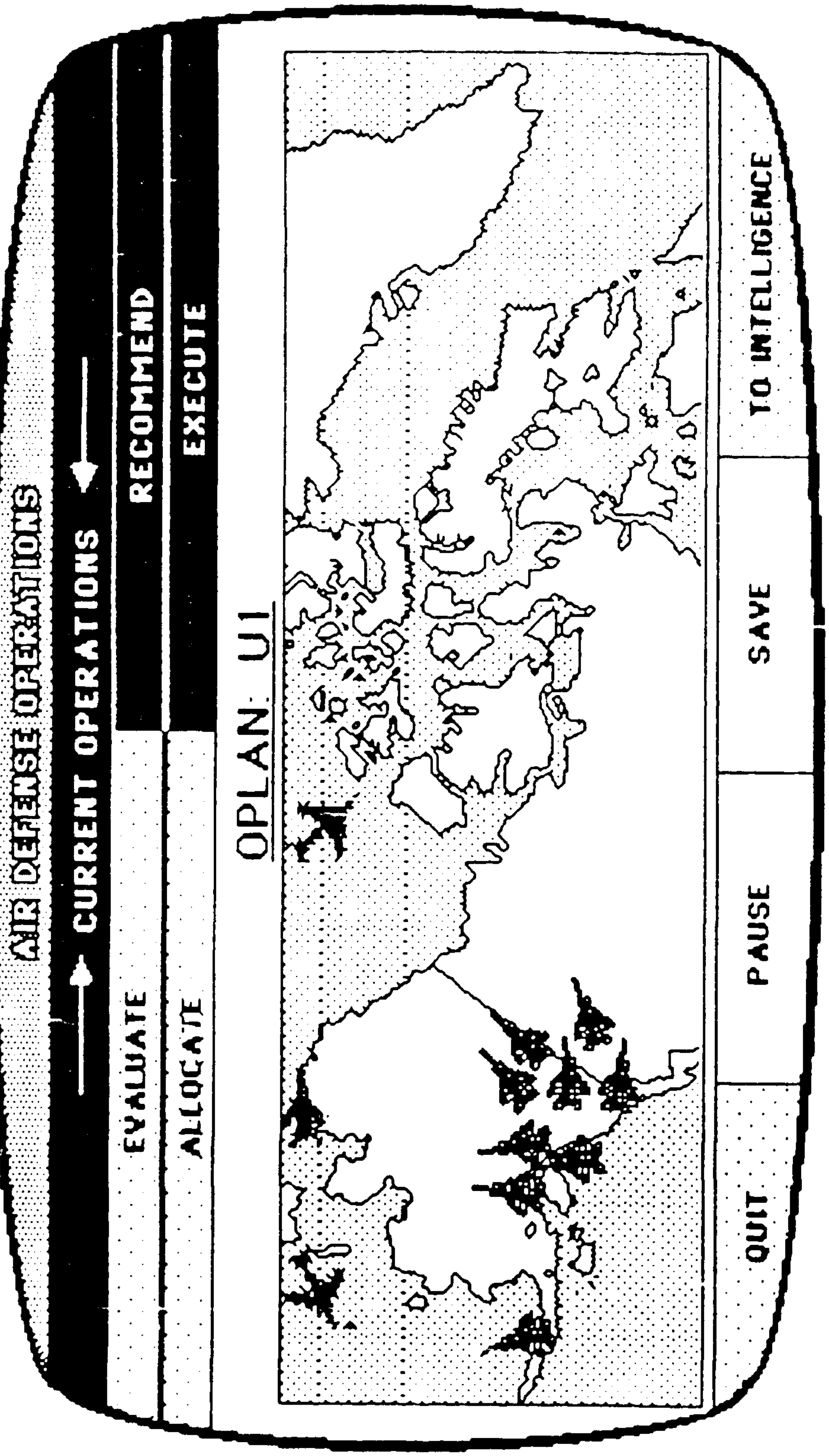

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: S1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

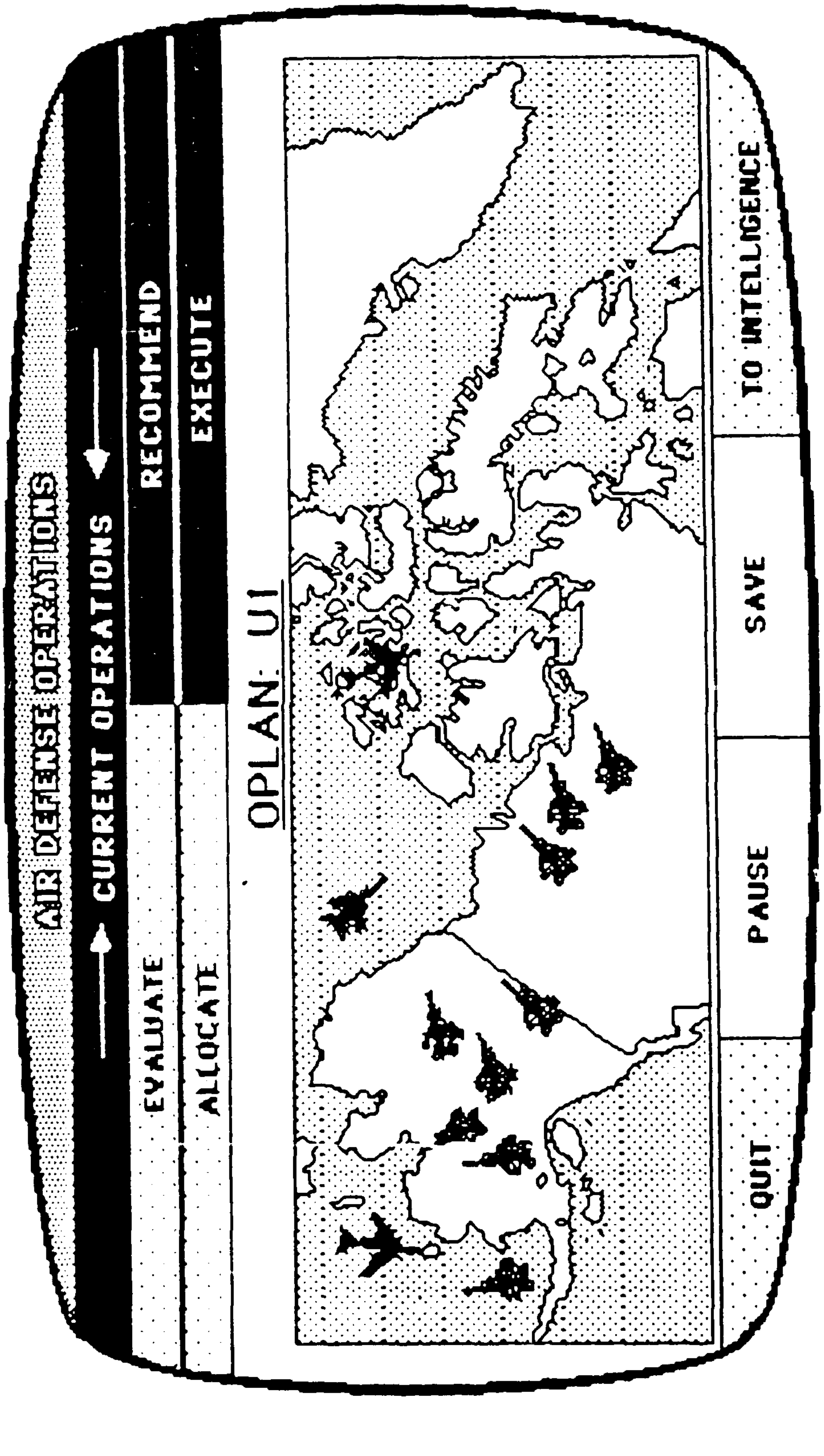

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: S1
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: S1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

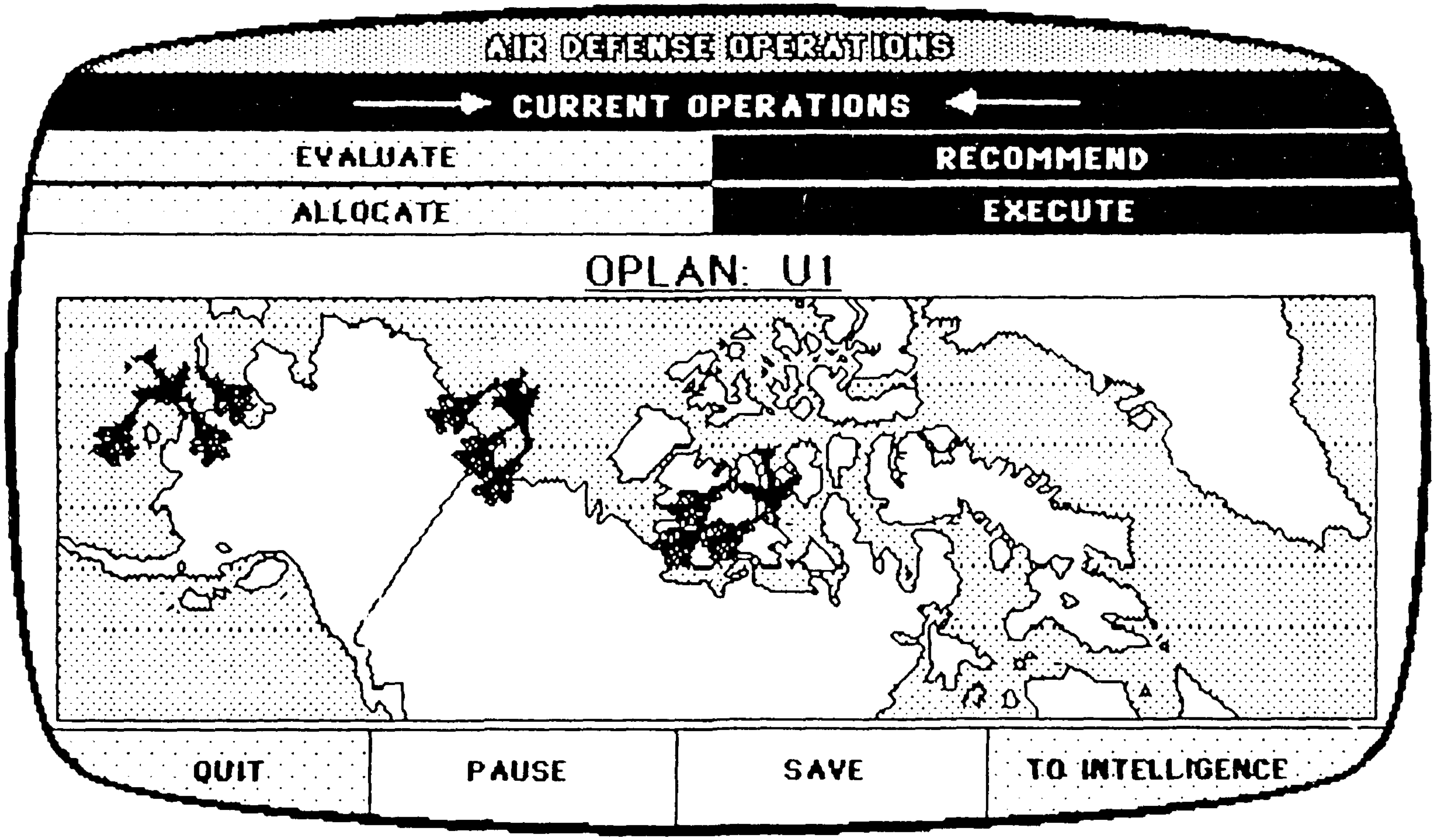


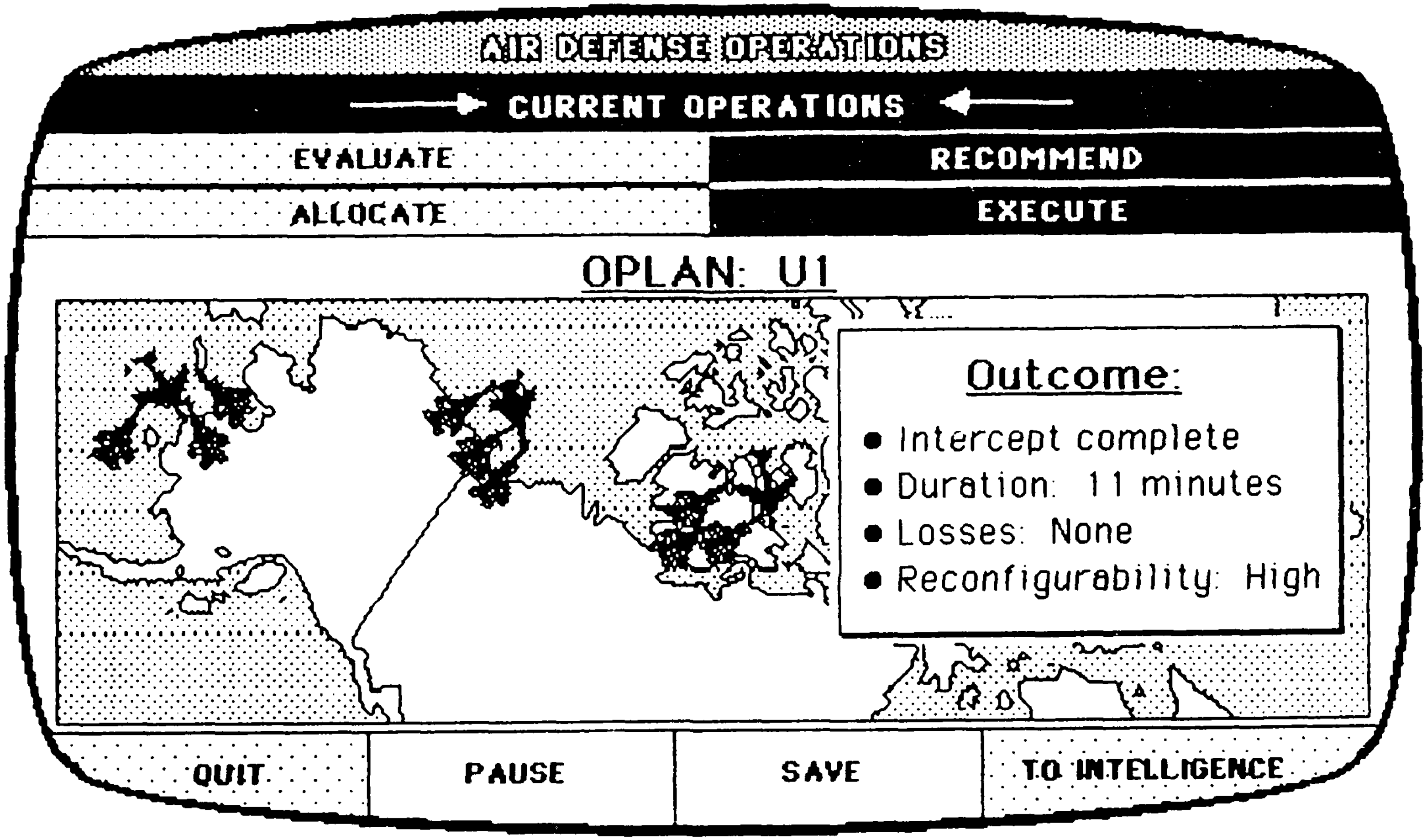
The system animates OPLAN S1 and presents a net effect expressed in terms of mission objectives, time, and costs.


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE



AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE



The system presents OPLAN U1 to the user. The user can then select the plan he prefers based -- according to the net outcome of the simulation -- upon the trade-off between time and asset reconfigurability. If the threat is expected to grow then reconfigurability may become very important. In order to decide which OPLAN is "best," the user needs more information, that is, more intelligence.

Air Defense Intelligence/
Operations Interface
Prototype

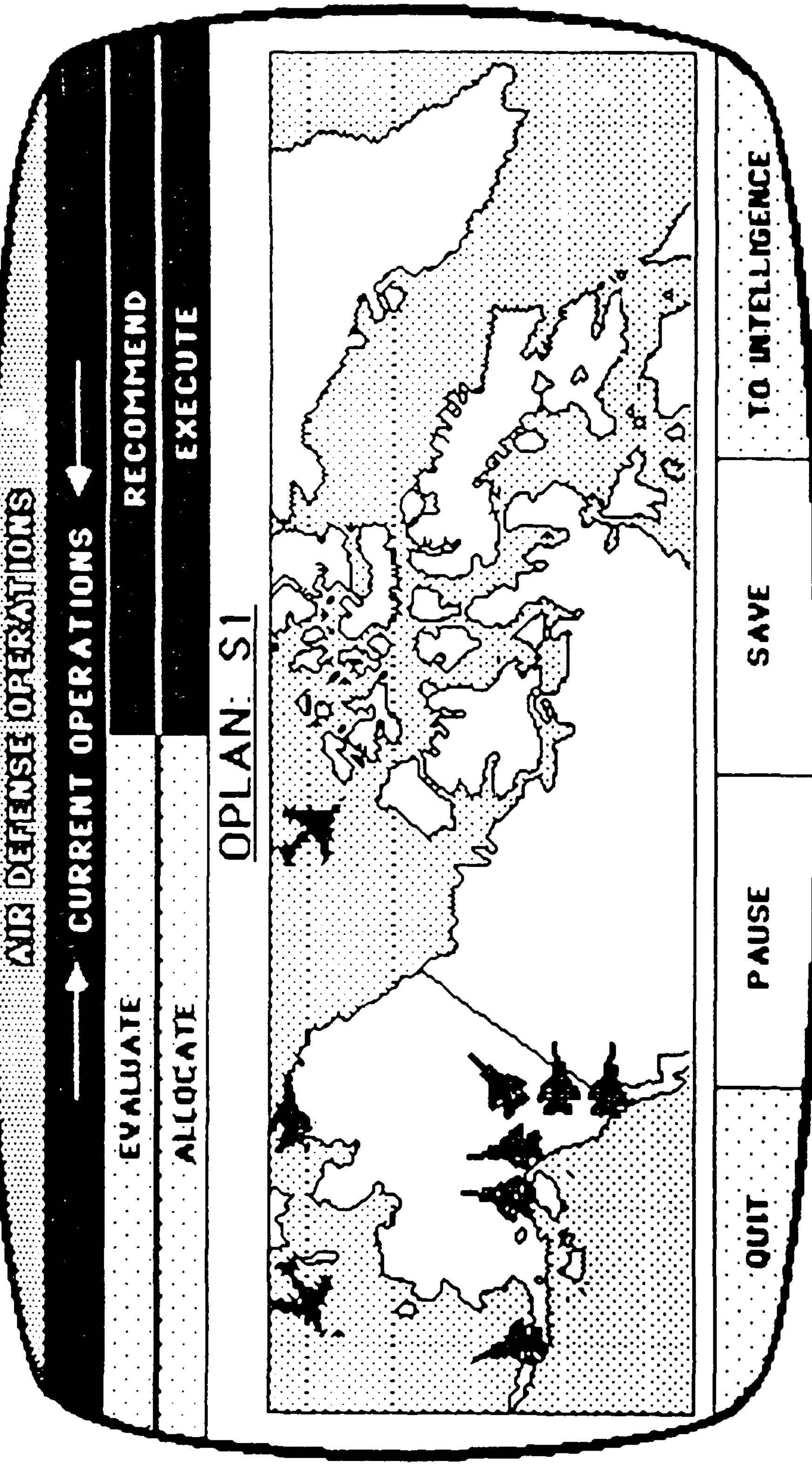
This prototype builds upon the
Air Defense Intelligence and
Operations Prototypes, demonstrates
the synergism between intelligence
and operations processes, and illustrates
how two computer-based systems can
be linked and shared

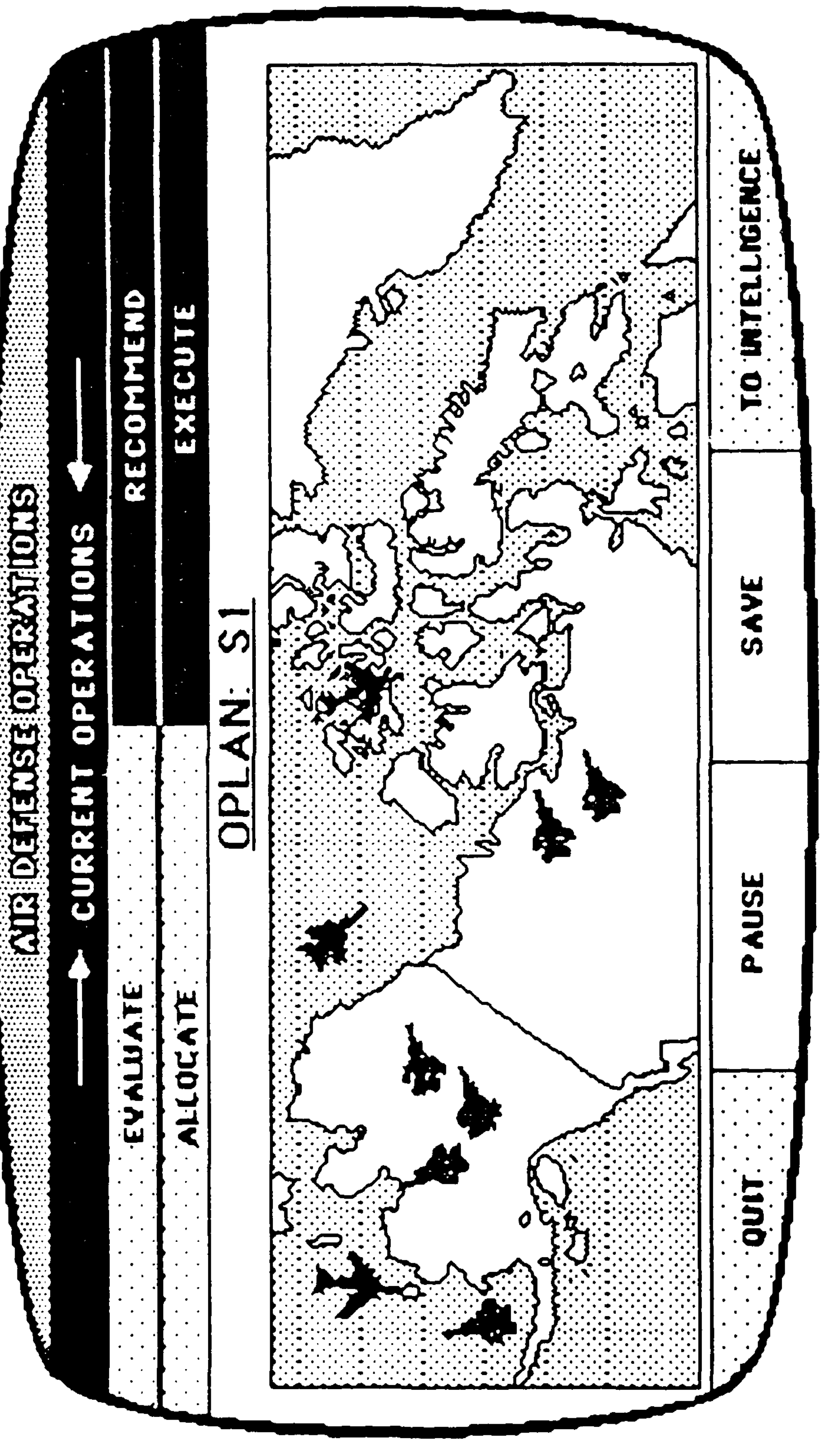
Demonstration #1

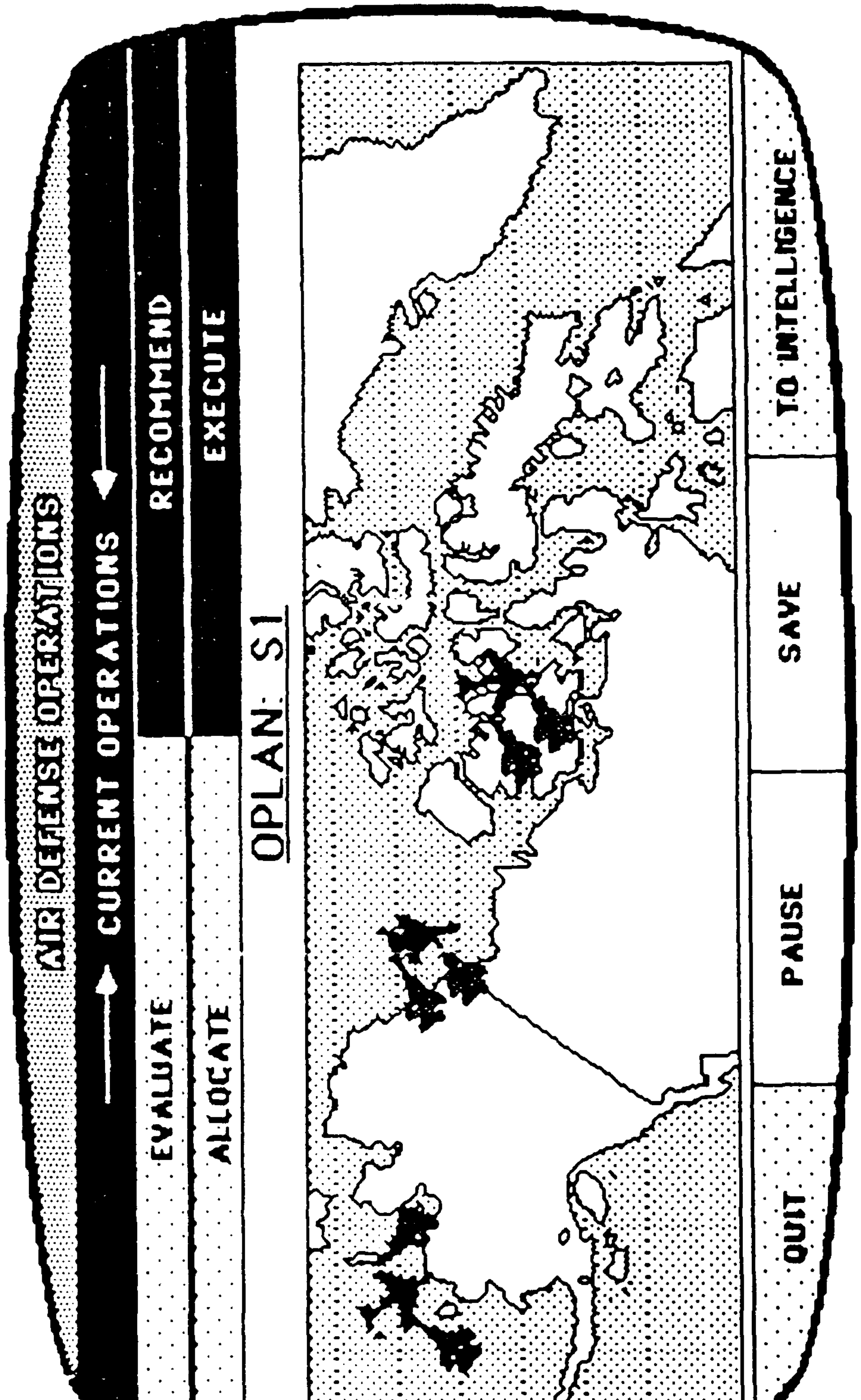
Intelligence/Operations Interface Demonstration # 1

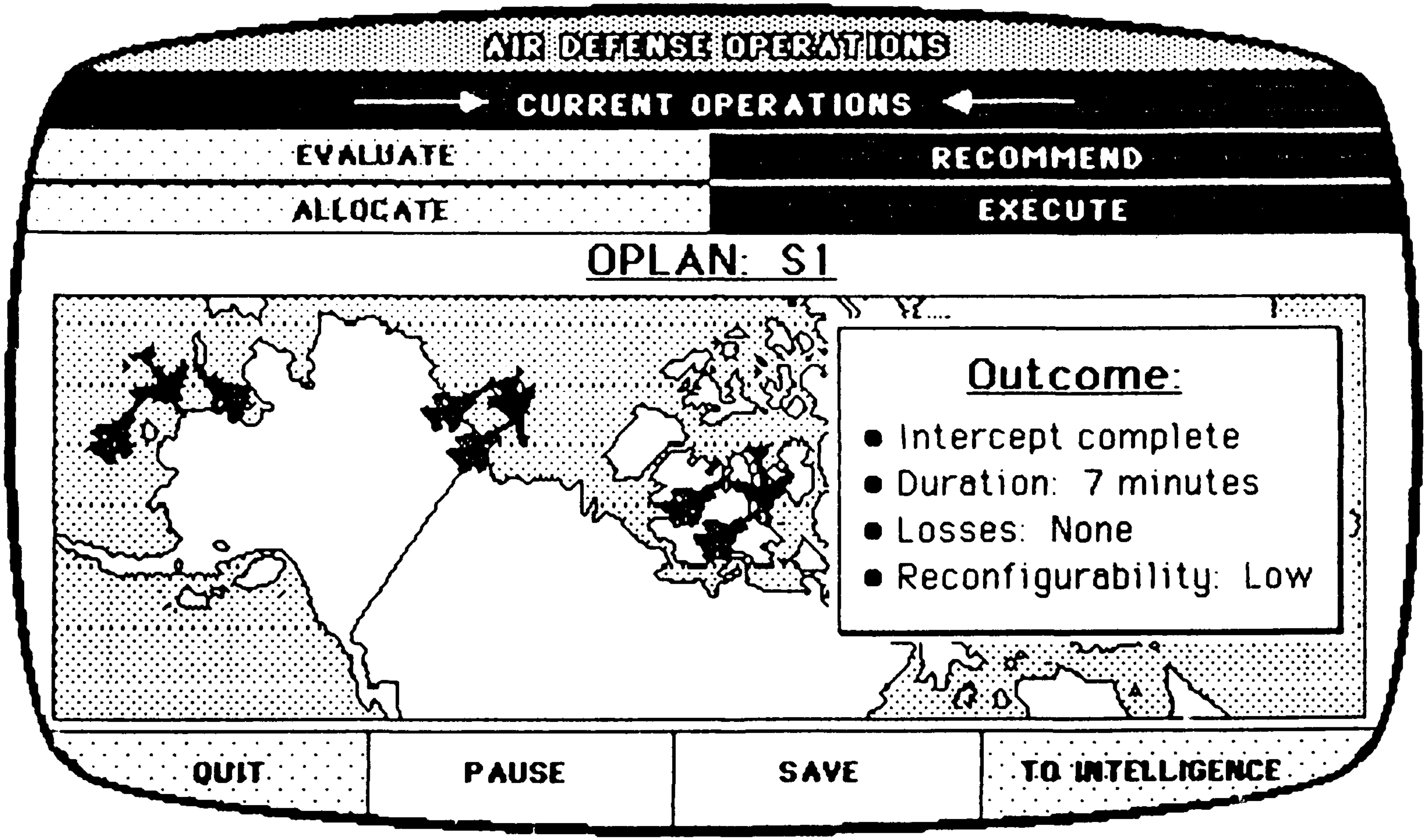
Scenario: Air Defense Operations at the Top ROCC (Elmendorf AFB)

Situation: Uncertainty regarding Alternative OPLANS, S1 & U1

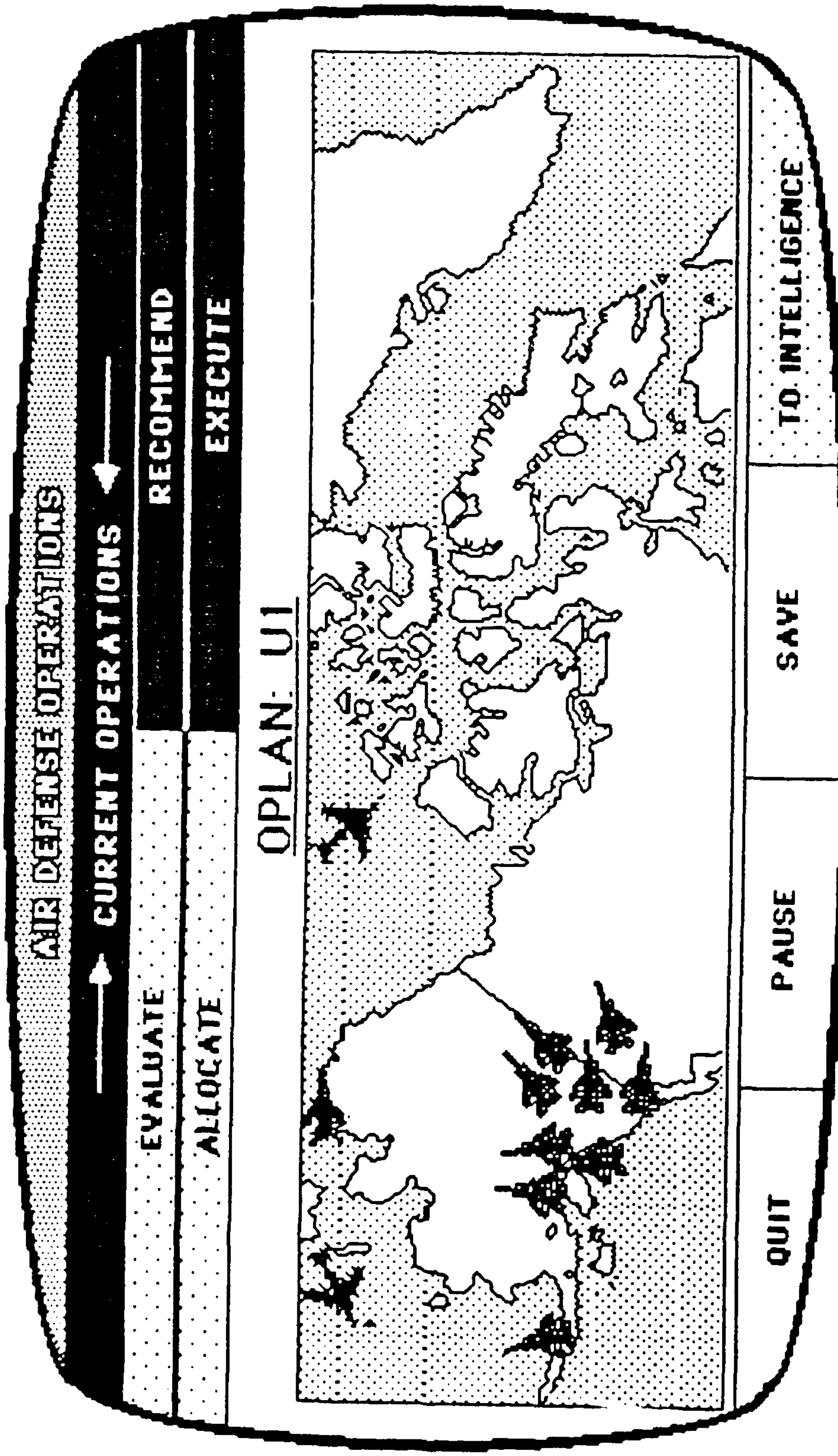

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: S1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

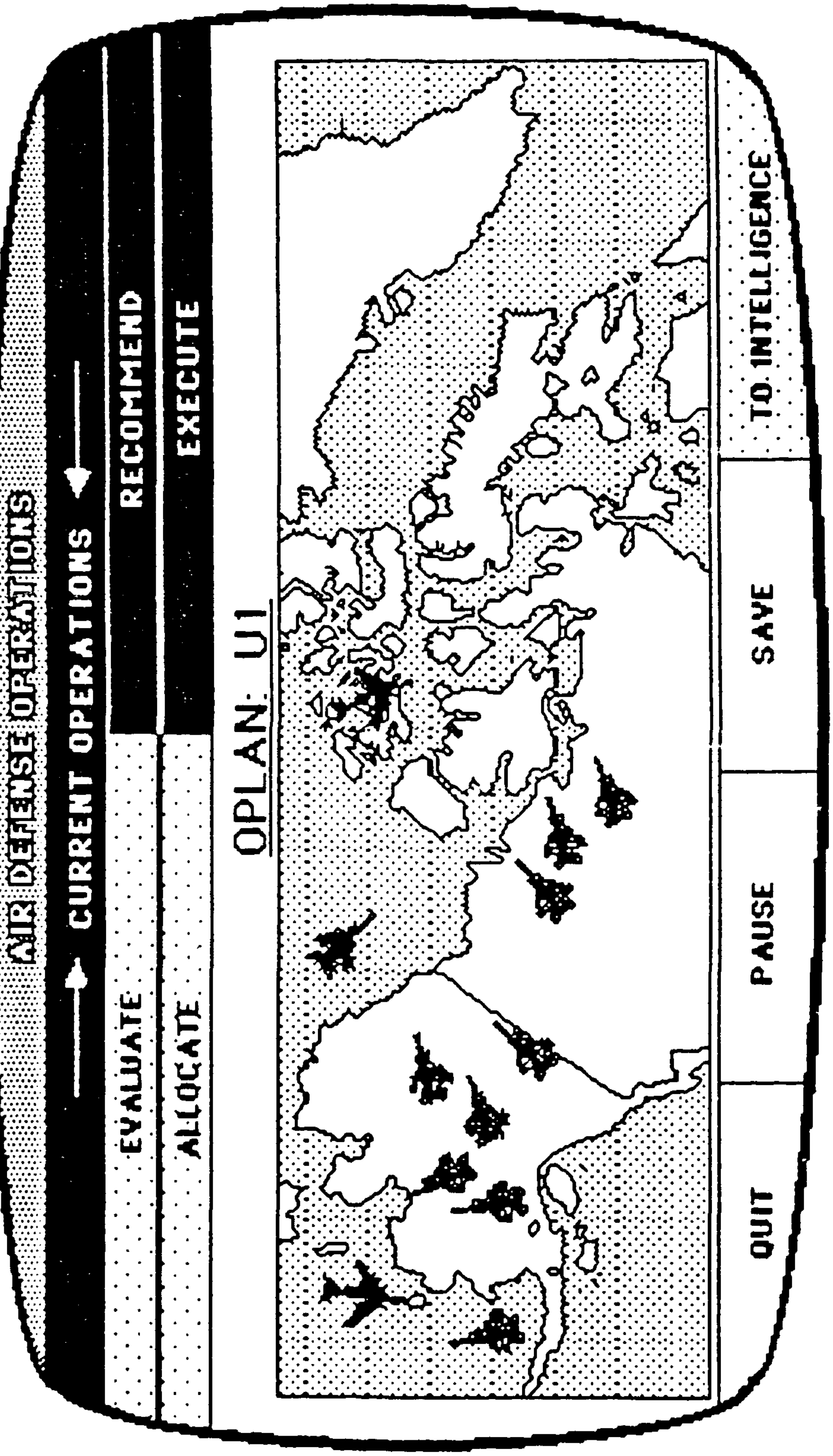

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: S1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

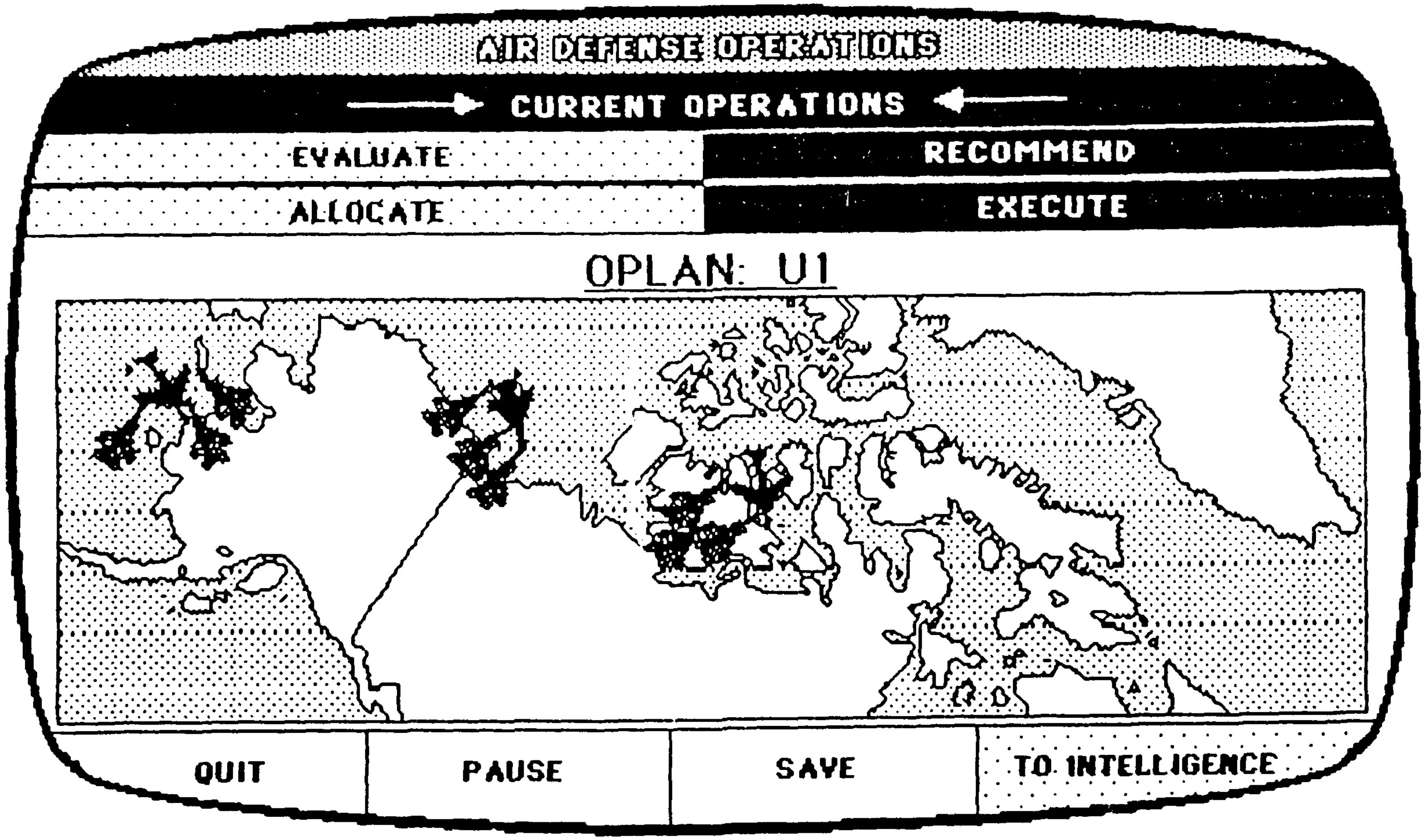

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
ALLOCATE
RECOMMEND
EXECUTE
OPLAN: S1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

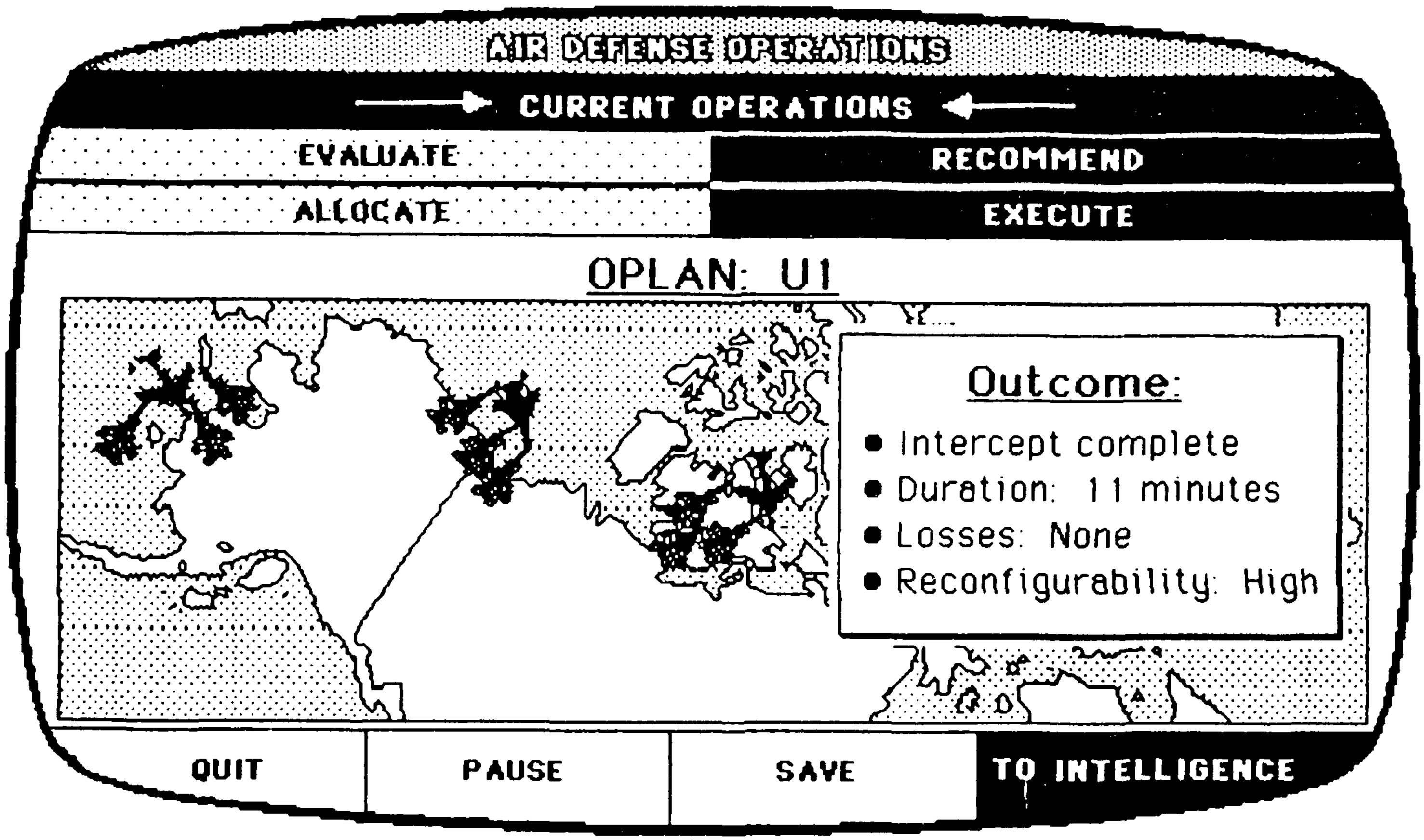


This display suggests that the Air Defense Operations planner is currently testing some plans against an embedded simulator of intercept activity. The system presents the results to the user.

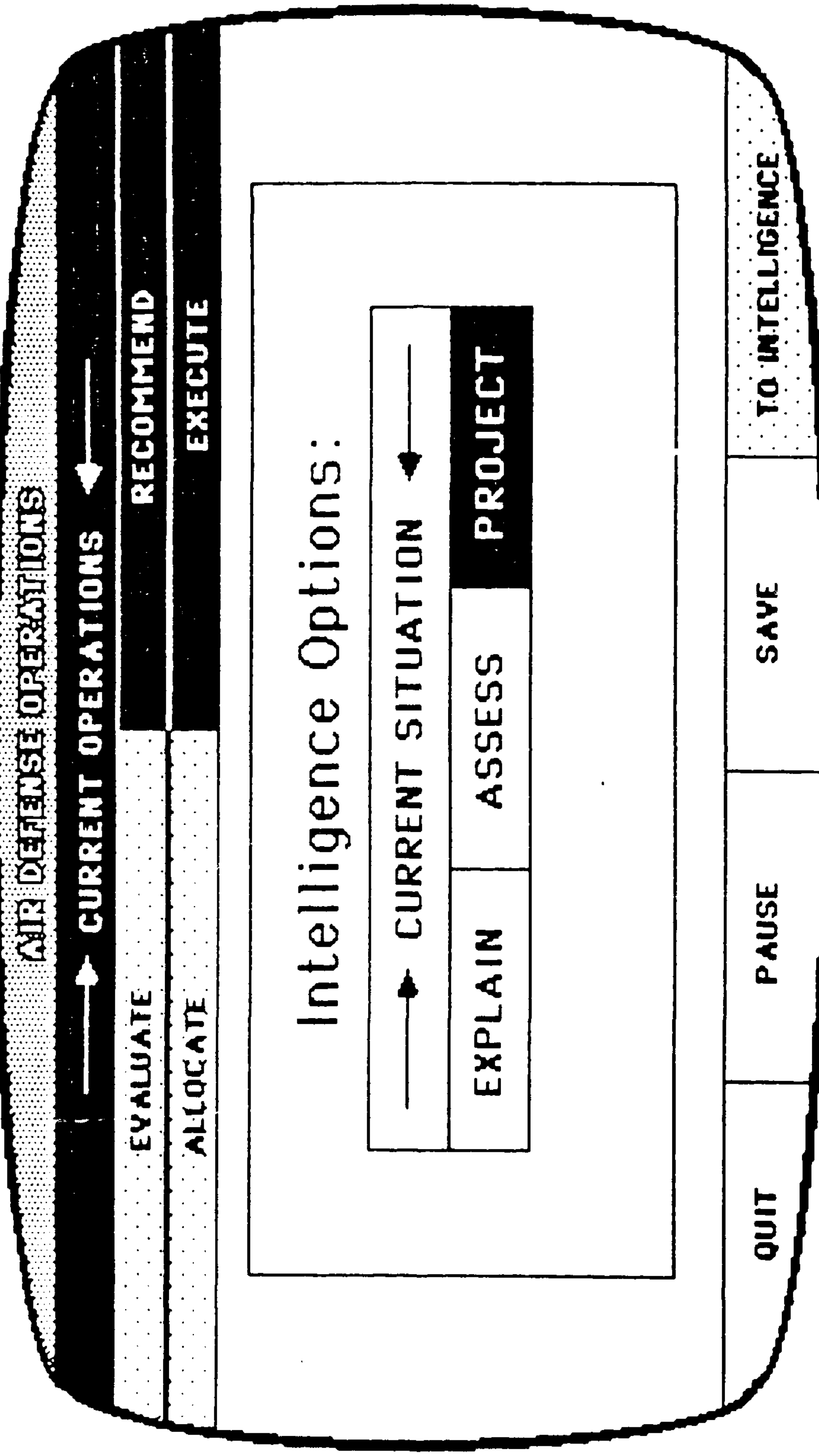

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

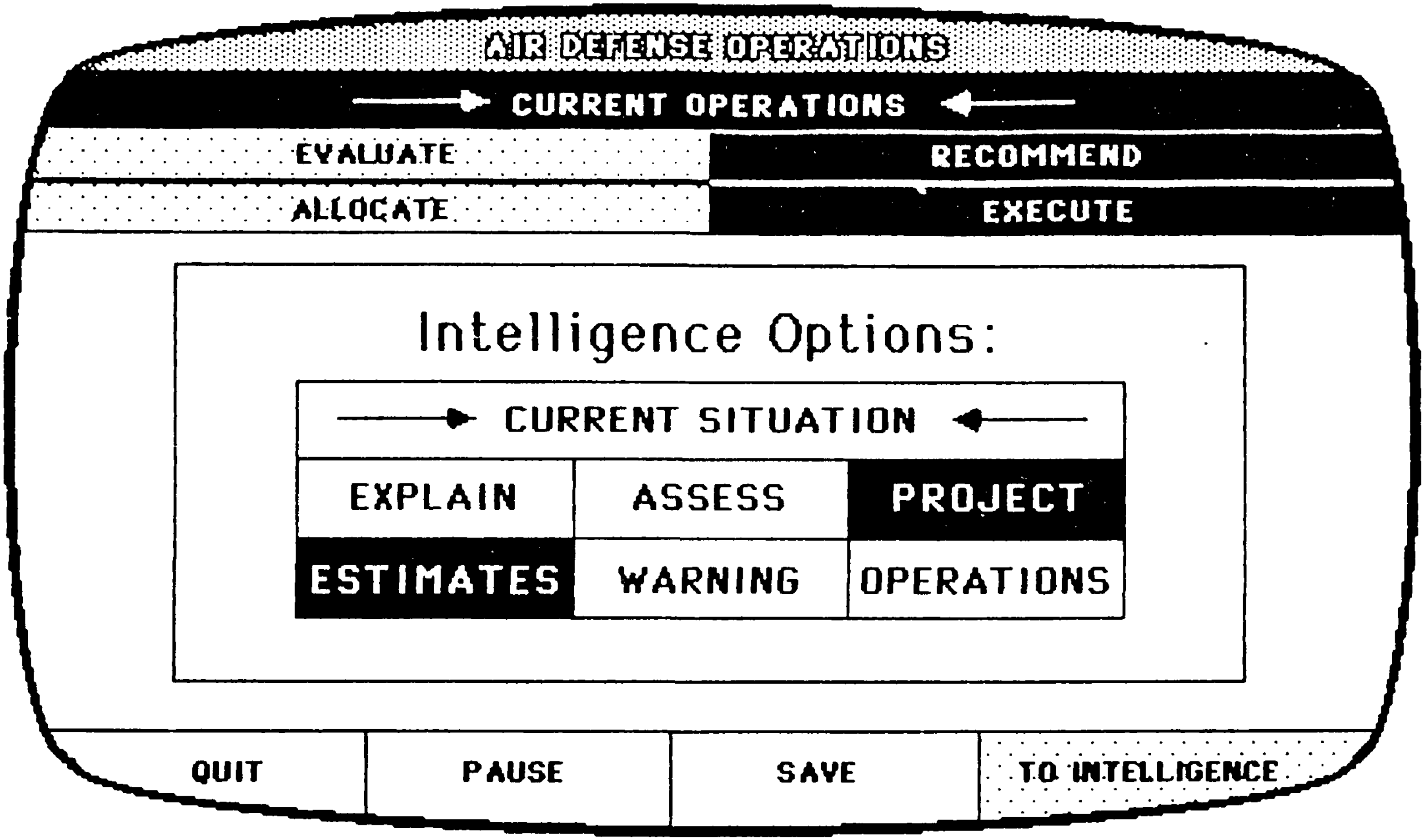

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
OPLAN: U1
QUIT
PAUSE
SAVE
TO INTELLIGENCE

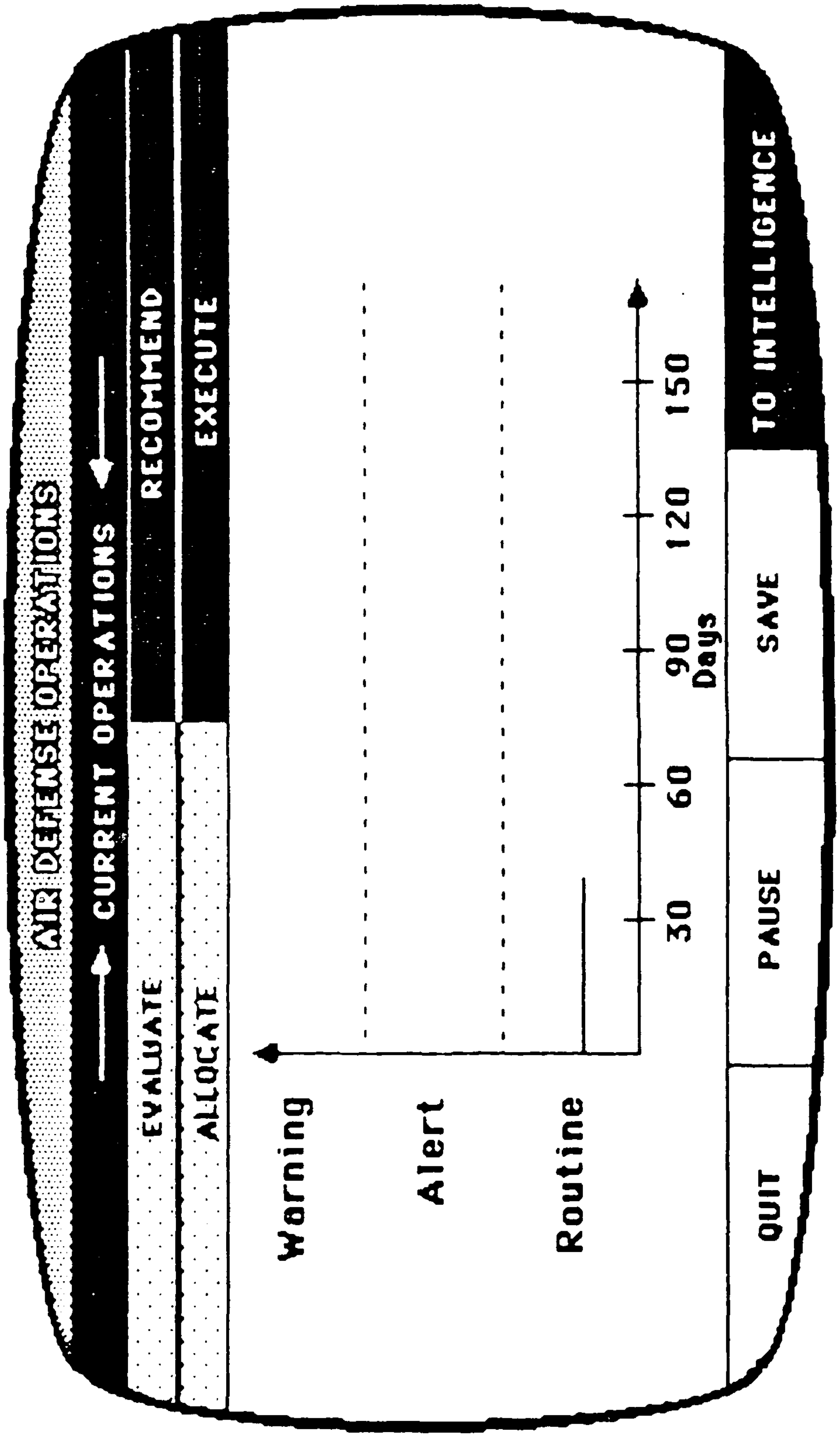


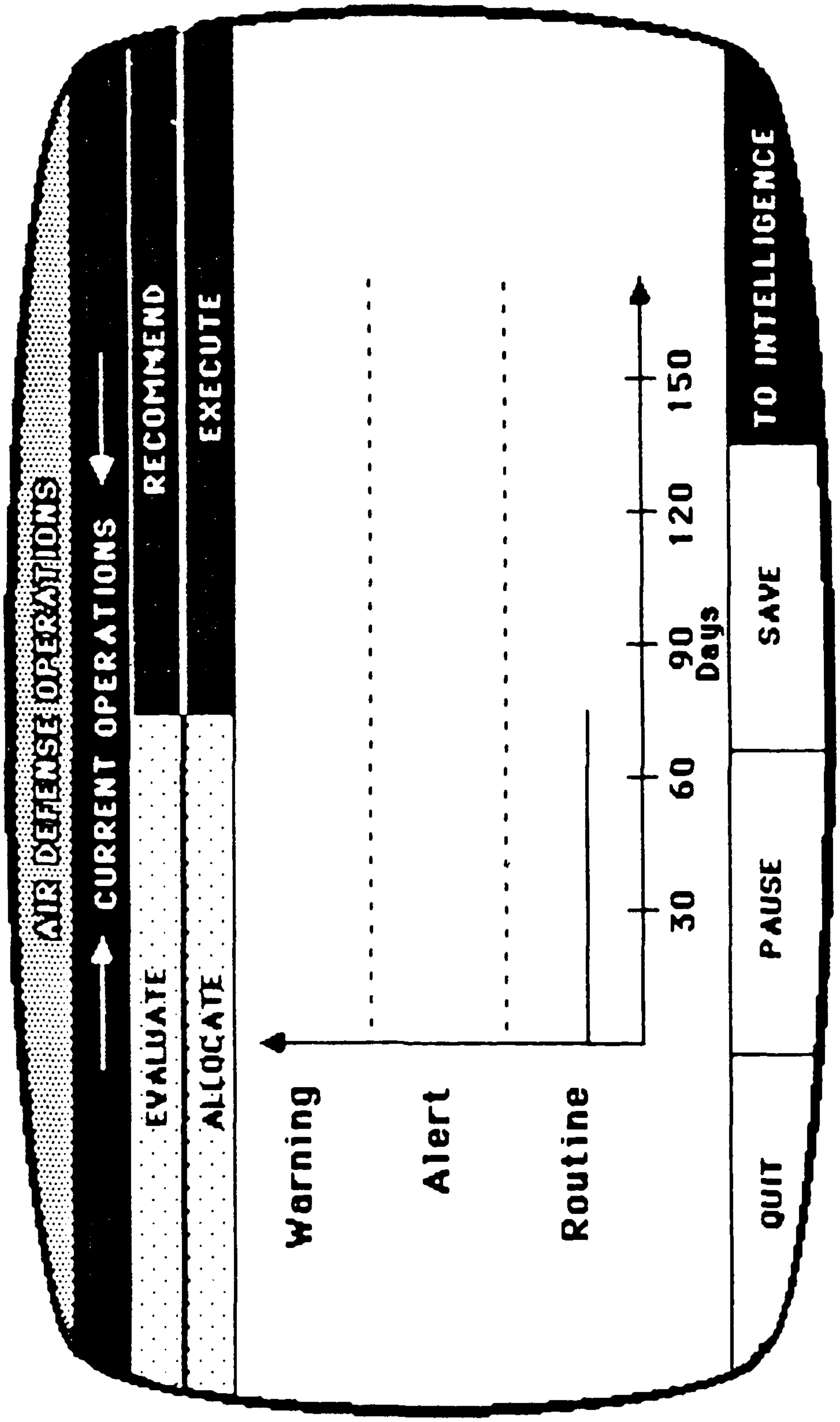
This display presents the results of a second plan. The trade-off is simple: time versus reconfigurability. If the likelihood of a sustained threat -- a war -- is great, or the likelihood of repeated air space violations is high, then there may be good reason to favor the reconfigurable plan over the "faster" one. But without information about the likelihood of these two events, the planner cannot make a good decision about which plan to select. He clicks on **To Intelligence** for real-time insight into the overall threat situation.

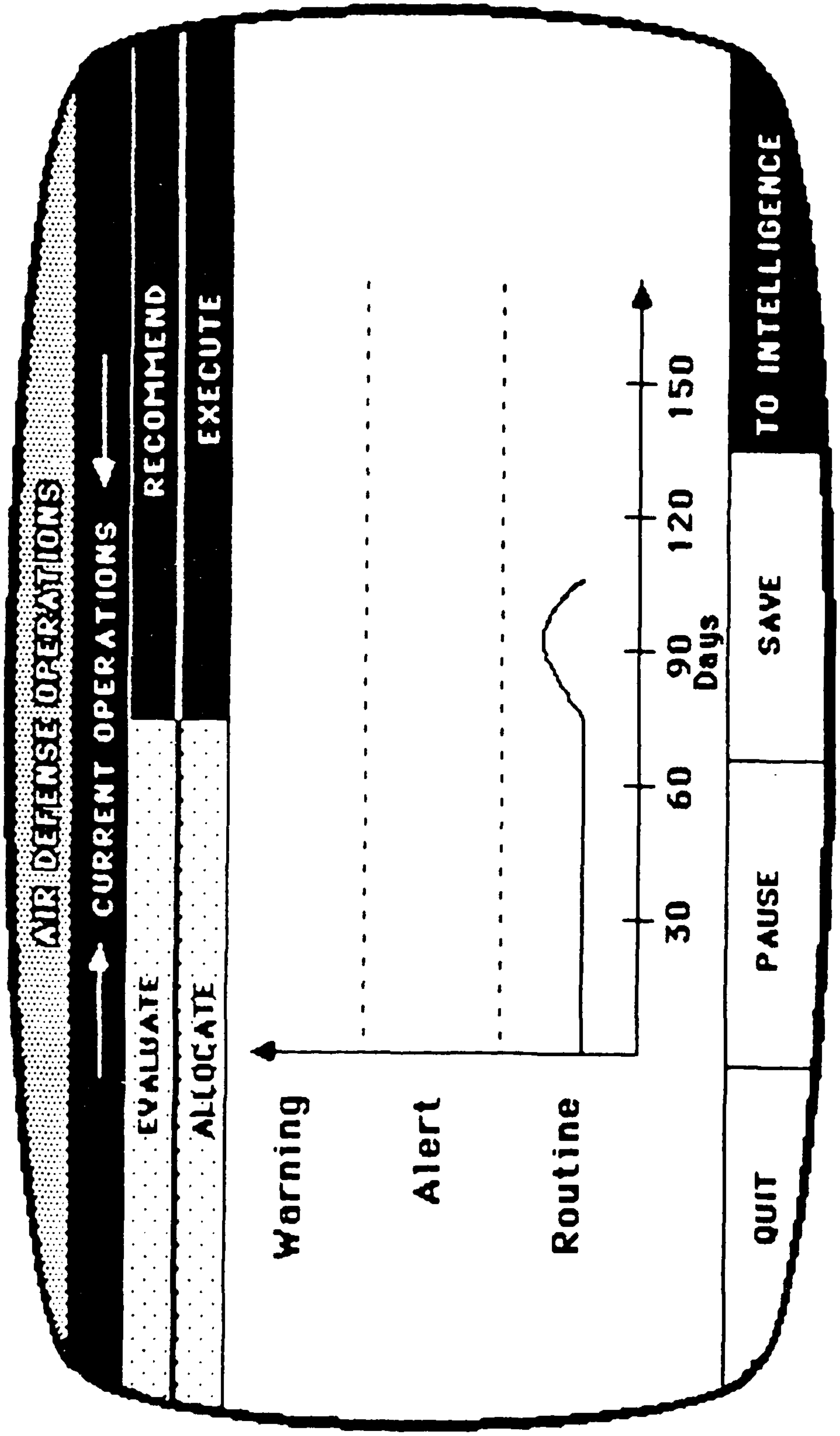

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Intelligence Options:
CURRENT SITUATION
EXPLAIN
ASSESS
PROJECT
QUIT
PAUSE
SAVE
TO INTELLIGENCE

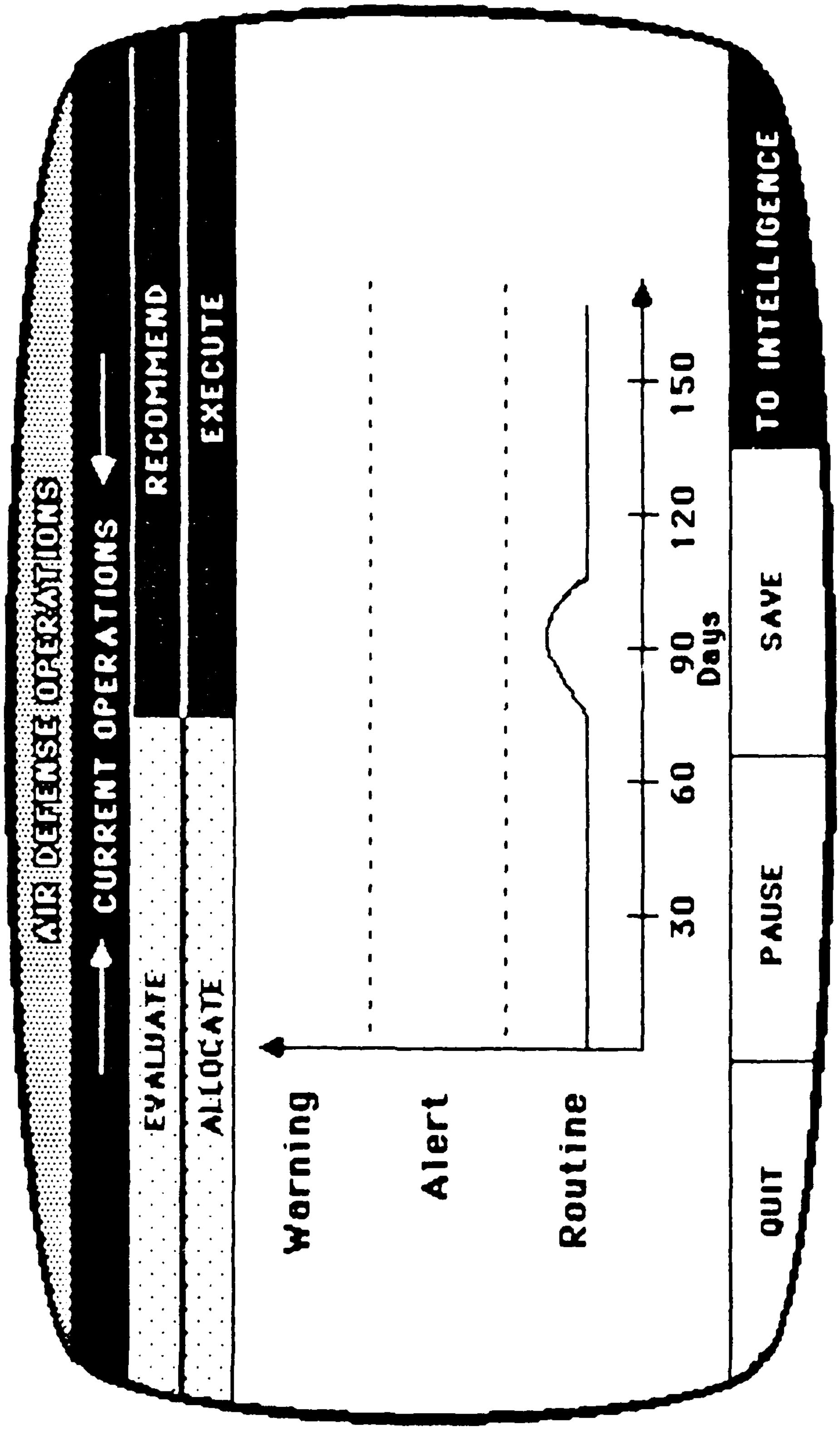


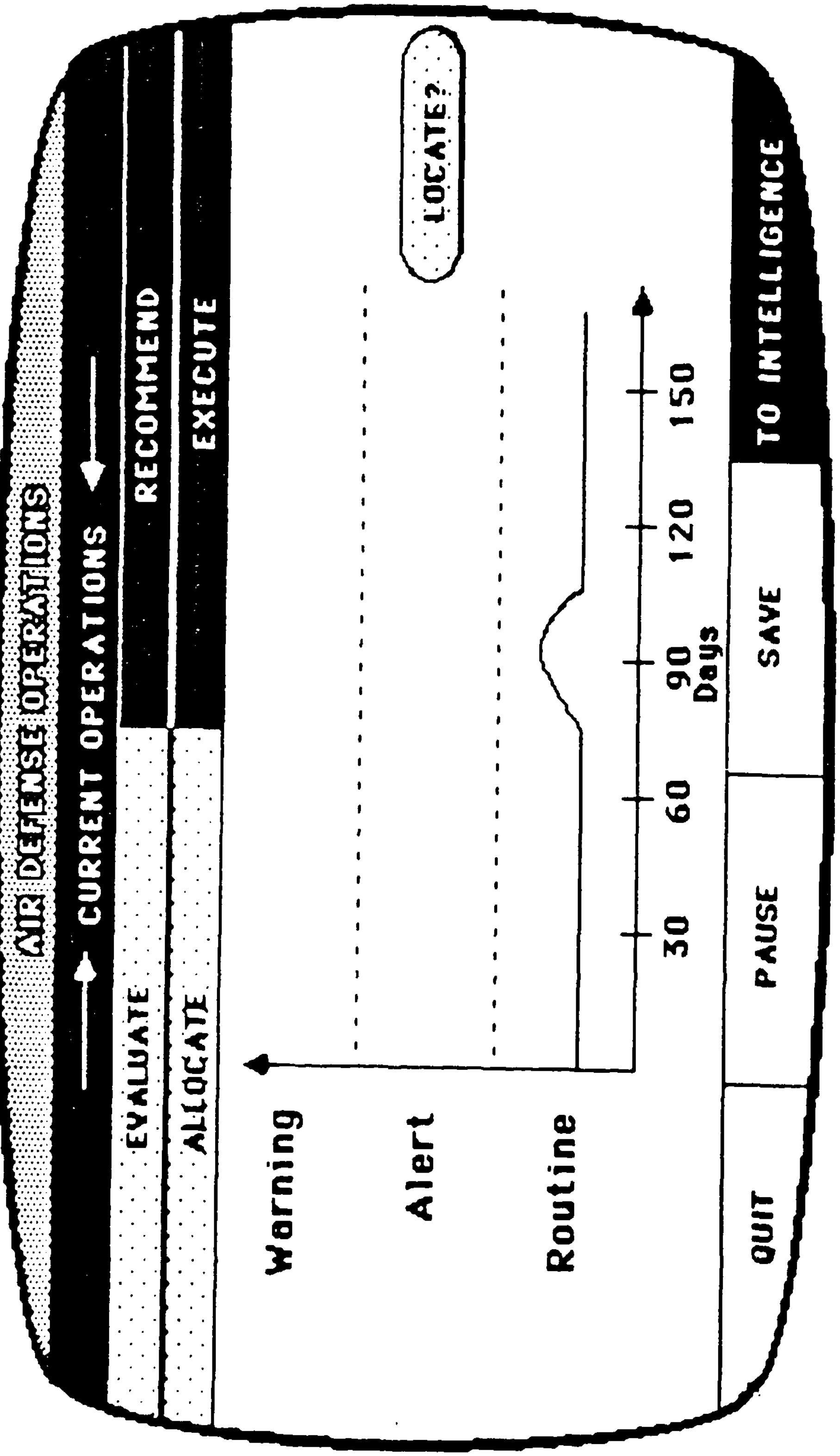
The planner is now in a different world -- the intelligence world. He has, in fact, entered the intelligence analysis and production system via his workstation. This linkage presumes electronic access to intelligence data and the intelligence process. The planner is presented a menu of intelligence analysis options. He decides to look first at the projections of US/USSR hostility likelihoods. He clicks on **Project/Estimates**.

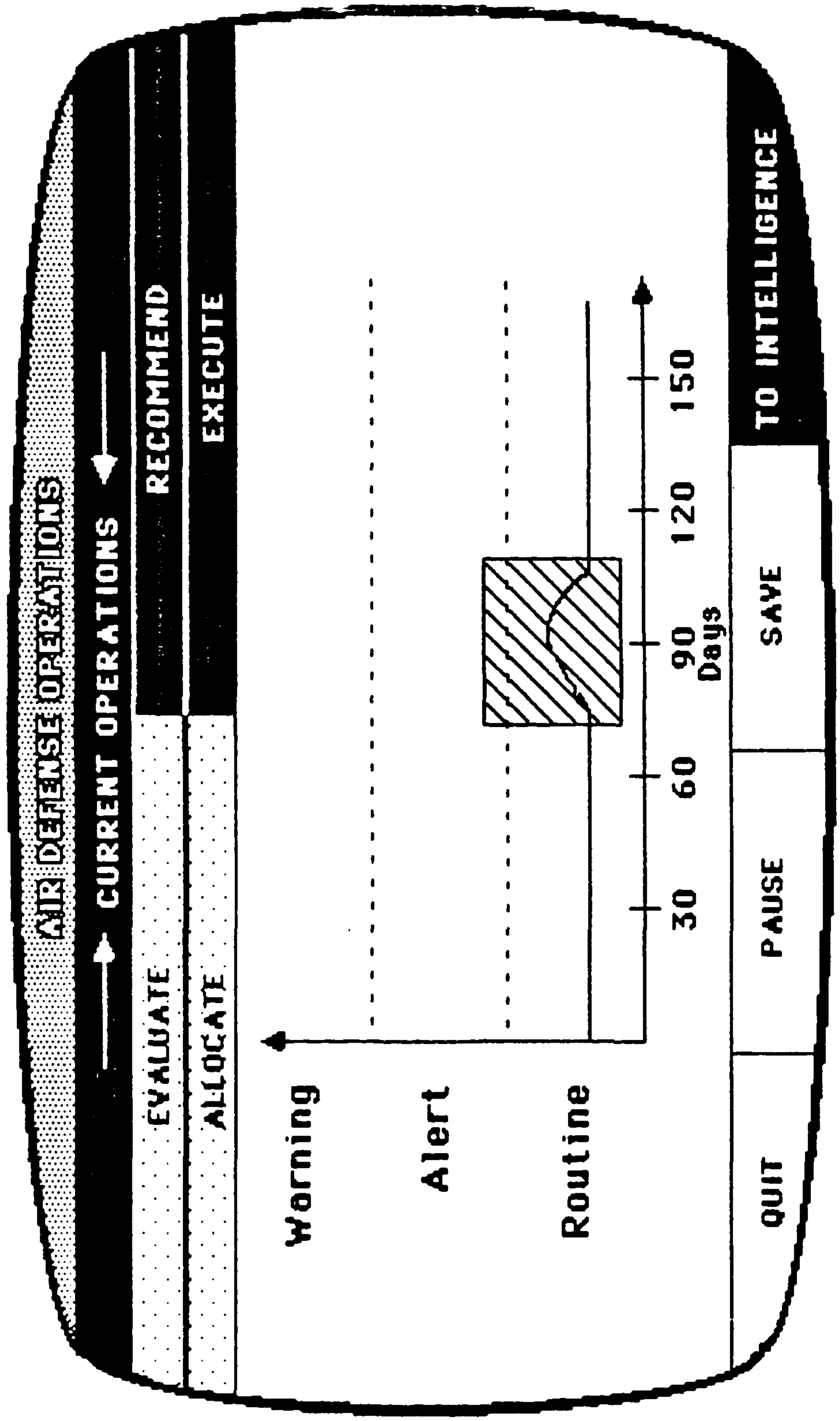

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO INTELLIGENCE

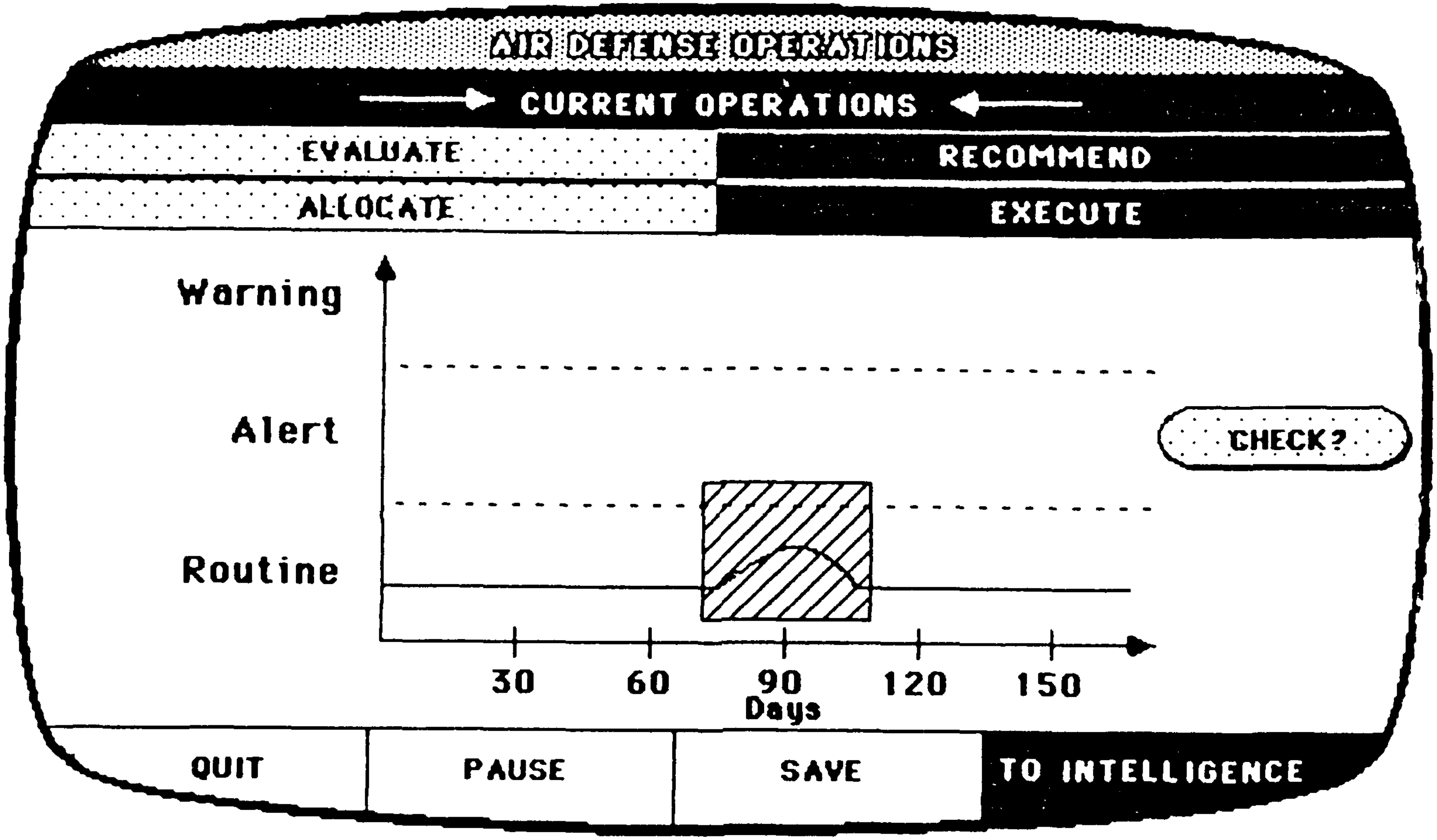

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO INTELLIGENCE

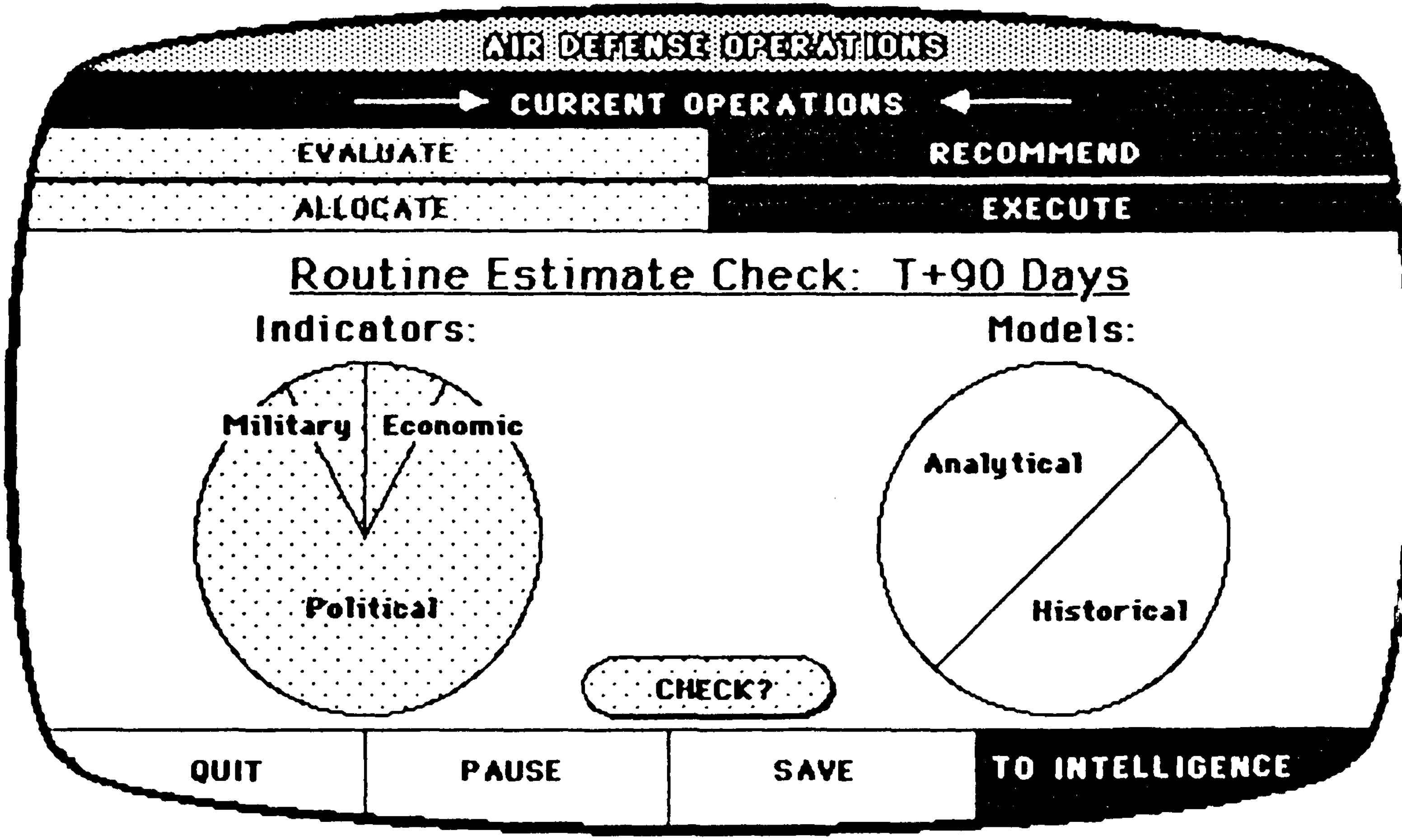

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Warning
Alert
Routine
30
60
90
Days
120
150
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
LOCATE?
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO INTELLIGENCE

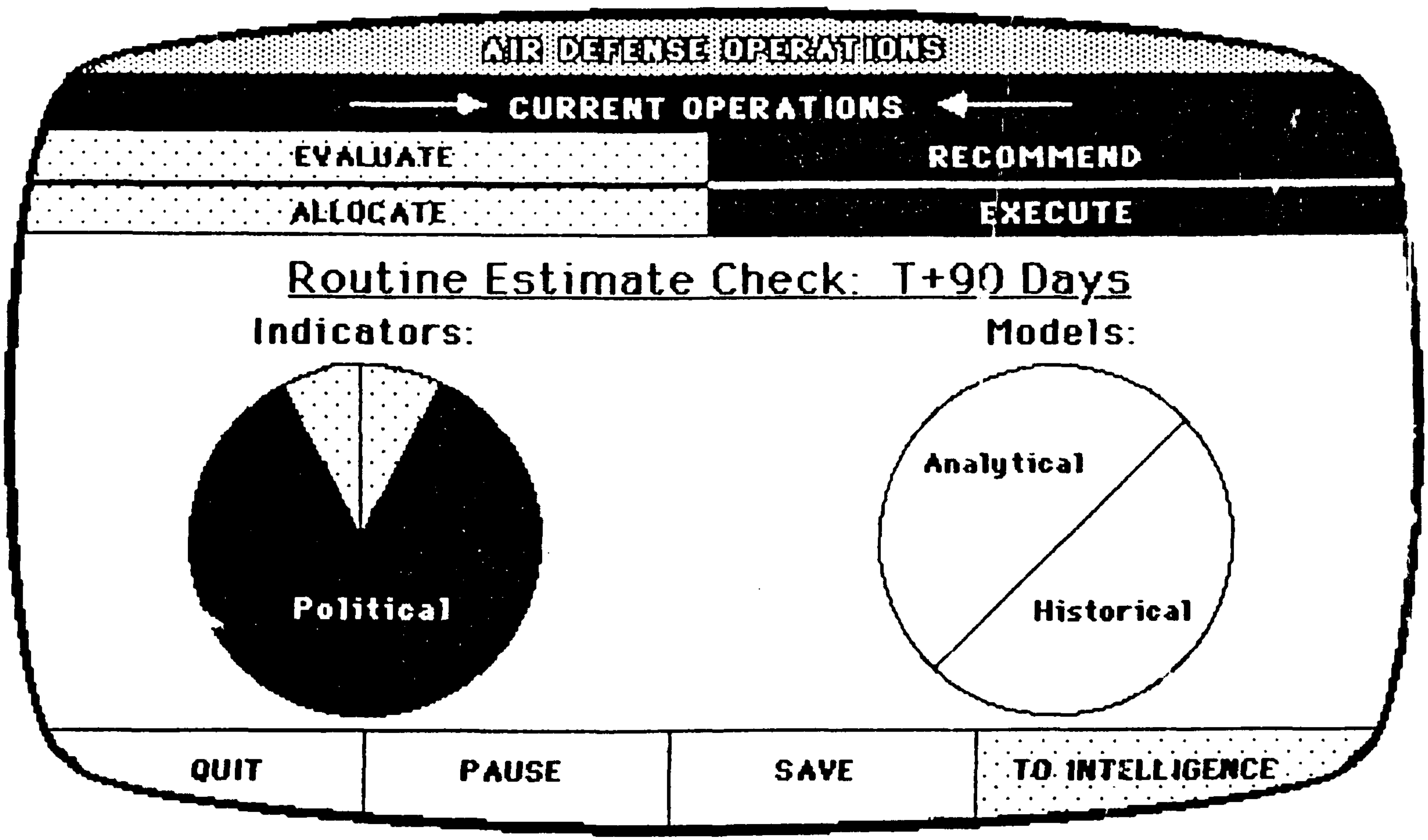

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Warning
Alert
Routine
30
60
90
120
150
Days
QUIT
PAUSE
SAVE
TO INTELLIGENCE

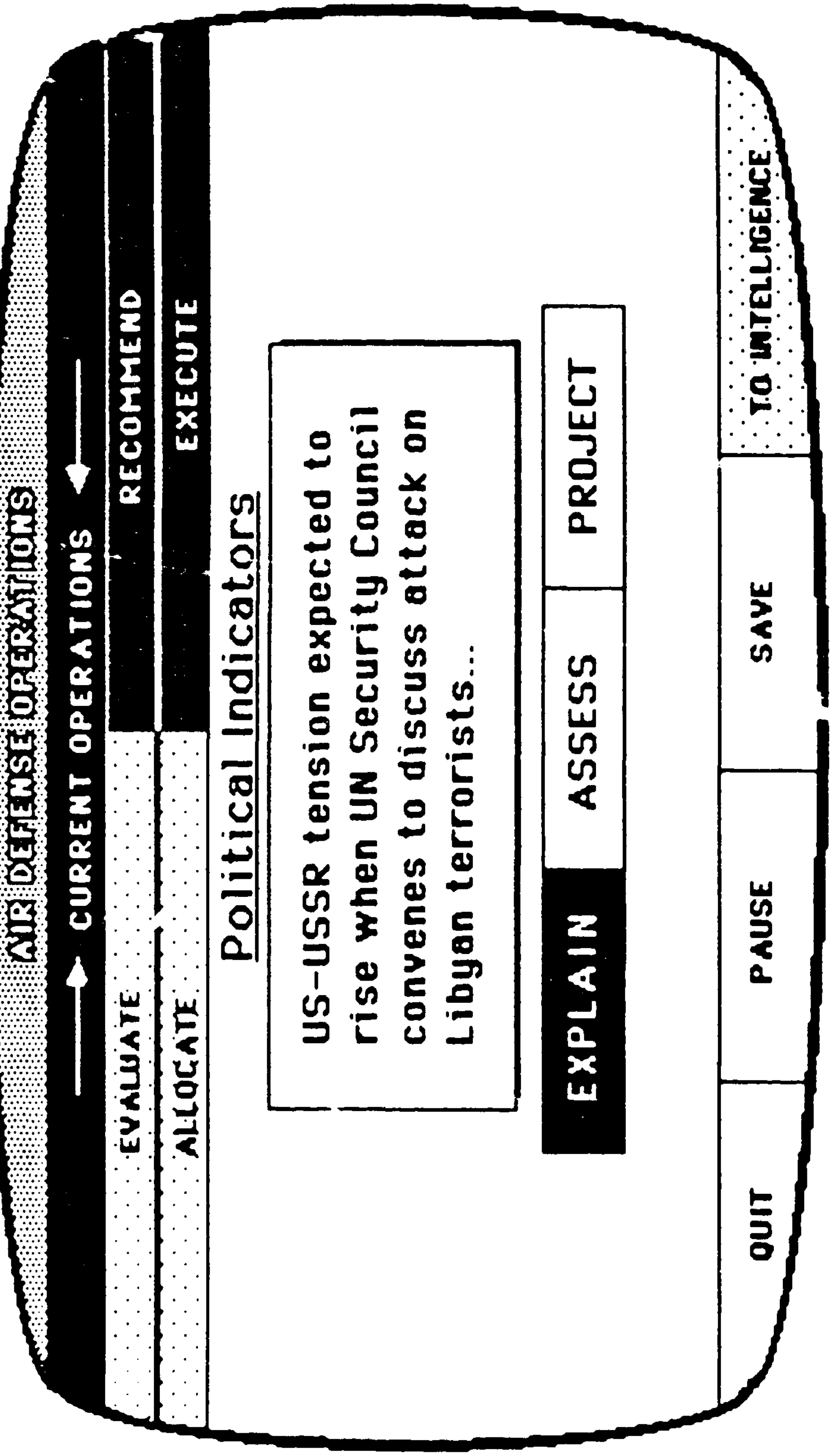


This display presents the planner with the intelligence analyst's estimate of the US/USSR hostility level (expressed in terms of routine, alert and warning behavior). The planner now sees the estimate of increased tension about 90 days out . . . he clicks on **Check?/**

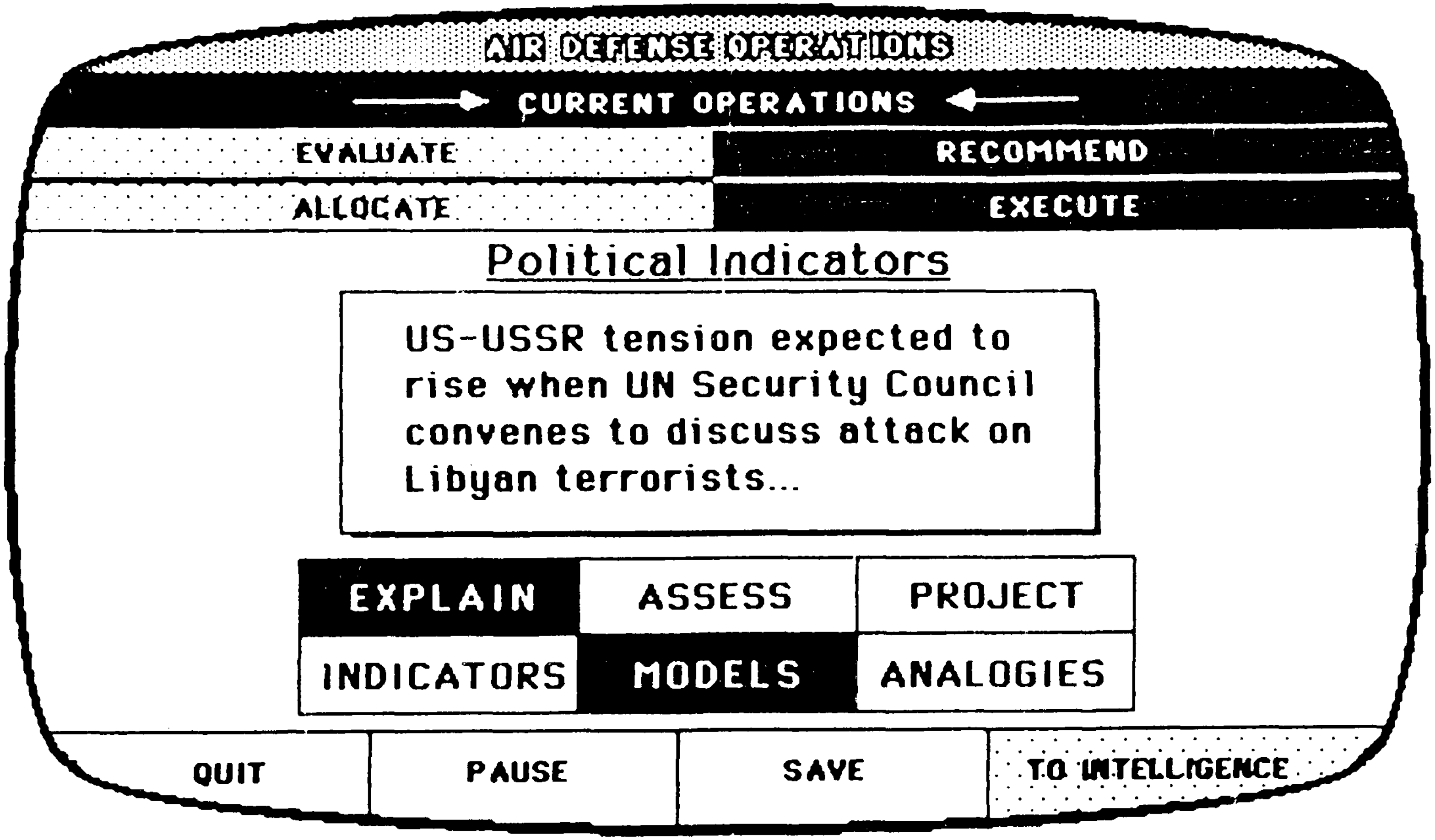


The intelligence system shows the planner the reason why increased tension is expected . . . he clicks on **Check?**.

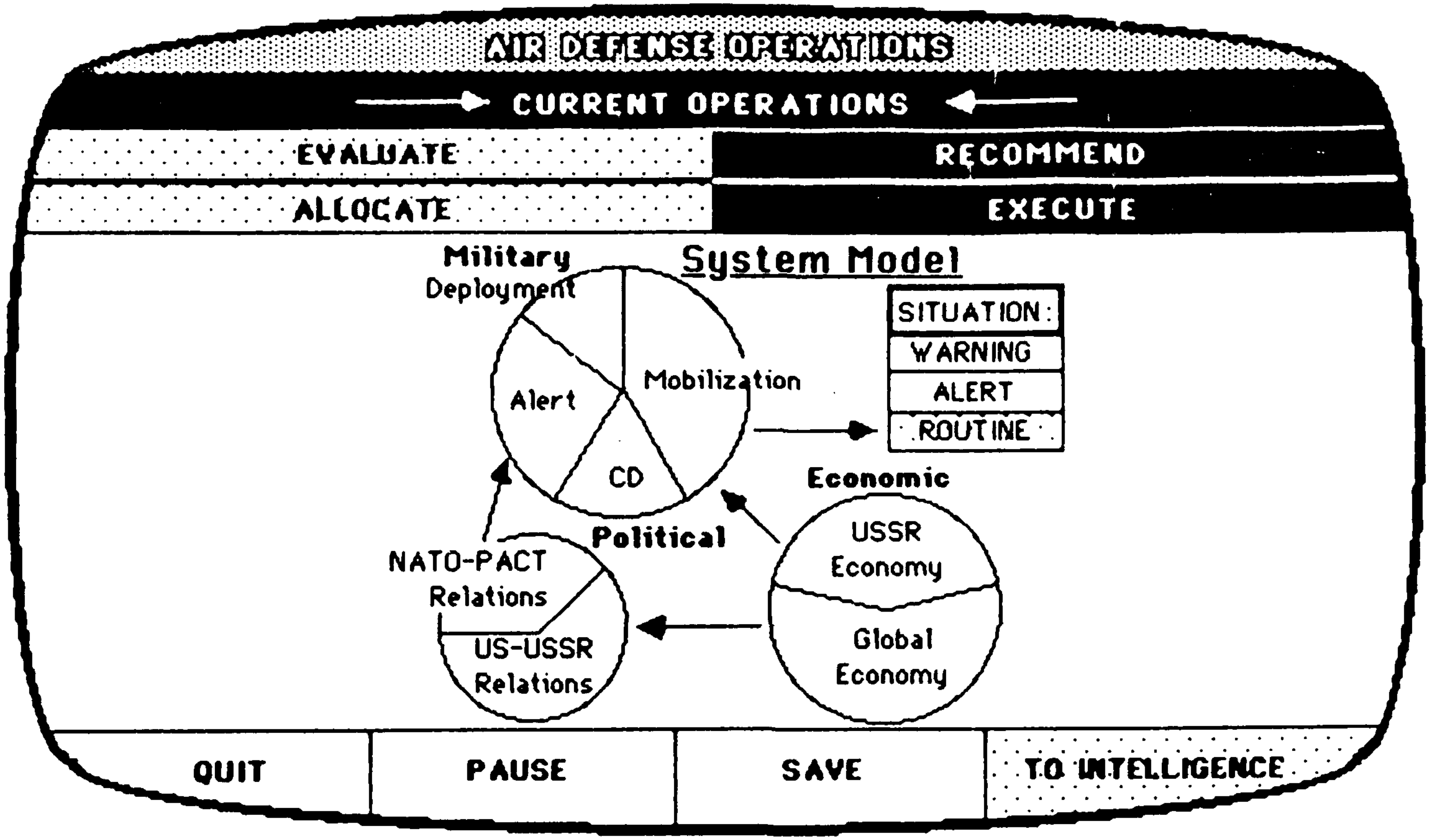

AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Routine Estimate Check: T+90 Days
Indicators:
Political
Models:
Analytical
Historical
QUIT
PAUSE
SAVE
TO INTELLIGENCE



AIR DEFENSE OPERATIONS
CURRENT OPERATIONS
EVALUATE
RECOMMEND
ALLOCATE
EXECUTE
Political Indicators
US-USSR tension expected to rise when UN Security Council convenes to discuss attack on Libyan terrorists...
EXPLAIN
ASSESS
PROJECT
QUIT
PAUSE
SAVE
TO INTELLIGENCE



The system presents the actual indicator expected to drive the increased tension likelihood. The system then presents the planner with additional intelligence analysis options, and the planner decides to inspect the models that drive the inference-making process. He clicks on **Explain/ Models**.



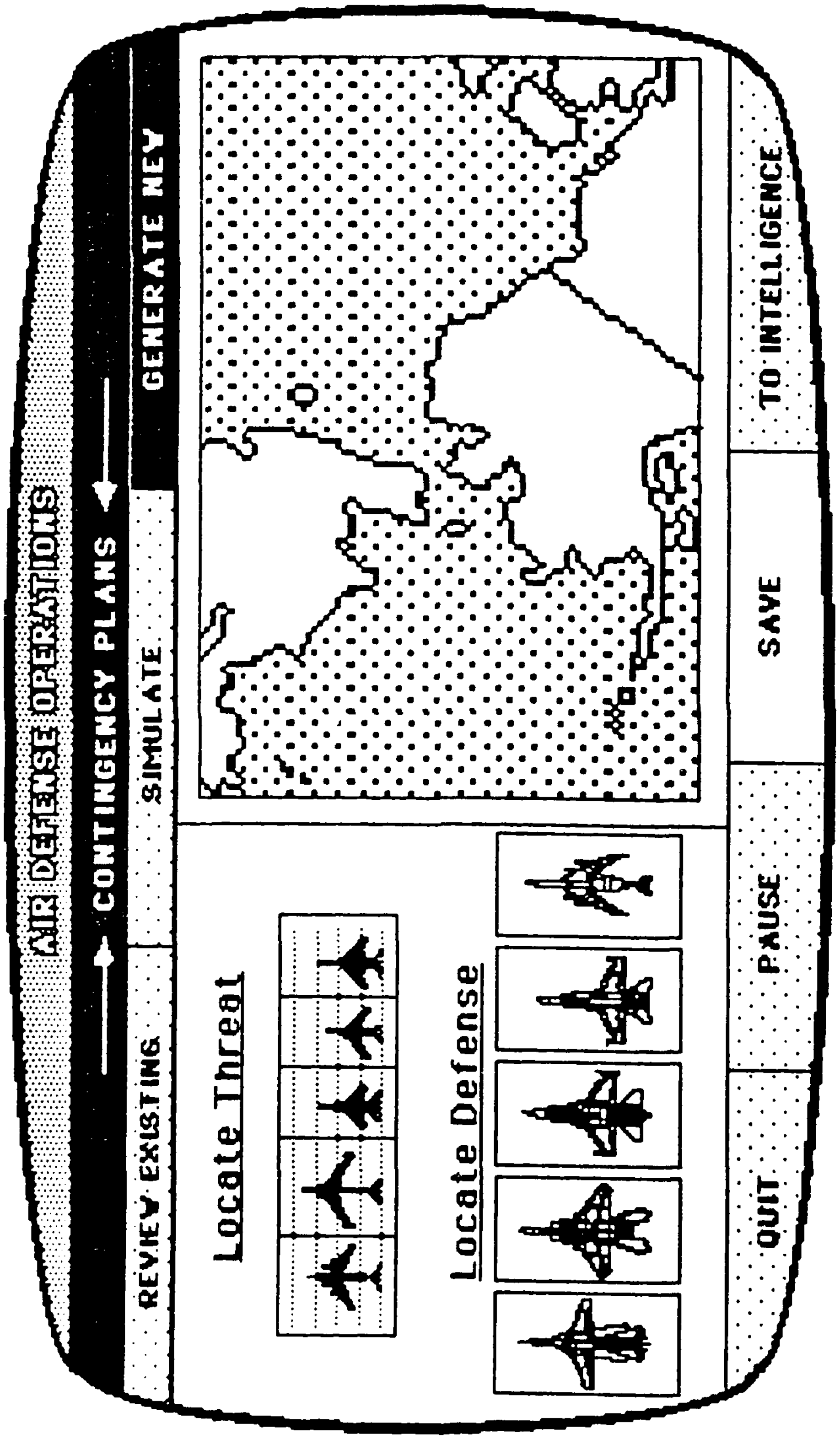
The system presents its inference model to the planner. Note that the planner is seeking information about the likelihood of increased tension between the superpowers to determine if he should favor reconfigurability over timeliness. The operations planning system provided direct access to the intelligence analysis and production system, as well as the capability to browse through the inference models embedded in the system. Specific queries can be made quickly and resolved much faster than if OPS tasked INTEL to conduct additional analyses.

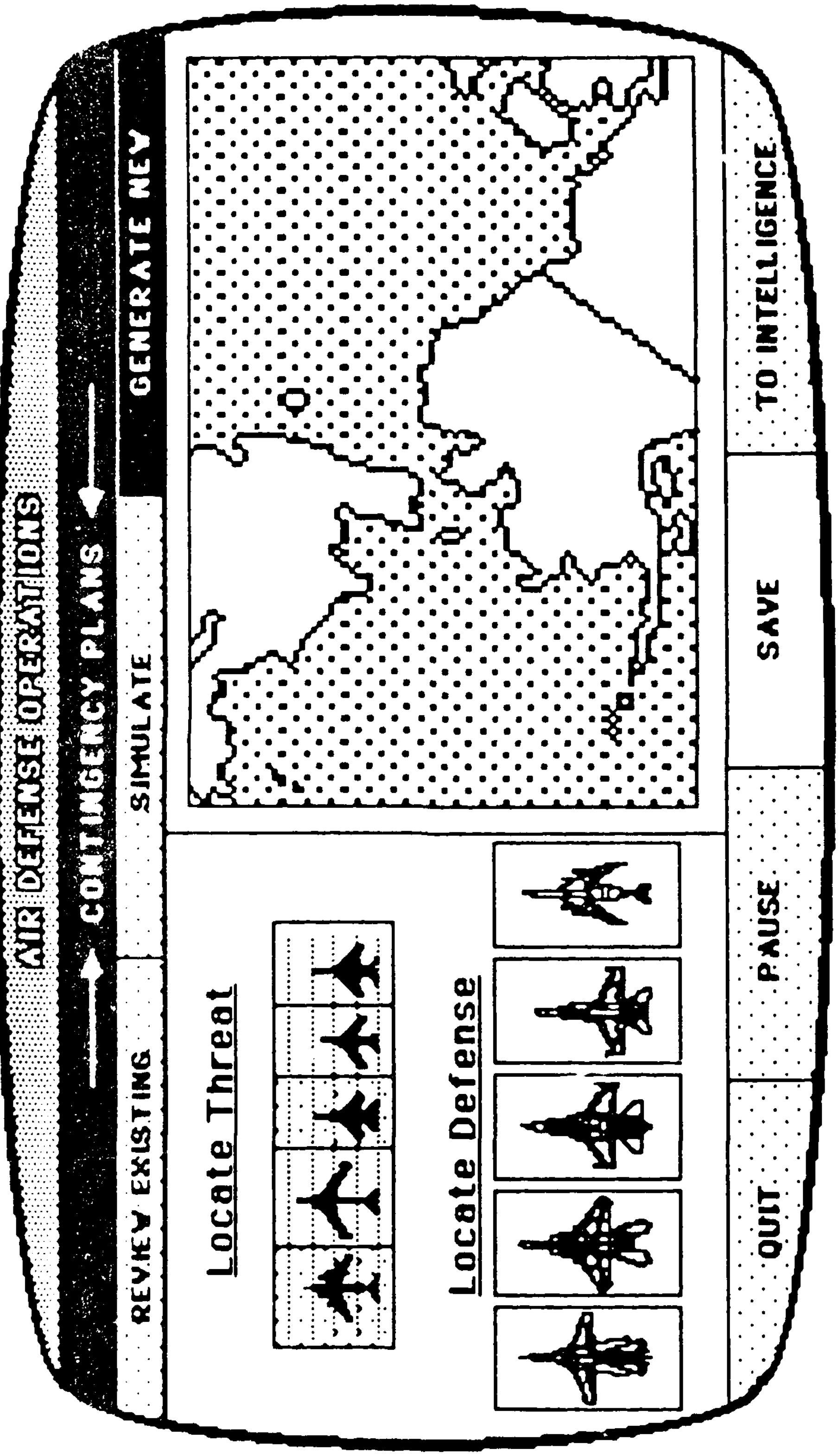
Demonstration #2

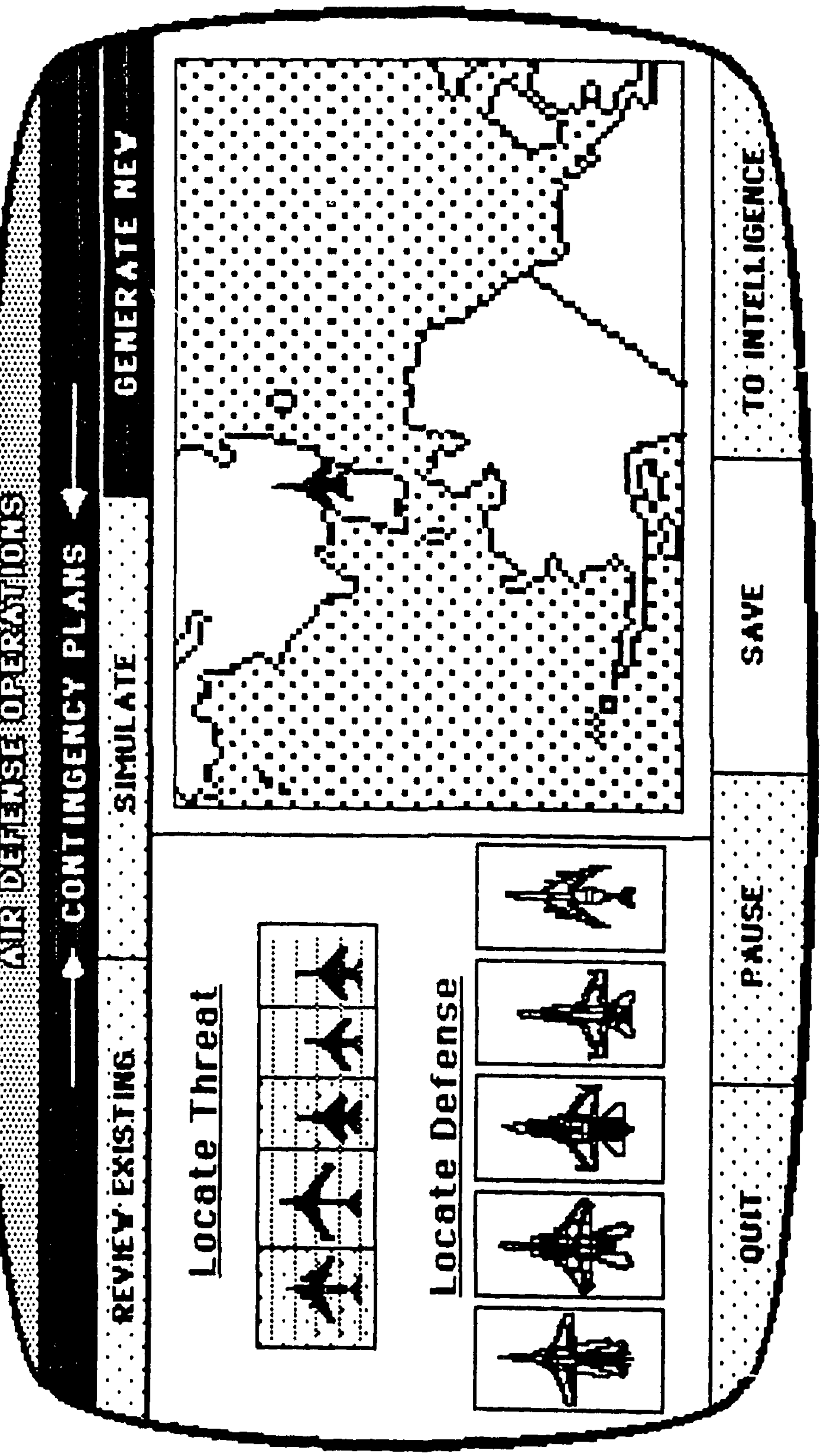
Intelligence/Operations Interface Demonstration #2

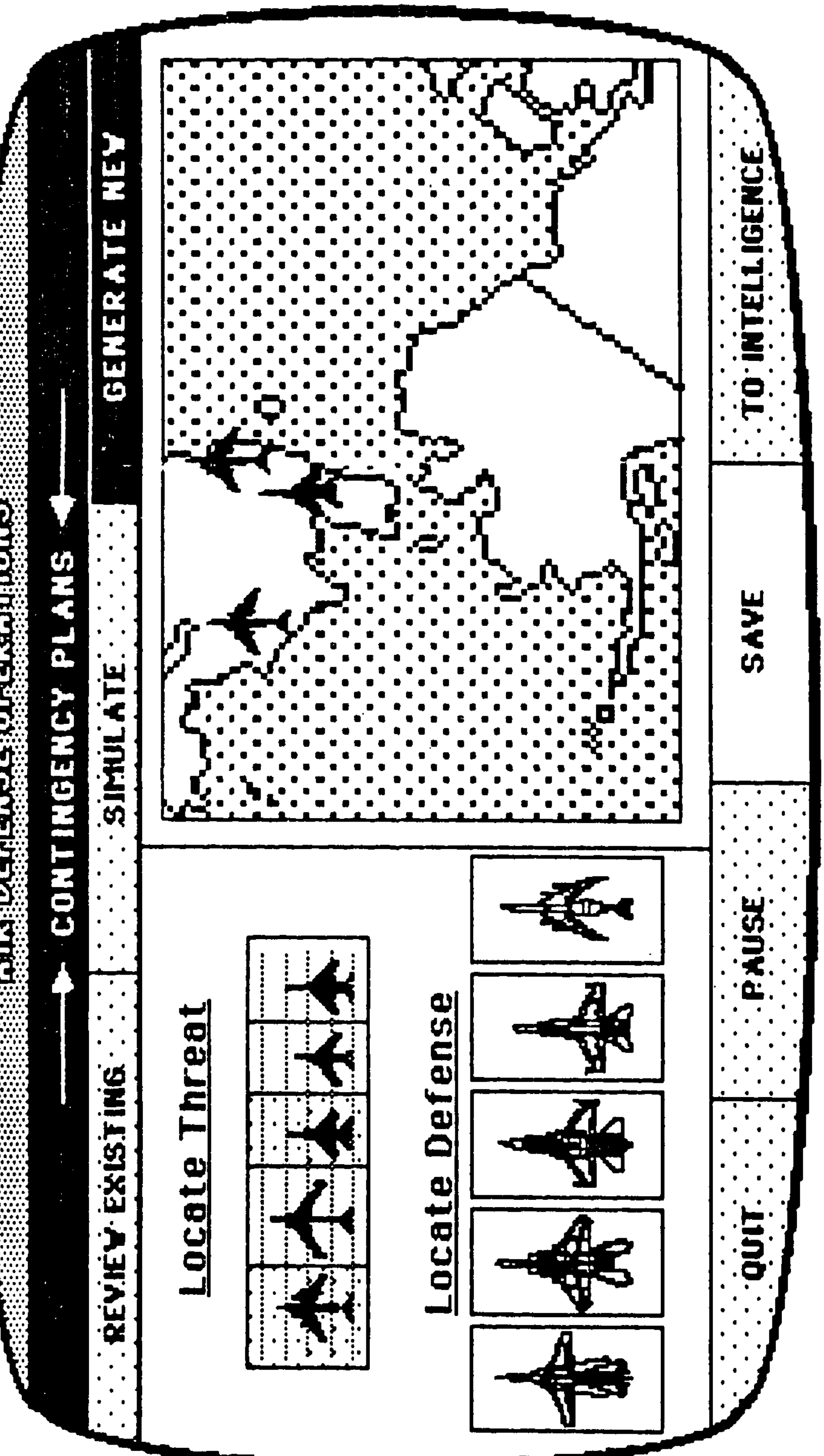
Scenario: Air Defense Operations Contingency Planning at the Top ROCC (Elmendorf AFB)

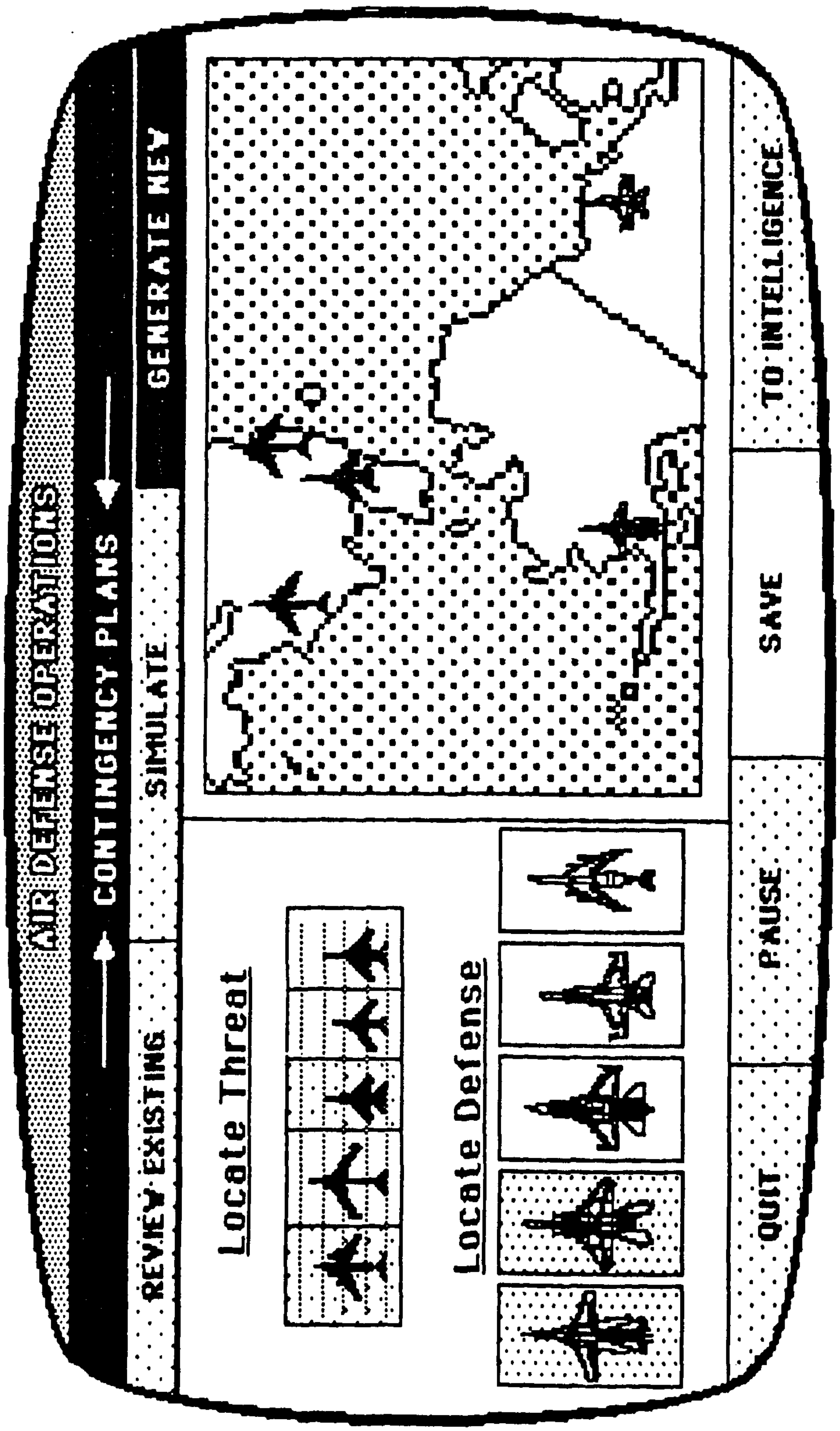
Situation: Generation and testing of alternative plans via Air Defense Intelligence Assessments

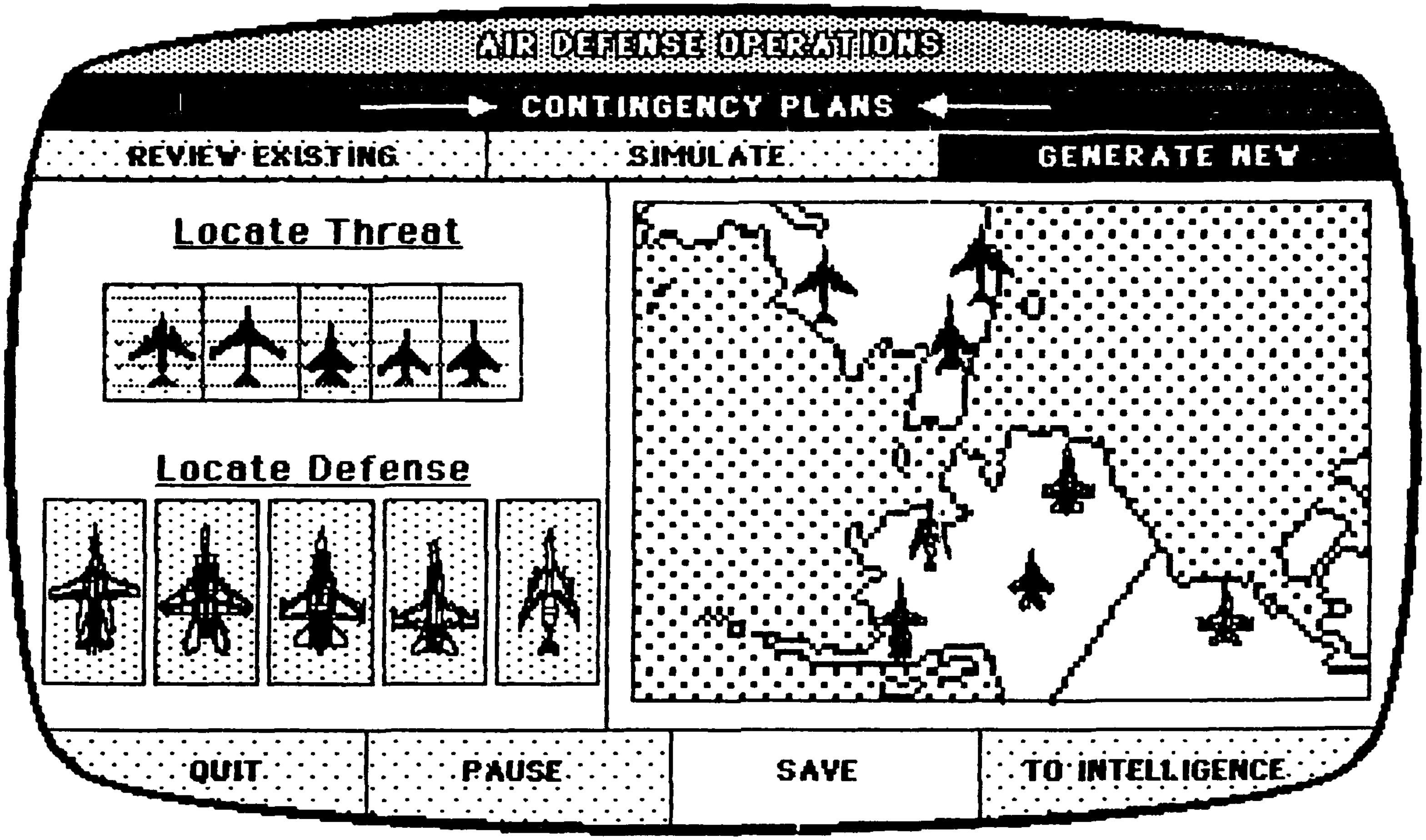

AIR DEFENSE OPERATIONS
CONTINGENCY PLANS
REVIEW EXISTING
SIMULATE
GENERATE NEW
Locate Threat
Locate Defense
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CONTINGENCY PLANS
REVIEW EXISTING
SIMULATE
GENERATE NEW
Locate Threat
Locate Defense
QUIT
PAUSE
SAVE
TO INTELLIGENCE

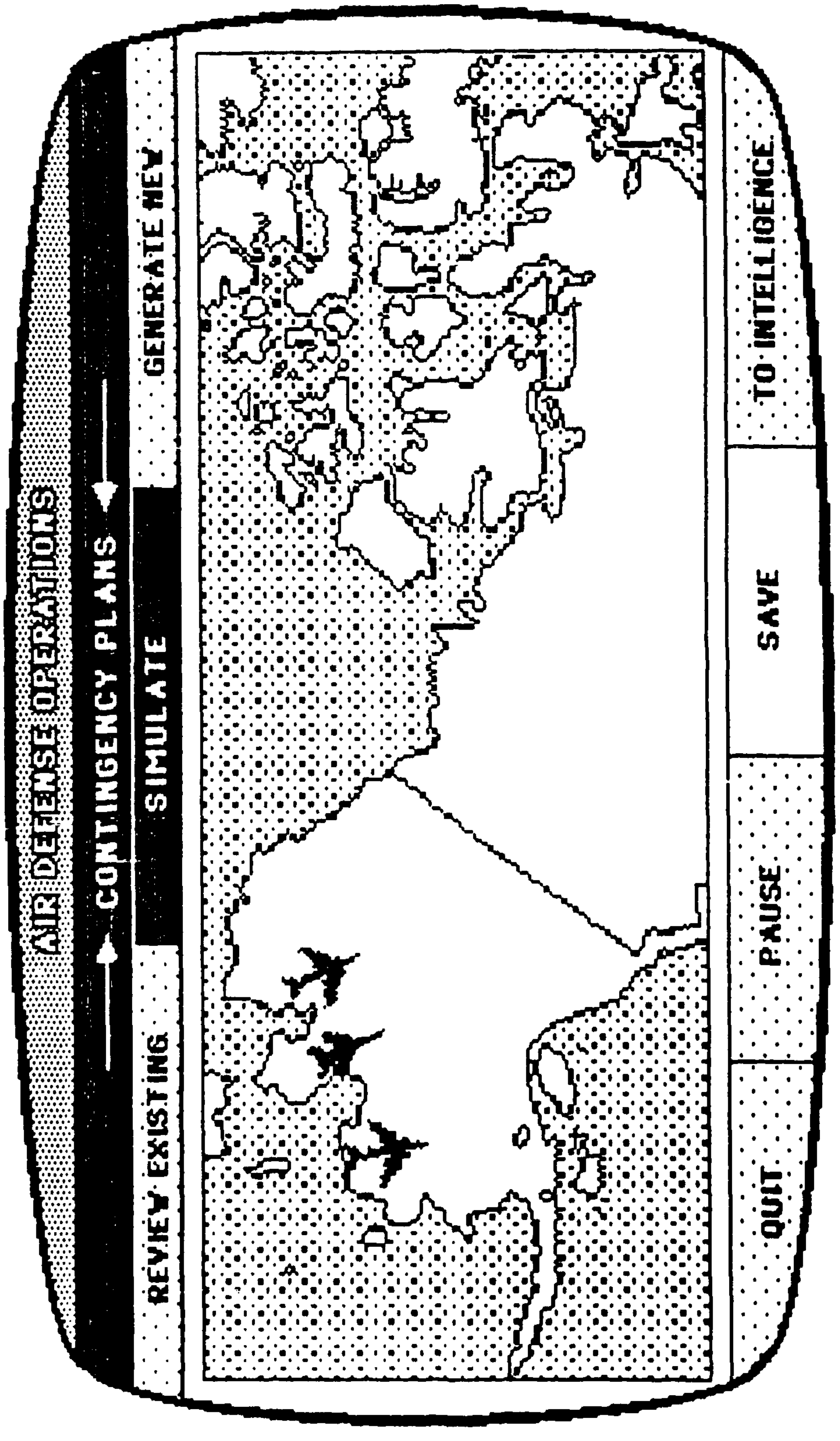

AIR DEFENSE OPERATIONS
CONTINGENCY PLANS
REVIEW EXISTING
SIMULATE
GENERATE NEW
Locate Threat
Locate Defense
QUIT
PAUSE
SAVE
TO INTELLIGENCE

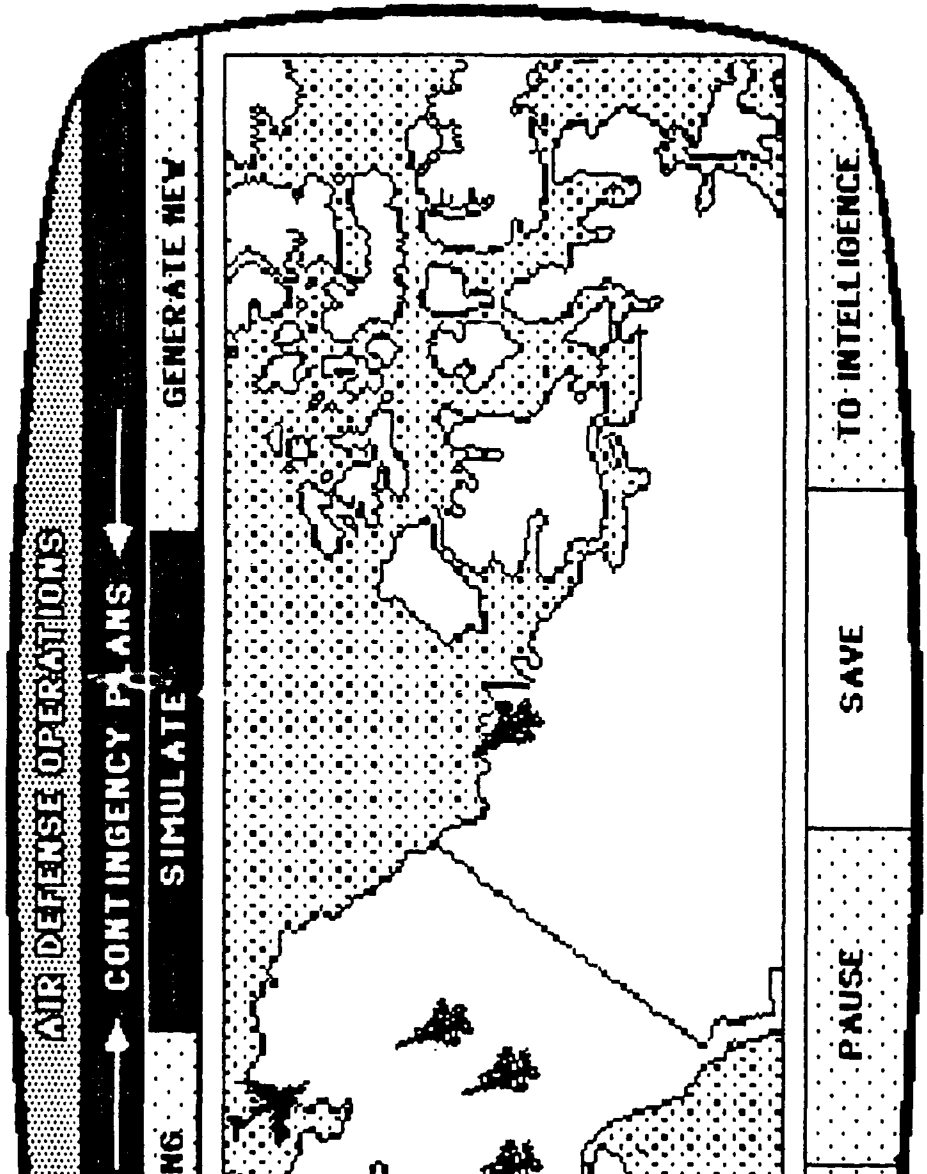

AIR DEFENSE OPERATIONS
CONTINGENCY PLANS
REVIEW EXISTING
SIMULATE
GENERATE NEW
Locate Threat
Locate Defense
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
CONTINGENCY PLANS
REVIEW EXISTING
SIMULATE
GENERATE NEW
Locate Threat
Locate Defense
QUIT
PAUSE
SAVE
TO INTELLIGENCE



This display suggests how an interactive system can be used to review old and test new contingency plans. It is also possible to simulate old and new plans. The user clicks on **Generate New** and the system presents the Top ROCC geographic map and icons for the planner to use to construct a new threat and plan.


AIR DEFENSE OPERATIONS
CONTINGENCY PLANS
REVIEW EXISTING
SIMULATE
GENERATE NEW
QUIT
PAUSE
SAVE
TO INTELLIGENCE


AIR DEFENSE OPERATIONS
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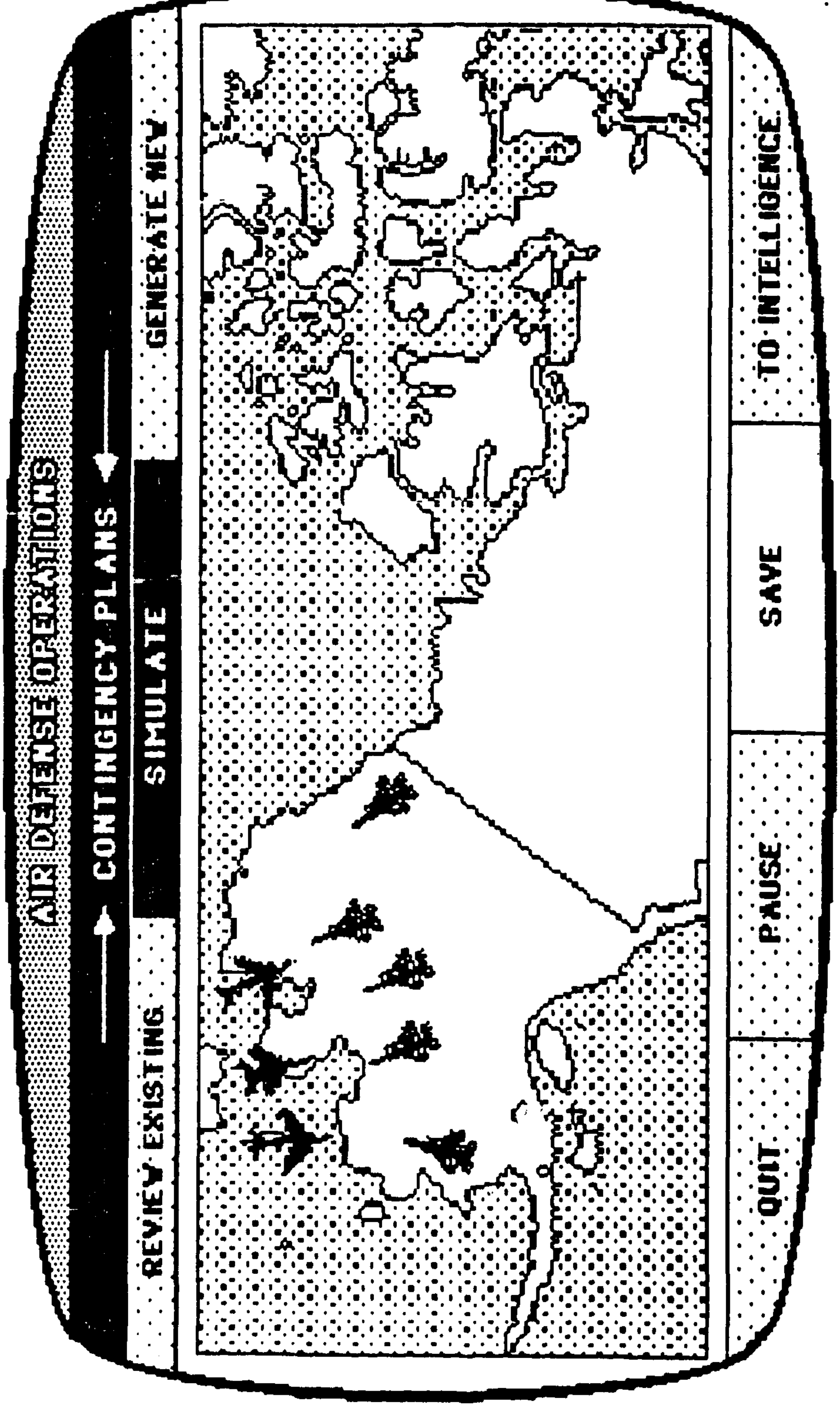
AIR DEFENSE OPERATIONS
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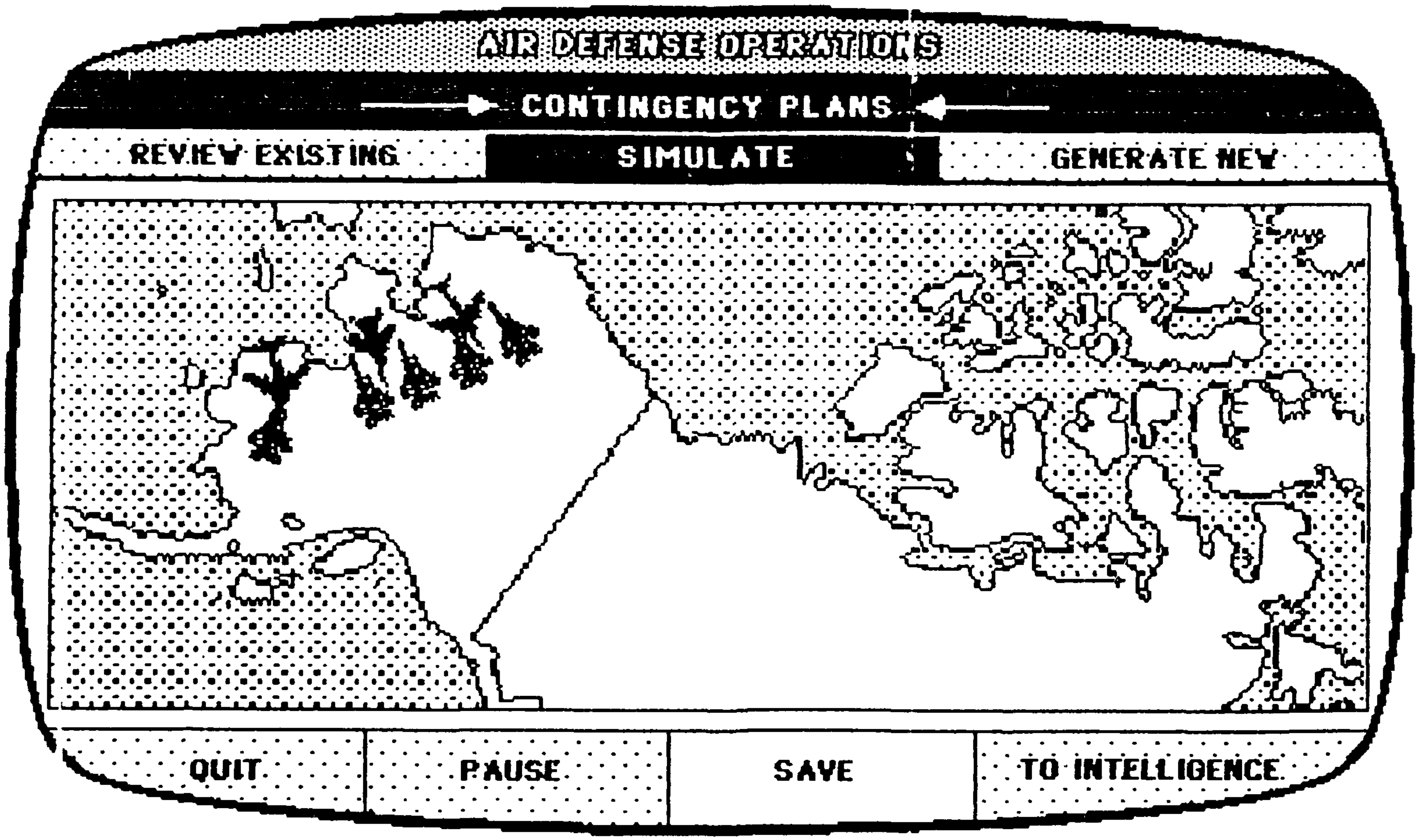
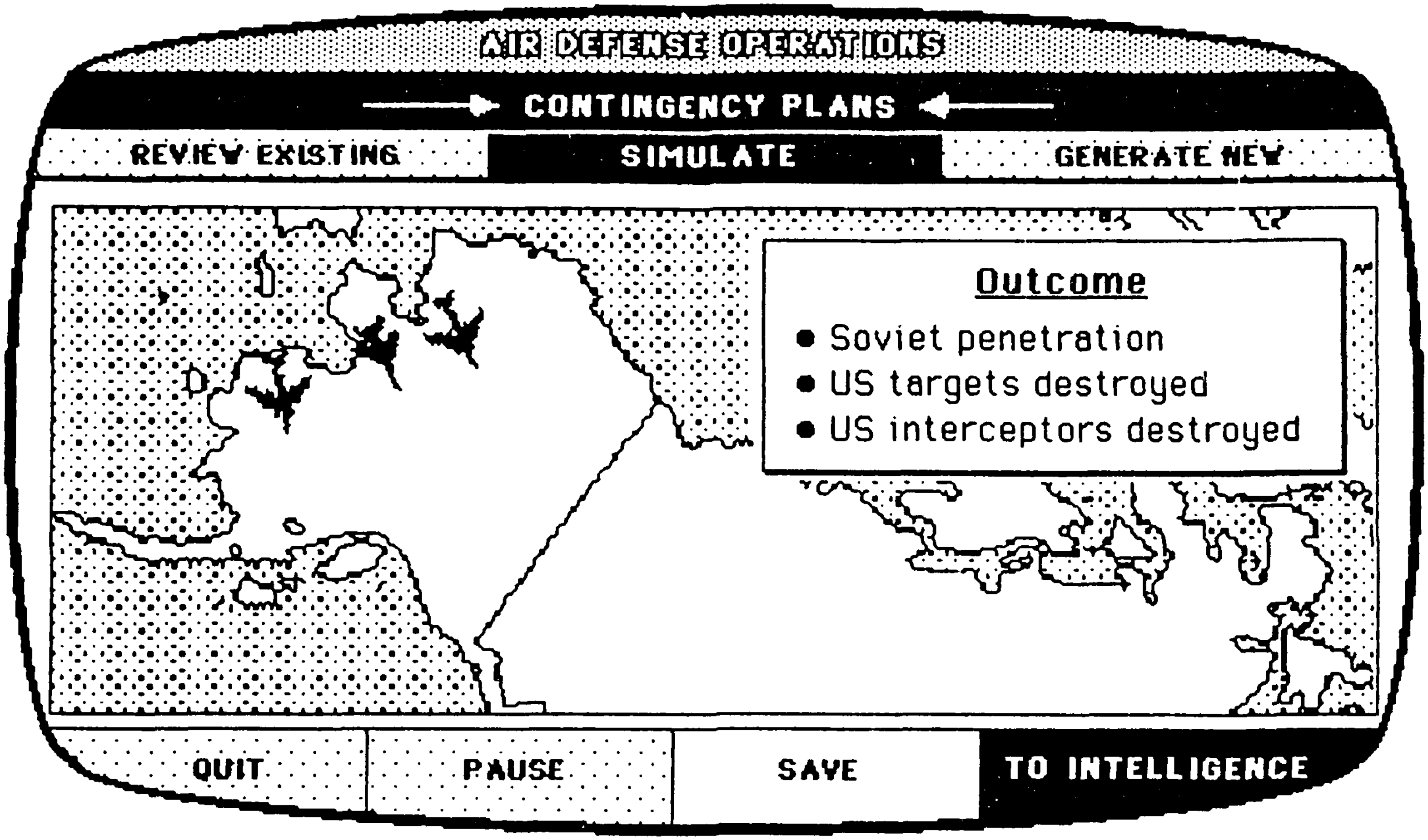
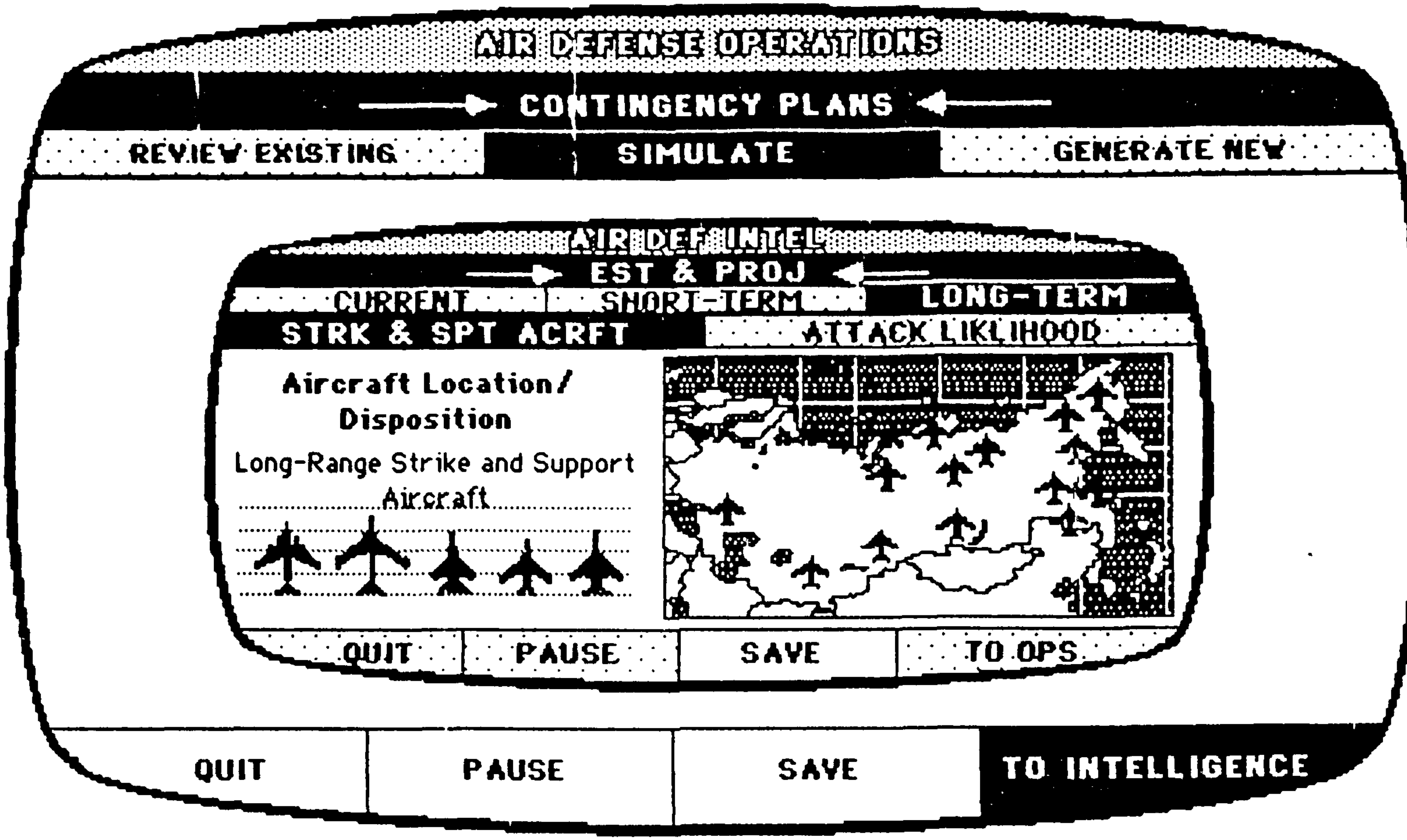


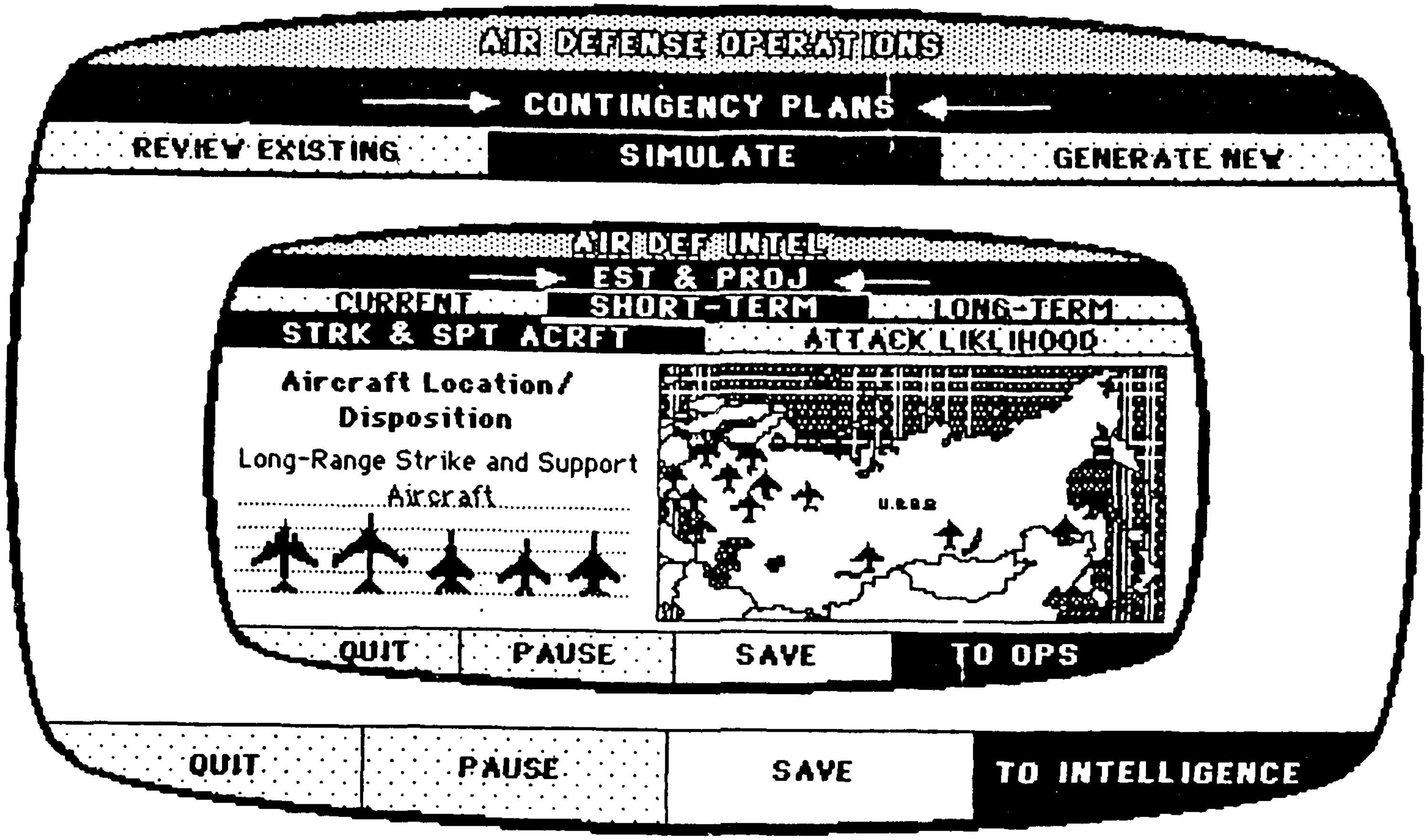
The planner clicks on **Simulate** to determine how well (or badly) the plan might work. The planner can observe intercepts, timing, and outcomes.



The system displays the "net effect" to the planner. He then decides to check with intelligence because the outcome was far from acceptable. The planner is searching for the likelihood of the threat assumed in the contingency plan. He clicks on **To Intelligence**.



The system displays a window into the intelligence system. The menu structure and interaction process is identical to "his" system. He clicks on **Long-Term Strike & Support Aircraft** to look at what intelligence believes is likely. The system presents him with its best estimate. He then clicks on **Short-Term Strike & Support Aircraft**. A variety of "what-if" activities would be possible via such interaction.



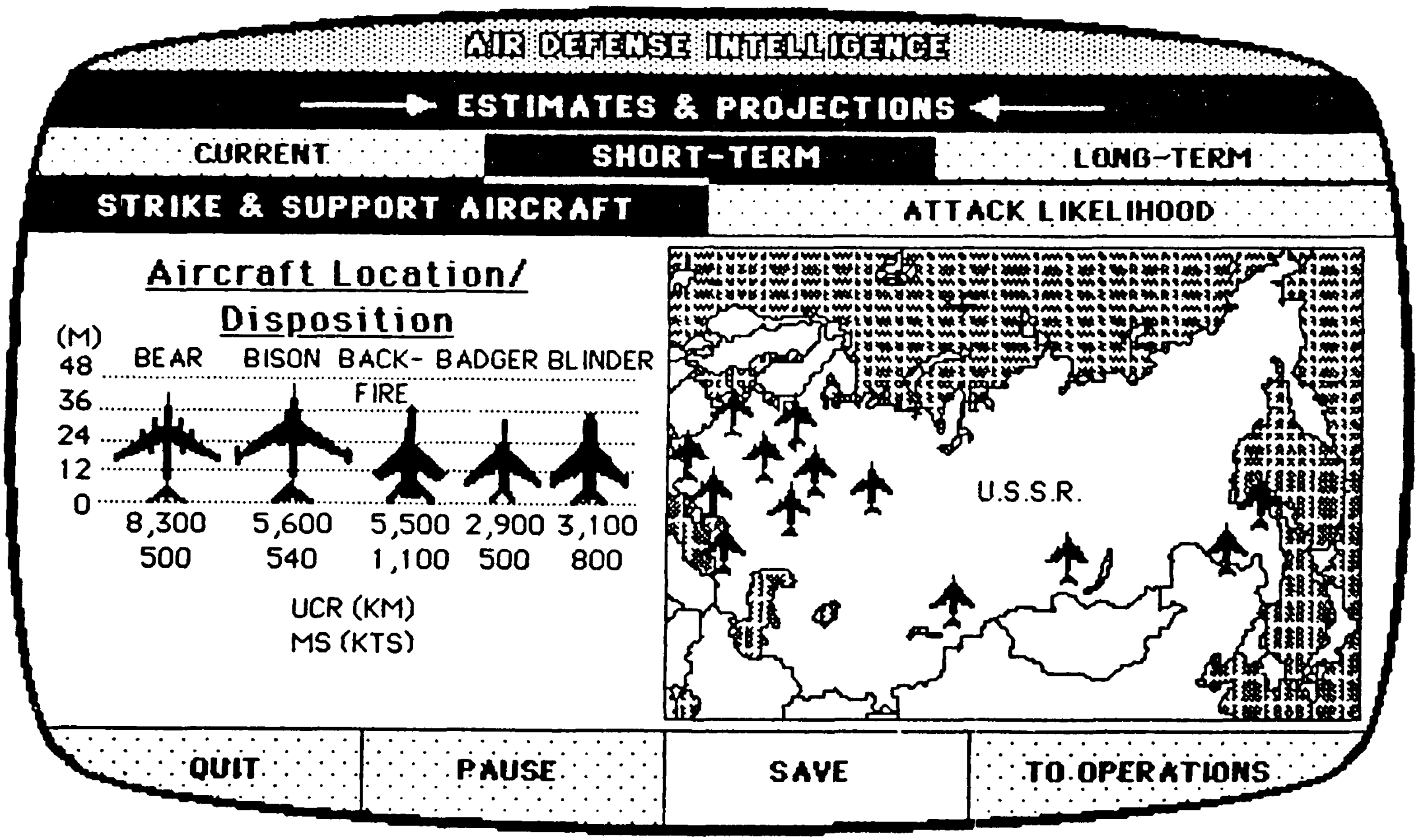
The system displays its most recent intelligence. The planner returns to Air Defense Operations Contingency Planning.

Demonstration #3

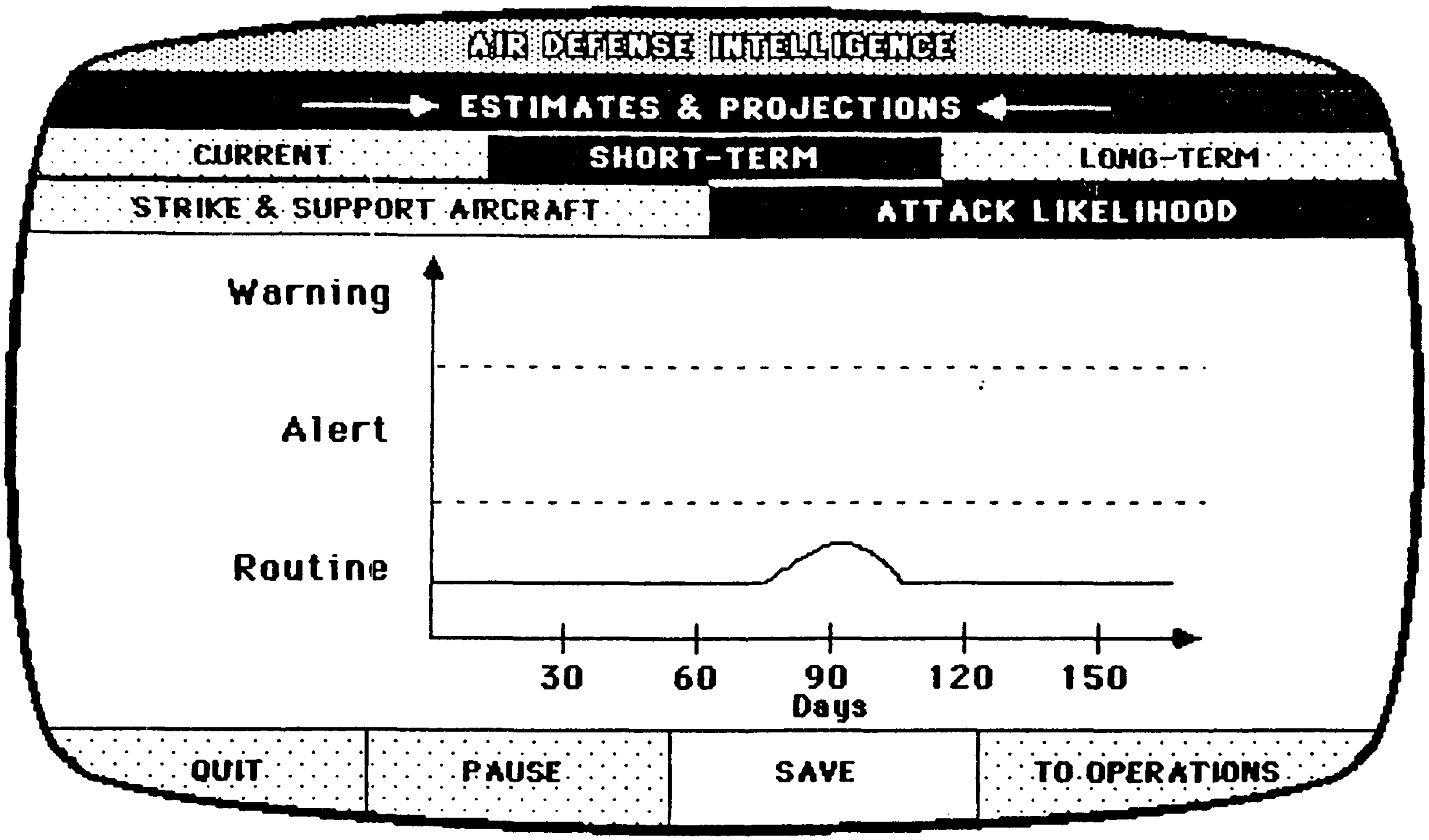
Intelligence/Operations Interface Demonstration #3

Scenario: Air Defense Intelligence
Short- and Long-Term
Estimates and Projections

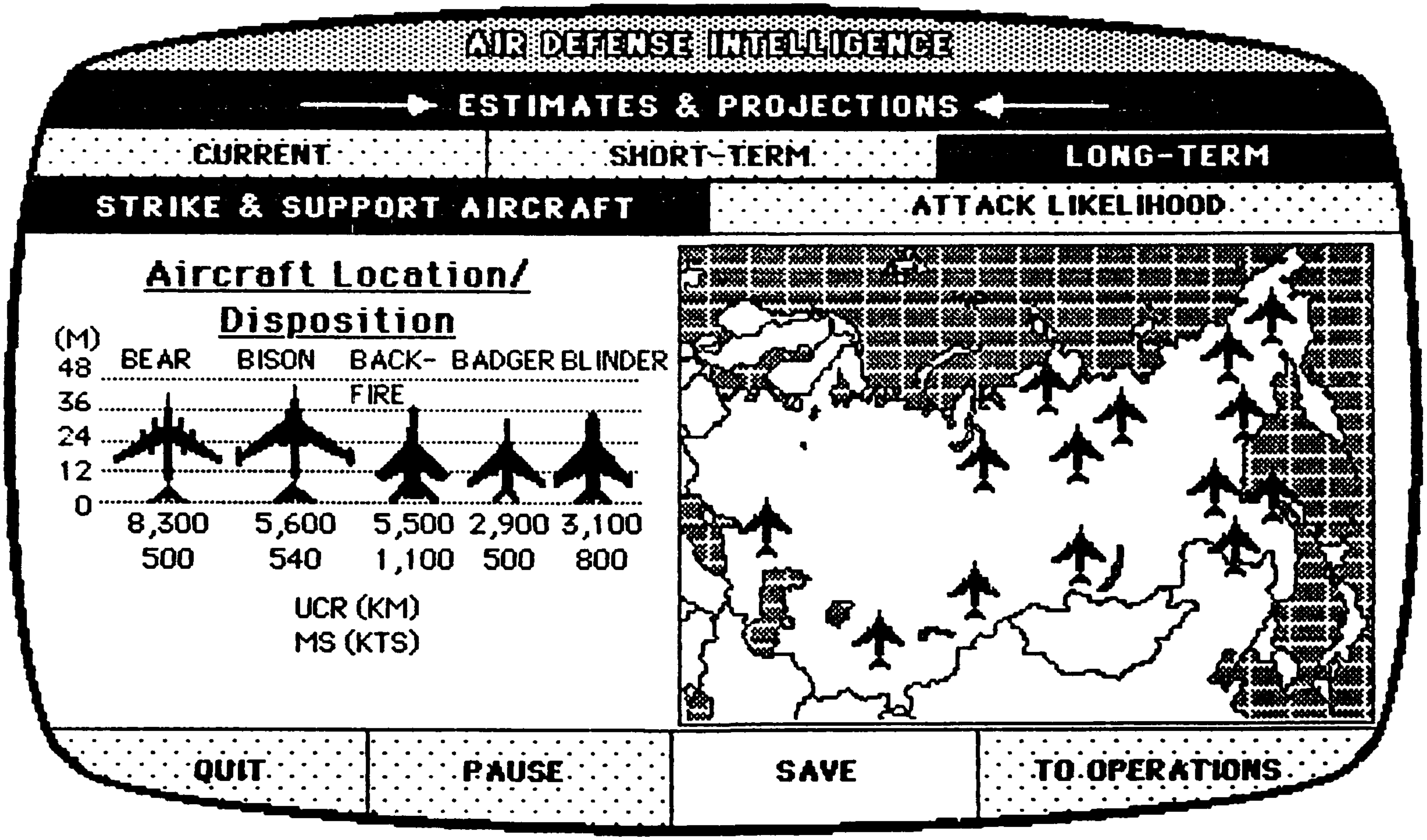
Situation: Intelligence analyses of Soviet
Threat with operational
implications



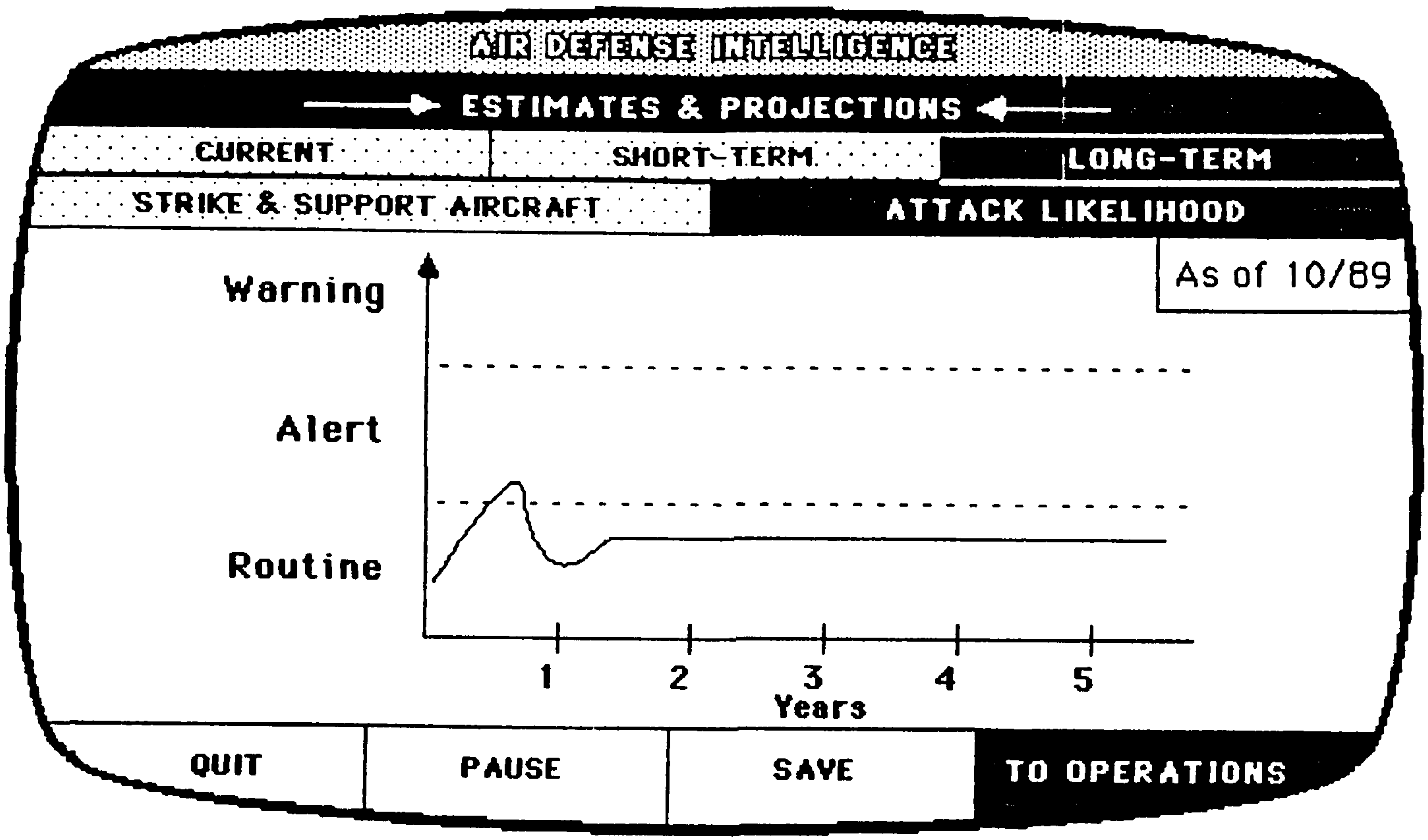
The intelligence analyst clicks on **Short-Term Strike & Support Aircraft** to detemine the current intelligence situation.



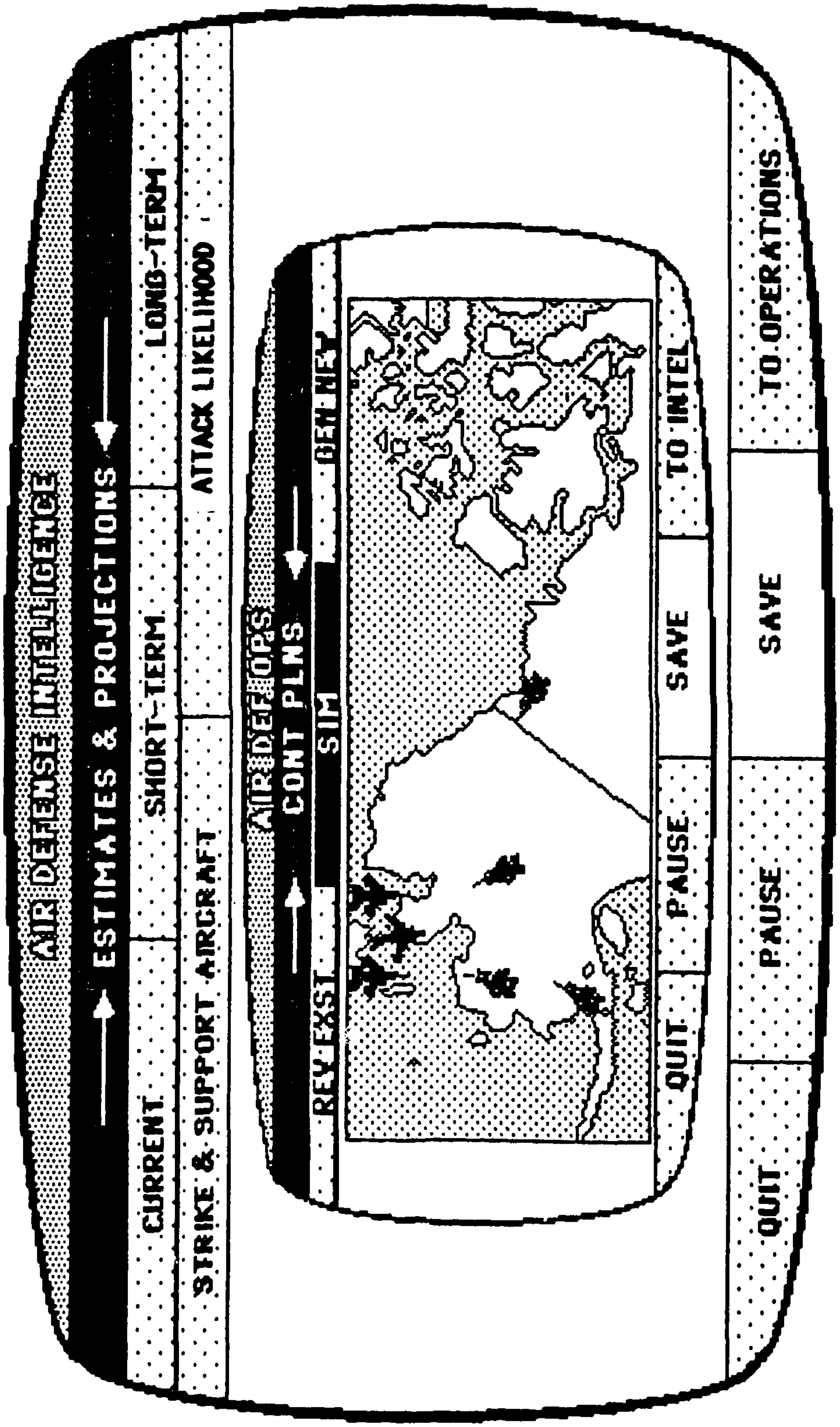
The analyst then looks at the **Short-Term Attack Likelihood**.

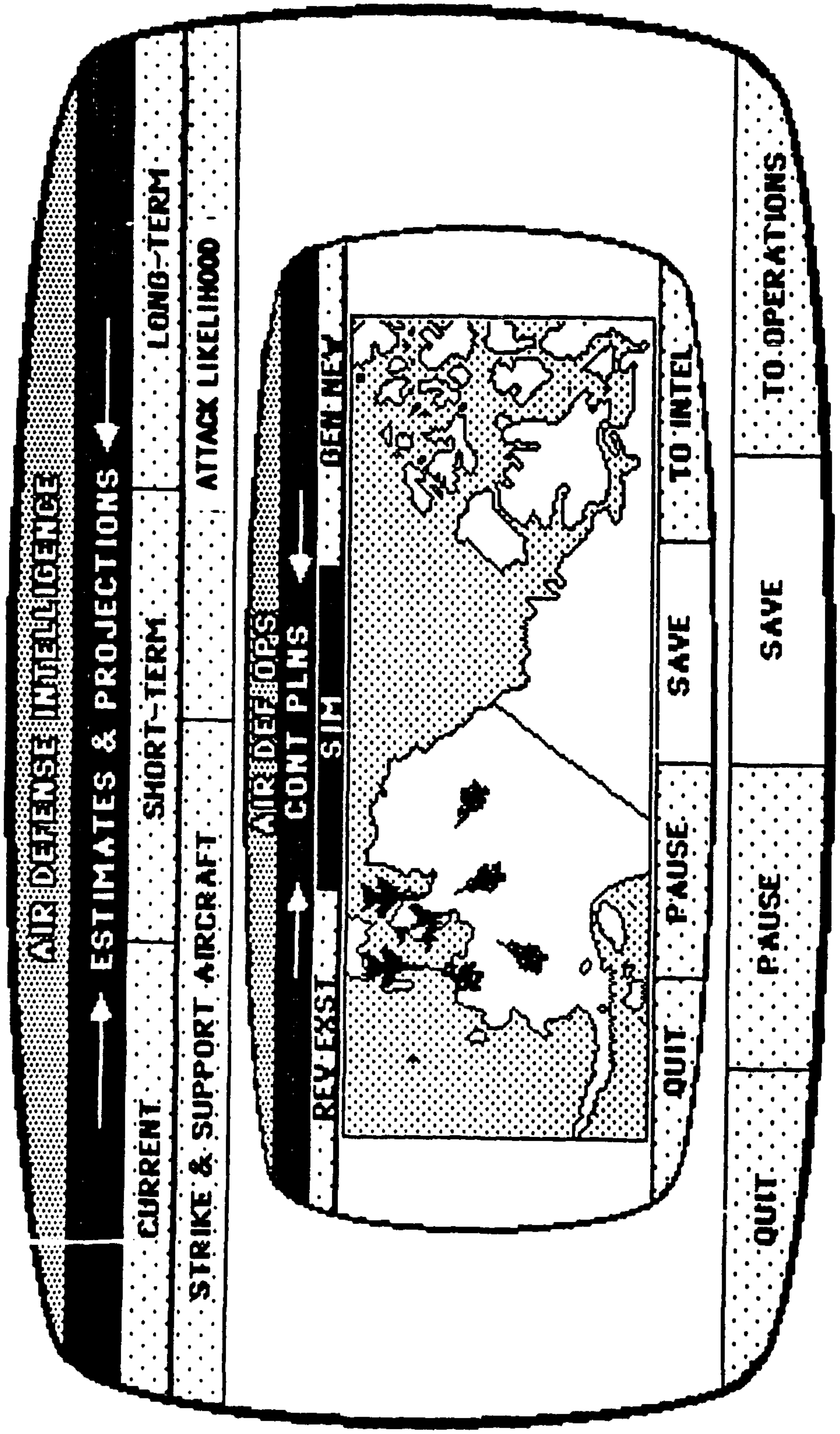


Long-Term Strike & Support Aircraft is selected and displayed.



Long-Term Attack Likelihood is selected and displayed on a time-line.


AIR DEFENSE INTELLIGENCE
ESTIMATES & PROJECTIONS
CURRENT
SHORT-TERM
LONG-TERM
STRIKE & SUPPORT AIRCRAFT
ATTACK LIKELIHOOD
AIR DEF OPS
CONT PLNS
REV EXST
SIM
GEN NEW
QUIT
PAUSE
SAVE
TO INTEL
QUIT
PAUSE
SAVE
TO OPERATIONS


AIR DEFENSE INTELLIGENCE
ESTIMATES & PROJECTIONS
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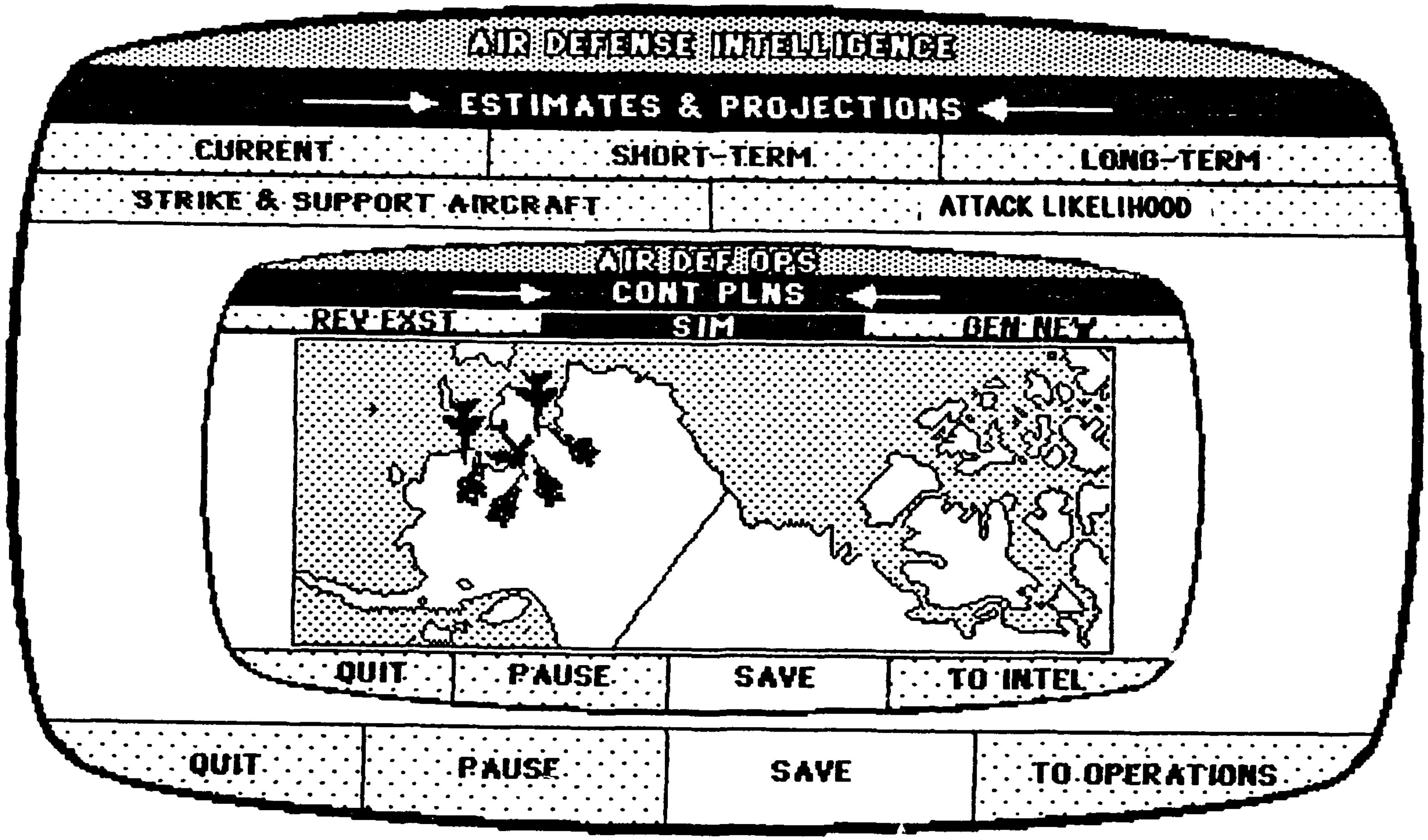
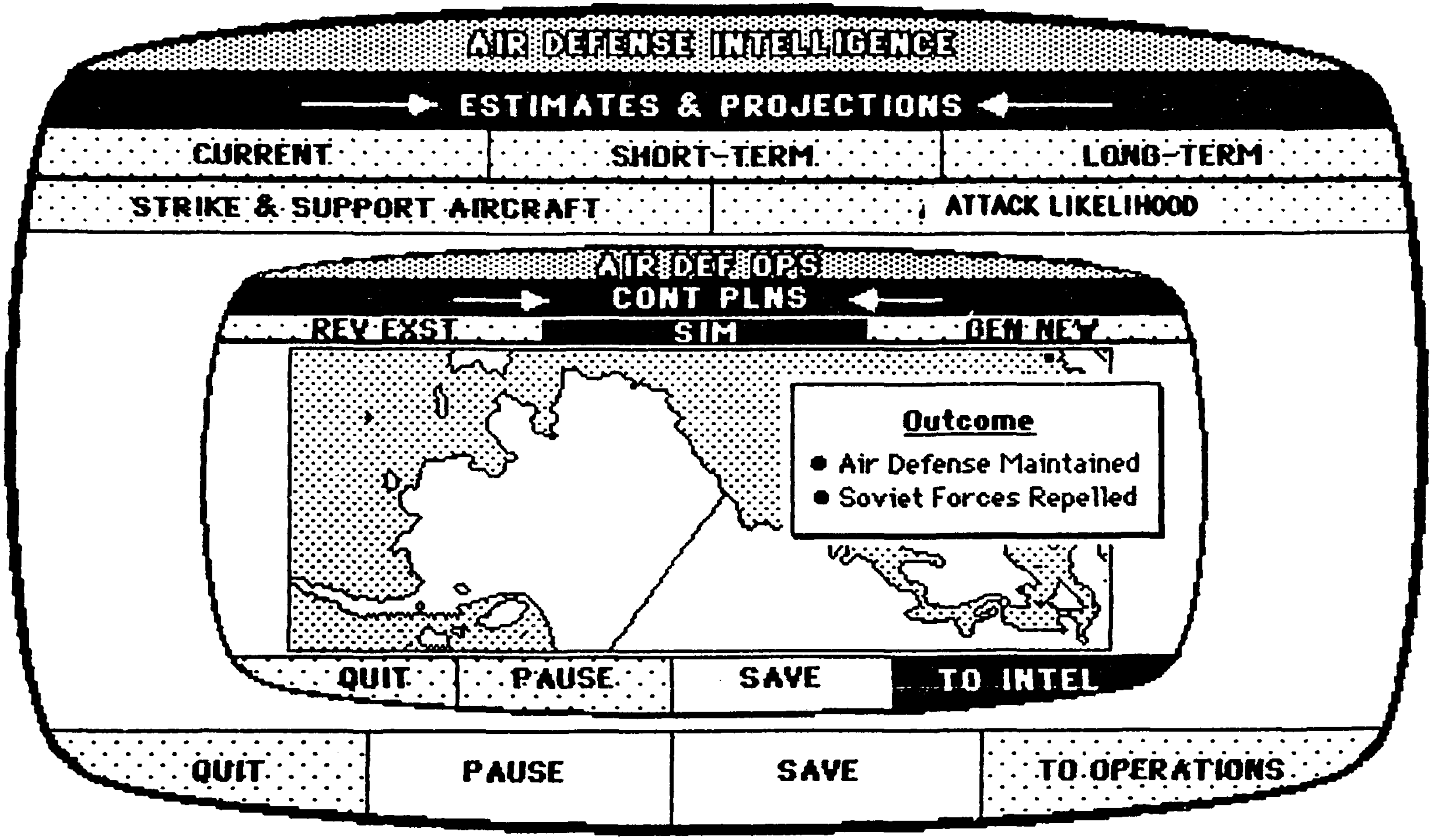


The analyst then enters the Air Defense Operations system via **To Operations**. Here the intelligence analyst decides to simulate some plans based on "his" intelligence estimates.



The system suggests that the plans are adequate, given current intelligence estimates. Had the plans been inadequate the intelligence analyst would inform Operations of potential problems.

U.S. Government Printing Office: 1990 — 748-002/00229