ABSTRACT

Data Fusion With Knowledge-Based Models: An Example Using an Air Drug Interdiction Planning Problem

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(D) Drug Interdiction

Data fusion is a process of creating and maintaining coherent views of the state of dynamic systems. These views are typically based upon limited data from a variety of sources that provide various input types. Achieving coherence requires that spatial, temporal, and object models exist that can be used to synthesize plausible views of current situation. Knowledge-based systems allow the definition of conceptual (symbolic) models that provide organizing "structures". These structures can be used to fuse the different inputs (data, information, and knowledge) in most plausible manners. These are patterned after the mental models used by expert analysts and can be used to document and consolidate knowledge held by many experts.

We will demonstrate the use of knowledge about contraband trafficking over the Caribbean region to perform data fusion supporting an air drug interdiction mission. The mission task is to sort through a large amount of situation data about air traffic and identify the most suspicious aircraft. The results are used to plan the interdiction mission (the assignment of intercept, tracking and apprehension aircraft and crews to potential suspects). Data inputs will simulate incoming intelligence from a variety of sources.

Models of air drug smuggling are encoded in knowledge bases that define the cues and indications of smuggler behavior. These are used to recognize and predict smuggler flight profiles for use in interdiction planning. The knowledge base includes definition of traditional smuggling lanes, suspicion reasons and levels, likely refueling, landing, suspect aircraft types and capabilities, and interdiction strategies and assets (bases, aircraft, personnel, and capabilities). These models define possible suspect behaviors in a smuggling region. Interdiction planning is based on a prioritized suspect list. When a suspect is posted and matches a behavior pattern, an instance of the behavior scenario is created and becomes the specific framework into which further intelligence about that suspect is fused. Evidence is accumulated from a variety of intelligence sources and put into each suspect framework. Default information within the suspect framework is applied when actual suspect information is missing. Using these techniques, the best available decision support knowledge can be applied at the required decision point.

A Distributed Architecture for the C^3I Collection Management Expert System

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Abstract

Problem solving under dynamic conditions is a major issue for C^3I decision makers. Traditional, algorithmic software systems require long formalized development and so cannot change to meet these dynamic conditions. Knowledge based expert systems, however, promise the flexible software environment needed to address dynamic C^3I requirements and computer processing resource allocation. Collection Management Expert System (CMES) [1] is a prototype system in the drug enforcement domain. CMES is a knowledge based expert system which was developed to investigate C^3I multi-sensor data fusion, situation assessment with uncertainty, and planning methodologies. CMES also addresses knowledge integration and software engineering issues associated with model based reasoning.

A distributed blackboard architecture for CMES is currently being developed with another internally developed tool, BB-Net (Blackboard Network). The future objective is to execute CMES on a network of computers using knowledge based scheduling and control with BB-Net. This will provide opportunism and parallelism in the execution and control of the C^3I modules. It will enhance throughput and error tolerance. It will provide a flexible, usable, modular system and will allow the user to interact with the current solution state from any networked monitor.

[1]supported by Monte Walters and Neil McCallion of Lockheed Space Systems Division C^3I Laboratory

Contents

1 PROBLEM DEFINITION

C^3I posture analysis and resource allocation are high national priorities. Source data to support analysis are characteristically high in volume and redundancy, while post analysis reveals both incomplete and inconsistent data. Posture analysis is labor intensive and results in low data utilization, long response times, and narrow problem domains. An information management system employing knowledge based technology and advanced computer science technology (hardware and software) can alleviate this bottleneck. Furthermore, a distributed blackboard architecture provides an environment to develop, evolve, and opportunistically execute C^3I functions. In order to initiate the transfer of these technology opportunities, Lockheed has prototyped the Collection Management Expert System (CMES).

1.1 CMES AS AN EXPERT SYSTEM APPLICATION

CMES is an expert system designed to aid the C^3I analyst in the detection of narcotic smugglers entering the CONUS in low-flying aircraft. CMES matches requirements from the U. S. Customs Service Air Interdiction System to driving mission constraints. These requirements result from the command, control, and coordination of Customs Service aircraft for interception, tracking, and apprehension of suspect aircraft. The constraints result from strategic and tactical information sources.

CMES demonstrates emerging technologies in order to communicate new problem perspectives. As a demonstration tool, it couples systems analysis with broad system capabilities. It acts as an information manager which allows hypothetical reasoning, interactive state analysis, and user defined scenarios.

As a C^3I system, CMES enables the investigation of blackboard techniques for architecting complicated C^3I modules.

As a planning system, CMES addresses priority ordering, overlapping tasks and resources, levels of resource, and uses a range of planning measures ranging from equipment counts to complex coverage calculations. Customs air interdiction is currently a situation assessment problem complicated by abundant dynamic data and complex interrelated suspicion factors. It requires flexible model/report correlation and suspicion updates. Monitoring correspondingly requires automatic integration of real time uncertain and often incomplete data from various interacting reports.

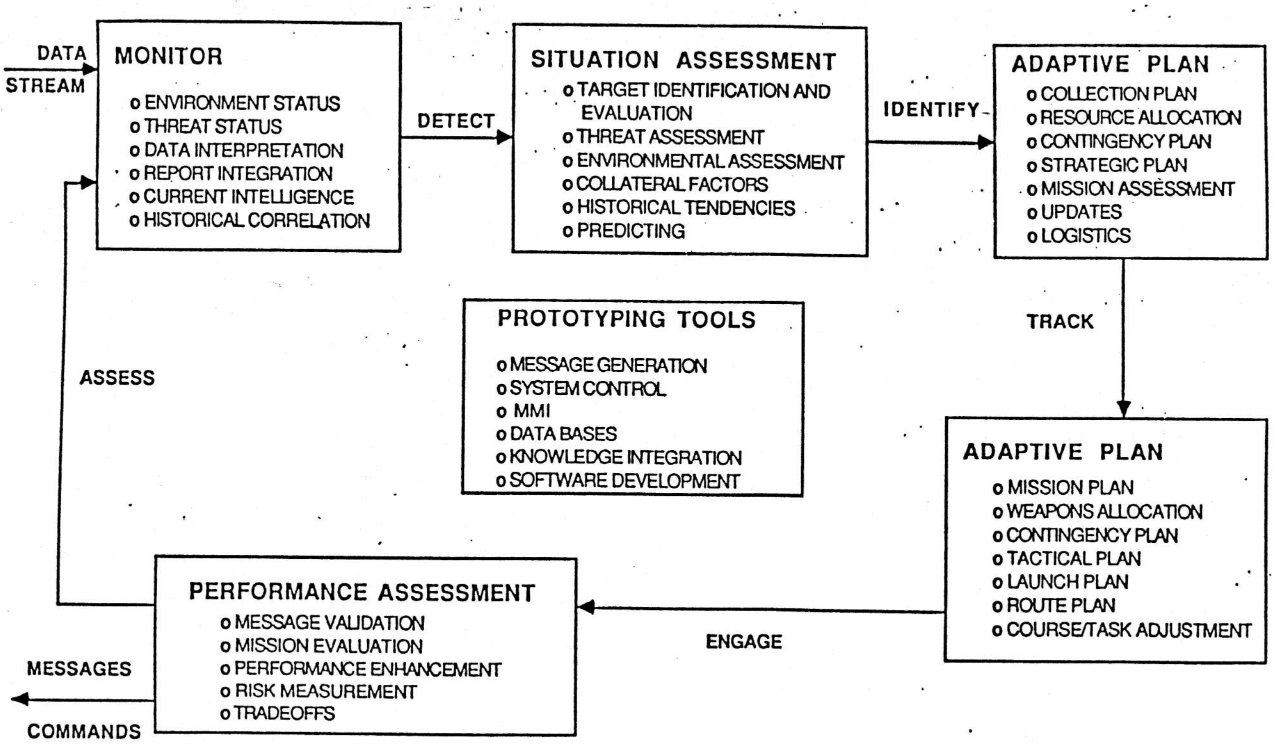

Figure 1: C^3I Analysis Functions Data Flow Diagram

In response to these C^3I requirements, CMES demonstrates various expert system techniques. Current arithmetic techniques can be complemented by the pattern matching available to expert systems. As a rule based system, CMES models the changing threat profile and inconsistent resources resulting from allocations and borrowed equipment.

1.2 C^3I FUNCTIONS

CMES supports several major functions: Profile Update, Situation Assessment, Adaptive Planning and Performance Assessment. Figure 1 shows a linear flow of typical C^3I functions as they are described in this section. Operationally, each of these functions must execute concurrently in an open cooperative system. CMES allows asynchronous operations of the functions as the external environment is asynchronous and the interfaces between the functions are capable of growing in an evolutionary manner.

1.2.1 PROFILE UPDATE

Profile Update uses immediate, actionable information on anticipated drug smuggling activity in order to pre-position interdiction resources. Several agencies produce data that must be integrated to create profile data. These agencies include Custom Service, Drug Enforcement Agency (DEA), U. S. Coast Guard, Department of Defense (DOD), Federal Bureau of Investigation, Immigration and Naturalization Service, and the Federal Aviation Administration (FAA). Data includes flight plans, law enforcement information, Coast Guard sighting reports, FAA registration of pilots and aircraft, smuggling levels, routes individual suspects, suspect organizations, equipment and seizures.

Profile Update continually monitors events and combines data into coherent structures for Situation Assessment. In order for Adaptive Planning to schedule Custom Service resources, Profile Update also monitors, the Custom Service resources (current capabilities, maintenance schedules, status, and location).

1.2.2 SITUATION ASSESSMENT

Situation Assessment anticipates drug smuggling behavior as determined by Profile Update to calculate aircraft suspicion. The Situation Assessment decision maker begins with an uncertain situation and looks for additional information. In a cyclic manner, new information is integrated into the knowledge base and the suspicion is reassessed. Information is continually requested until a final assessment is made, or until the aircraft is no longer of interest.

Smugglers thwart attempts at profiling by mimicking legal flight profiles and filing flight plans. They follow decoys with drug-carrying aircraft and often flood sectors with simultaneous flights. Custom Service Officials use rules which act on smuggling behavior models to determine suspicion and to predict behavior.

1.2.3 ADAPTIVE PLANNING

Adaptive Planning matches Customs Service resources with driving mission constraints in order to command, control, and coordinate Customs Service aircraft for the interception, tracking, and apprehension of suspect aircraft. Constraints result from strategic and tactical information sources. The diverse, strategic information sources include boundaries, position data, smuggling files, environmental data, FAA aircraft registry, pilots registry, suspect and suspect aircraft information, and various criminal and observation reports. Tactical information sources include ground-tethered radars, UBASS sensors, loaned aircraft (P-3s and E-2s), Customs Service aircraft, weather, flight plans, and other real time data. Adaptive Planning describes current and future U. S. Customs Service needs which result from growing resources.

Several features complicate C^3I planning and control systems. These systems consolidate multi-source data. Many experts from different problem domains are needed to plan, control, operate, and evaluate the system. This expertise is often a heuristic understanding gained from years of experience. Different users dictate conflicting mission requirements. Interdependent resources complicate performance evaluation. Resources change. The threats change. Changing environments (day, night weather) dictate the use of limited equipment. While equipment or aircraft are usually allocated for specific tasks (e.g., Blackhawk helicopters for interdiction), other options are possible and should be considered. These complicated features are analyzed and partitioned using a blackboard architecture, and the complicated relations are captured in flexible data structures. For example, representing a specific allocation plan (Blackhawk for apprehension, Piper for tracking, and Citation for interdiction) allows interactive modification of that strategy during planning.

1.2.4 PERFORMANCE ASSESSMENT

The final evaluation of the system depends on the outcome and success of running various scenarios. As data is collected and compared with the situation assessment judgements, the system functions are evaluated.

Performance Assessment accumulates information from Profile Update, Situation Assessment, and Adaptive Planning in order to validate messages (internal, incoming, and outgoing) evaluate missions, enhance performance, and measure tradeoffs. Mission evaluation includes the appropriate use of resource levels (e.g. considering equipment on planes, planes on bases, bases in regions), choosing and evaluating allocation strategies (different measures of success, different planning strategies) and the evaluation of observed and modeled behavior. Meta-information about module relationships are used for process and message validation. These structures also allow the threat, environment, or asset models to be varied and evaluated for risk measurement, tradeoffs, and performance evaluation. For example, Performance Assessment enables responses to dynamic C^3I conditions:

- Changes in Smuggler Tactics – Where will new threats appear? How will profiles change? How can change in historical prospective be identified?

- Long Range Investment Decisions – What kind of surveillance assets will be needed and will produce the highest payoff? Where should new assets be located? What value does mobility or relocatability of assets have?

2 ISSUES

2.1 FEASIBILITY

During CMES development, real world complexity was explicitly implemented in the Customs application as well as the general C^3I application. The system was structured such that major complications were modeled. Complicated C^3I planning features for CMES included: multi-level resources, plans composed of several related tasks, overlapping resources (resources which satisfy more than one task), n! allocation choices of resources for n targets or resources, dynamic threat, and time dependent data. Finally, in order to demonstrate a representative problem, CMES capabilities were tied to and demonstrated through standard system analysis functions.

2.2 USER INTERACTION

The basic C^3I functions provided a common language for CMES communication. Also, much of the development addressed the man-machine-interface (menus, dynamic graphics, windows) in order to make presentations understandable.

User interaction is critical to the rapid customer involved development goals of Lockheed's C^3I Laboratory. Capabilities, requirements, problem descriptions, and implementation are closely developed and change iteratively. The use of development tools by operators or experts quickens this development process by allowing operators to view quick implementation of requirements. CMES demonstrates, for example, a scenario editor, primitive explanation and rule generation integrated into the entire system.

2.3 S/W ENGINEERING

2.3.1 KNOWLEDGE BASED TOOLS

As expert system technology is brought into industry, the appropriate use and maintenance of its tools must be established. Initial Lockheed prototypes such as CMES not only demonstrate feasible new approaches, but also investigate system maintainability.

The software tools (software functions, frames, rules, and blackboards) which implement the C^3I system capabilities in CMES also define its architecture. Frames and blackboards organize information and define the control structure for rule execution. The flexibility of these tools enable the architecture to evolve with the application.

Functions implement standard operational logic and control such as window manipulation (MMI), arithmetic calculations, string manipulations, and initialization. Rules capture the dynamic non-algorithmic application logic. They provide heuristic solutions and strategies (as in planning) which are easily changed. Rules modify facts and other rules in order to model a changing or hypothetical environment. Additionally, by modifying facts and other rules, they bring development capabilities to the operational level for maintenance, understandability, and iterative implementation.

Frames categorize and control. They contain related data such as: aircraft capabilities, TAG suspicion, resource availability, and scenario information. Also, Control frames contain basic scheduling constraints and strategies for adaptive planning.

At a higher level, blackboards segregate and categorize frames. Each blackboard contains the information and rules required for its processing. Global information such as TAG reports are posted at the root and viewed and changed by all other blackboards.

2.3.2 BLACKBOARDS

Blackboards permit the redefinition of large categories of information. Blackboards are used for: functionally independent knowledge sources (KS), global communications data base, and a control structure. In order for the knowledge sources to be truly independent they must only communicate through global blackboards. This central communication allows knowledge to change as the architecture evolves without effecting the overall processing.

Five knowledge sources were initially defined during CMES development: suspect behavior, planning, geopolitical environment, spatial analysis, and man-machine interface (MMI). Suspect behavior and planning blackboards isolate facts and rules associated with those capabilities. The spatial analysis blackboard contains rules and functions which assess observable behavior (of either Customs resources or suspect targets) and perform calculations for behavior assessment and planning. Geographical modeling consists of the geopolitical information contained in that blackboard. Information in these blackboards is developed interactively via rules on the MMI blackboard. By allowing the MMI blackboard rules to track the state of the system, the implementation closely matches the application.

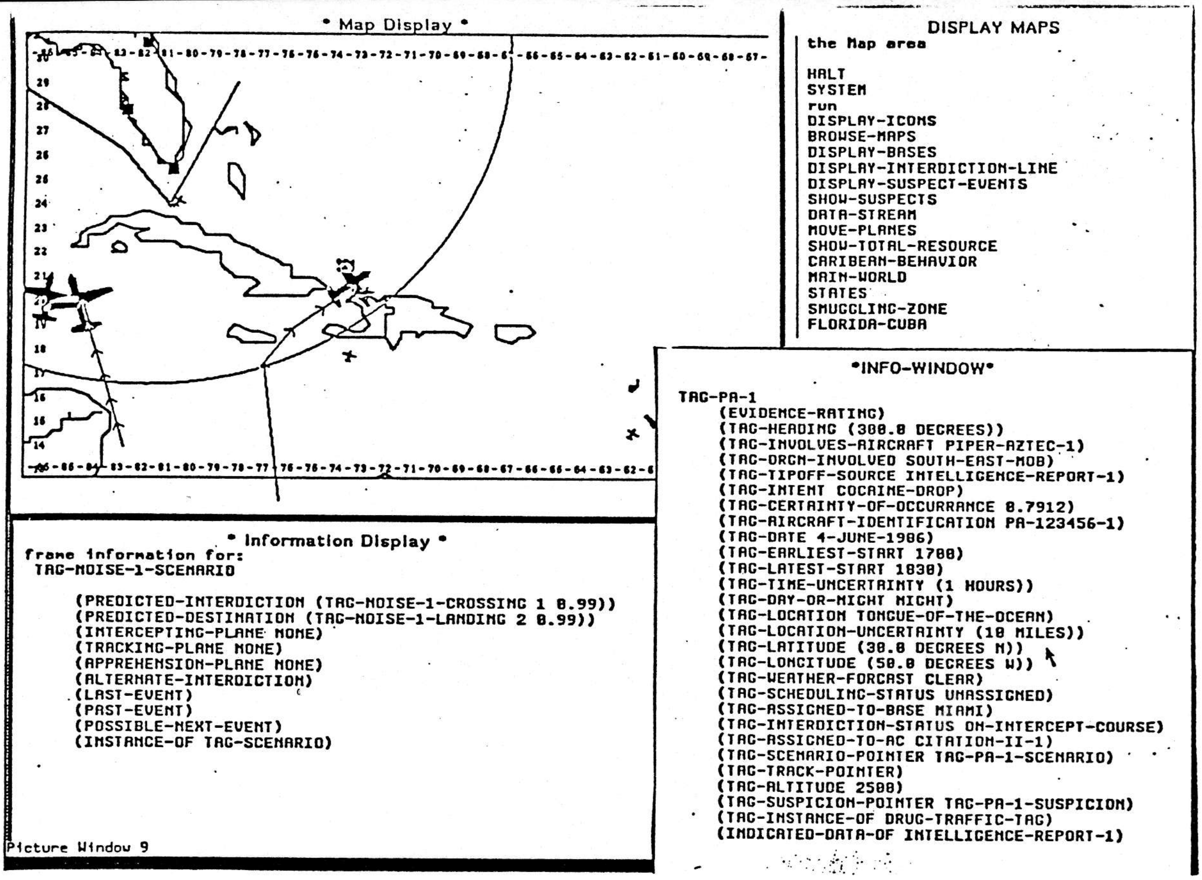

Figure 2: THREAT PROFILE UPDATE SCREEN

3 IMPLEMENTATION

3.1 PROFILE UPDATE

Profile Update provides information management by monitoring, integrating, displaying, and updating data (see figures 2 and 3). In a C^3I system, user interaction is critical in all of these areas and is available in knowledge based systems such as CMES. Initial scenarios and profiles are interactively defined when the user designates routes and route activities, threat aircraft and aircraft parameters, and corresponding intent. A correlation between current reports and report formats allow incoming data (emulated by data files read periodically by asynchronous functions) to be automatically integrated into the knowledge base and suspicion intent updated. All updated information can then be examined through the menu/window directed operator interface and then modified with the frame editor. Figure 2 is a screen display of some of the dynamic data associated with two potential smugglers (TAG-PN-1 and TAG-PA-1). Regional bases (squares), an interdiction line, and base interdiction range (ellipse) are also shown. The information is displayed by choosing menu items corresponding to the mousable icons.

3.2 SITUATION ASSESSMENT

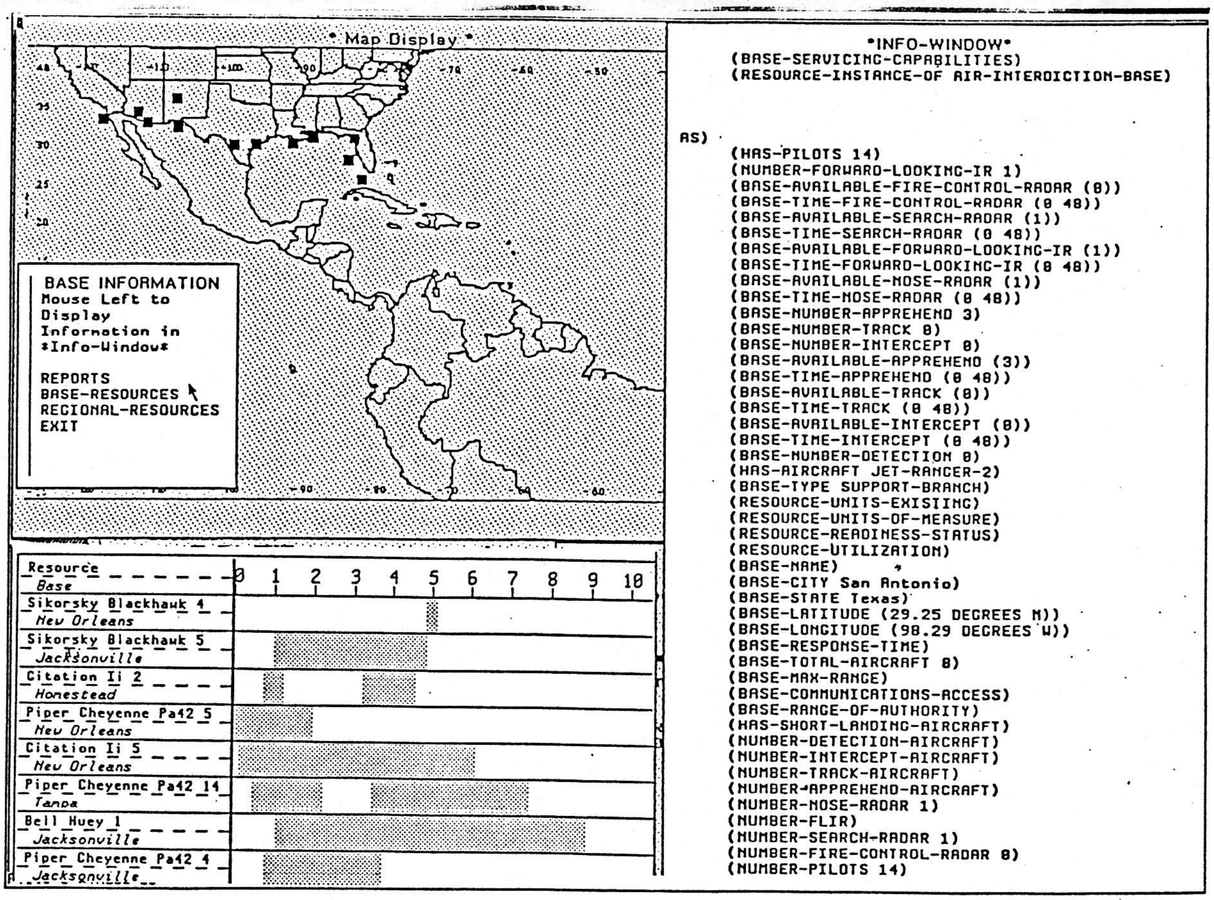

Figure 3: ASSETS PROFILE UPDATE SCREEN

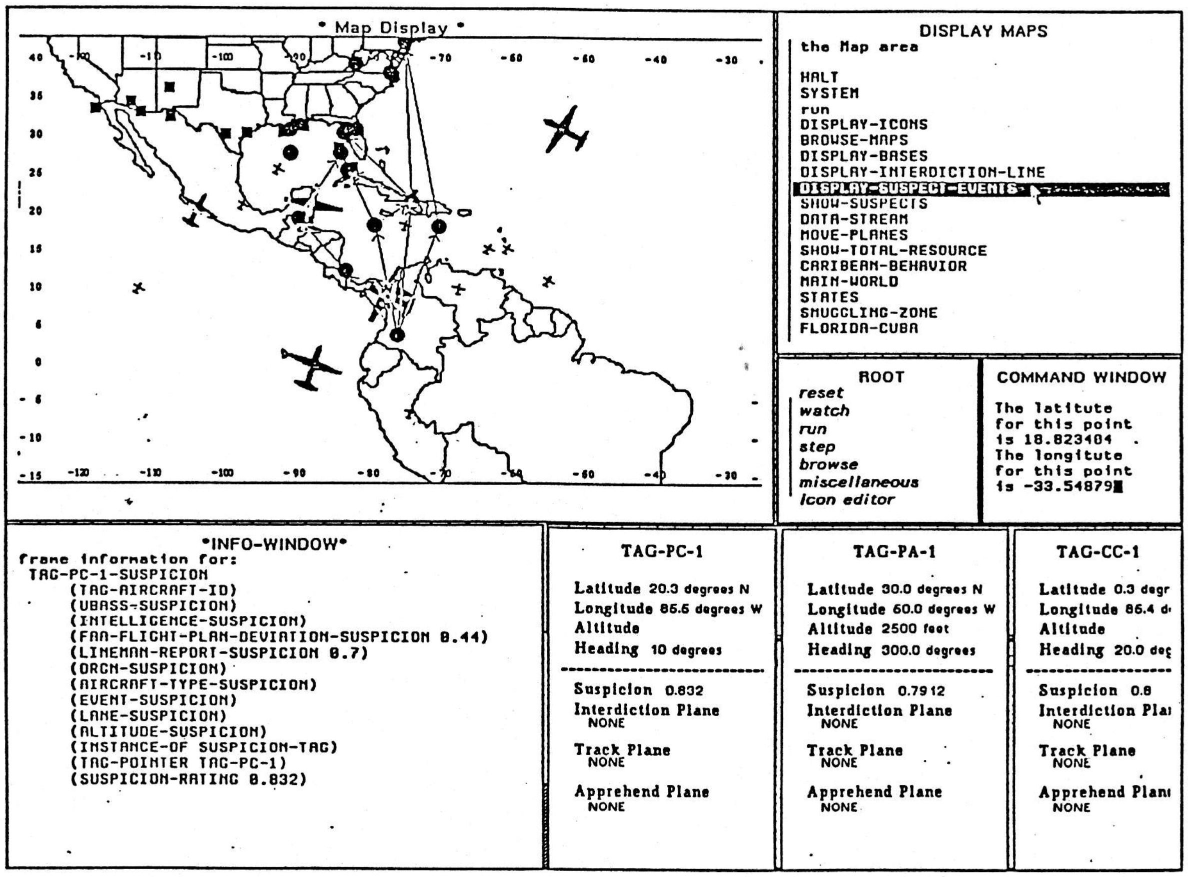

Figure 4: SITUATION ASSESSMENT SCREEN

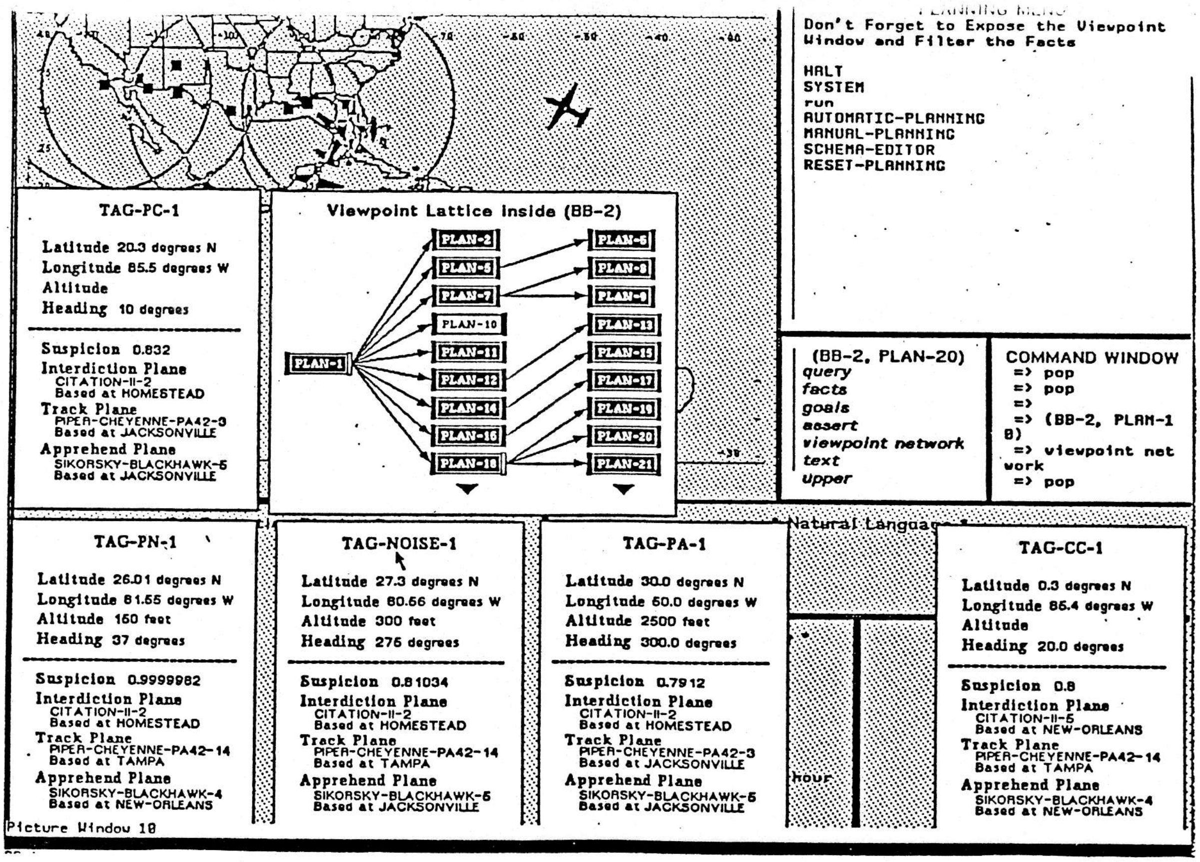

Figure 5: ADAPTIVE PLANNING SCREEN

Situation Assessment performs target identification and evaluation along with environment, threat, and resource assessment in order to predict threat behavior and intent. Figure 4 displays the CMES threat model in which target aircraft (TAGs) locations are matched against typical smuggling lanes and corresponding behavior at lane nodes. This correlation is combined with incoming suspicion report information from a variety of reports in order to determine an overall suspicion rating and likely interdiction and apprehension locations (see figure 2). The slots in the suspicion frames of figure 4 indicate specific suspicion reports and threat ratings generated by those reports. This information is combined using MYCIN propagation for an overall suspicion rating.

Figure 3 displays two aspects of the resource model: base resources and aircraft availability. This type of interactive information management allows the user to view and analyze the resource state before continuing to adaptive planning. All facts are mouse sensitive, yielding either an explanation or a rule trace implemented by run-time rule definitions. Situation Assessment demonstrates three operator capabilities previously limited to developers: ability to display canned explanations of dynamic facts, the ability to examine and evaluate system reasoning and the ability to generate new (but constrained) code during system execution. These features enable a highly user interactive, evolvable system.

3.3 ADAPTIVE PLANNING

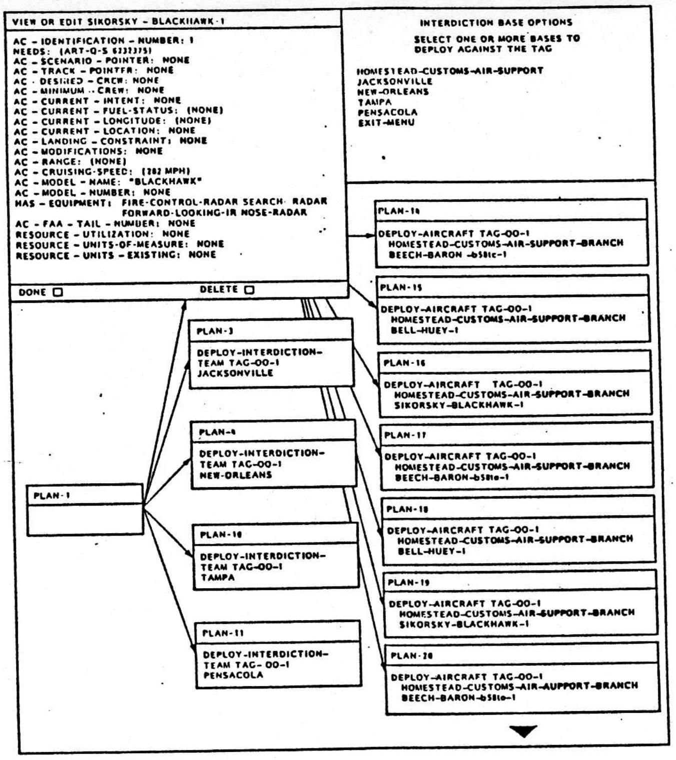

Figure 6: PLANNING INTERACTION

Adaptive Planning matches Customs resource to the high priority threats identified by Situation Assessment. Customs resources consist of people, aircraft, aircraft-types, aircraft-ranges, aircraft use, and radar equipment as available over 24 hours. Assessment rules determine an interception and apprehension point for each suspect and match aircraft and base assets for three tasks: interception, tracking, and apprehension. Suspects are considered in order of suspicion. The single planning strategy is to find the fastest team composed of a Citation for interception, a Piper for tracking, and a Blackhawk helicopter for apprehension. If the desired type of aircraft is not available, the strategy is to find the fastest plane for interdiction, the plane with the longest range for tracking, and the apprehension craft with the smallest landing requirement. This strategy is encapsulated in a frame so that it can be easily modified and enhanced.

The total number of alternatives in the CMES scenarios are on the order of 200 factorial (200 cubed for each TAG). Alternatives are pruned by 8 filters (e.g., range, speed equipment, previous allocation). Although these filters are not currently interactive, they are modified or increased by a developer in minutes and have been used for basic sensitivity analysis. In this manner, filters limit possibilities, and dozens (instead of millions) of alternatives are spawned. An allocation of aircraft, equipment, and people are chosen for three tasks per TAG, and the corresponding items, bases, regions, and total resources are updated in a few minutes, allowing the user to examine the results and make changes accordingly.

During planning, the user can manually limit and modify the planning process or allow the system to choose and schedule available aircraft. He can also bound planning by designating base or aircraft alternatives and change assets during planning. Figure 5 displays some dynamic information (position, current allocations, base ranges) surrounding a network of plan alternatives encapsulated in blackboards. Figure 6 demonstrates user interaction during planning: a display of plan alternatives and a frame editor to manually update information.

As CMES develops the planning testbed, contingency plans, tactical and strategic plans (e.g, task allocation methods and simultaneous TAG consideration methods), and various evaluation techniques (e.g., all high priority targets neutralized in contrast with an overall weighted scoring criteria) will be encapsulated in each plan blackboard, for Performance Assessment.

3.4 PERFORMANCE ASSESSMENT

Message validation and control is a Performance Assessment function critical to every C^3I system. A Performance Assessment model of the C^3I system greatly facilitates the communication within and outside the system. CMES anticipates this modeling by capturing methodologies in data structures (e.g. resource levels, tasking strategies, behavior events) which are incorporated into blackboards. Mission evaluation, performance enhancement, risk measurement, and trades are accomplished through the analysis of the system model and comparisons with functional results. Comparisons are produced by Performance Assessment. Different methods of measuring allocation success include:

- number of targets neutralized
- percentage of high priority targets neutralized
- percentage of resources used
- amount of resource held in reserve.

Performance Assessment tracks multi-level resource allocation options so that it can analyze planning and form a planning testbed. Similarly, the threat behavior model explicitly represents predicted behavior (interdiction and landing points, drop areas, suspicion report correlation) and behavior alternatives which can be examined and analyzed by Performance Assessment to form a behavior testbed.

By controlling and analyzing alternatives in separate blackboards, Performance Assessment examines hypothetical behavior and enables the system to evolve.

4 FUTURE PLANS

4.1 COLLABORATIVE PROBLEM SOLVING

Global perspectives can be lost in local problem solving of distributed systems. Dr Douglas Lenet recently examined the state of national C^3I operations, and related twelve C^3I global difficulties at the Fifth Intelligence Community Artificial Intelligence Symposium:

- No Loop Closing: there is no feedback to analyst regarding policies which their analyses influence.
- Predetermined Conclusions
- Wrong or Missing Precedents: ill-chosen scenarios and procedures are realized after analysis is completed.
- Lack of Institutional Memory
- High Turnover Rate
- Momentum of Expertise: by doing what is always done, analysts are unable to adapt to new techniques, procedures and environments.
- Delayed Reporting: reports are delayed because of uncertain or bad news.
- Lack of Blue Information: information on United States forces is often unavailabile or unaccessable.
- Overworked Analysts
- Mirror Imaging: by focusing too heavily on US culture, important collateral factors are ignored.
- Outdated Material: by clinging to tradition, outdated models are not adapted to changing environment, threat, and resources.

These concerns will be ameliorated in Lockheeds C^3I Laboratory by an integrated framework of expert system techniques (as shown in figure 7): hypothetical reasoning, explicit representation of computer decisions and matches, analysis of alternatives, scenario generation and powerful operator interaction, an evolving domain knowledge base, and

	hypothetical reasoning	explicit representation	alternative analysis	user interaction	evolving knowledge base	uncertainty representation
no loop closing				✓	✓	✓
predetermined conclusions	✓		✓	✓		✓
wrong or missing precedents	✓	✓	✓	✓		✓
lack of institutional memory		✓		✓	✓	
high turnover rate		✓		✓	✓	
momentum of expertise	✓	✓		✓	✓	
delayed reporting	✓		✓	✓	✓	✓
lack of blue information		✓		✓	✓	
overworked analysts		✓		✓	✓	
mirror imaging	✓		✓	✓	✓	✓
outdated material	✓	✓	✓	✓	✓	

Figure 7: Global C^3I Concerns

uncertainty representation. Hypothetical reasoning is accomplished by the blackboard encapsulation of relevant information and alternatives. Explicit representation is accomplished by symbolic processing and the flexible expert system data structures, allowing the display of data with minimal or no internal manipulation. Powerful user interaction is the ability to halt system processing, examine and alter the system state. As models evolve, the expert system knowledge base hastens the use by new operators and inhibits model stagnation by capturing current expertise. Easily incorporated uncertainty algorithms broaden many C^3I assessment techniques which, when evaluated with typical scenarios, tailor systems to specific needs.

Lockheed's C^3I Laboratory integrates modeling, user interface, and analysis tools into a system which relates their use to: C^3I system functions (Profile Update, Situation Assessment, Adaptive Planning, and Performance Assessment), operations (detection, identification, tracking, engagement, assessment, and communication) internally developed projects, and specific applications. In anticipation of system reconfiguration in these areas, another Lockheed internal development project, BB-Net, researches the control and communication problems of dynamic systems.

BB-Net will provide an environment to develop, upgrade, and integrate a set of C^3I expert systems using a distributed control architecture and blackboard control technology. This environment must allow the system to be rapidly upgradable to respond to any C^3I customer question.

The Lockheed C^3I Center presents a cost effective time-saving capability to represent to the customers, the end-to-end characteristics of a problem, with specific issues and capabilities incrementally integrated into the common-core system for prototyping and demonstration.

4.2 BB-NET: AN ENVIRONMENT FOR DISTRIBUTED BLACKBOARD SYSTEMS

BB-Net provides a tool for implementing multiple blackboard systems executing concurrently in a distributed processing environment or on a multiprocessing computer.

Concurrency is achieved through parallelization by task decomposition into subtasks. Subtasks are assigned to different processing elements and executed as interacting program units, thus forming a network of solution procedures. By making use of existing hardware protocols, BB-Net serves to configure the solution net, assists in coordinating activities, and relays messages and commands between processes. BB-Net also promotes parallelization by offering options for the concurrent evaluation of LISP expressions on different nodes. The solution net is dynamically reconfigurable under the control of a knowledge based scheduler.

BB-Net features an interactive supervisory program which lets the user establish the solution net and manually exert control over its functions.

The user defined model consists of many spatially separated but overlapping blackboard panels distributed over the nodes of the network, all storing information of global interest. Truth maintenance is facilitated by the automatic replication and retraction of global information.

4.3 TECHNICAL OBJECTIVES FOR DISTRIBUTED PROCESSING

BB-Net provides a method of incrementally allocating distributed processing resources to expert system tasks. The application knowledge sources assert goals (and tasks to obtain these goals) to the BB-Net Software Controller/Agenda Manager (BB-Net AM). BB-Net AM manages this goals list, using the application supplied goal dependencies and processing resource cost functions, to perform resource allocation.

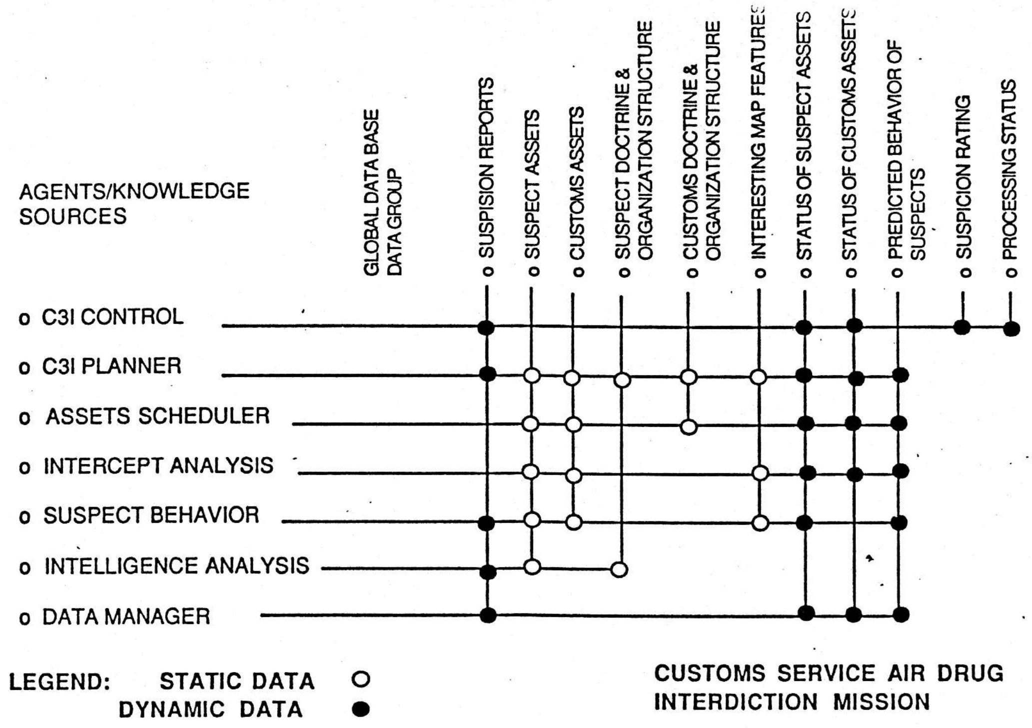

Figure 8: C^3I Data Types, Characteristics, and Distribution

BB-Net will resolve the control problem by developing a C^3I Meta Control with domain knowledge which will interface between the application knowledge sources/software modules and the BB-Net Software Controller/Agenda Manager. The C^3I Meta Control with the BB-Net environment will provide the framework for a rapidly reconfigurable hardware/software capability, and MMI to interface with data bases and utilities peculiar to the problem set identified by the customers. As such this architecture will allow concurrent execution of application functions in an open cooperative system. It will provide an environment in which large-scale open systems can be easily implemented and studied.

4.4 REQUIREMENTS FOR DISTRIBUTED PROCESSING

In 1988, CMES will focus BB-Net development in order to portray distributed processing requirements. The C^3I Service applications require a dynamic environment with constant data sharing (see Figure 8). Each C^3I functions will operate concurrently and asynchronously in an open cooperative system. The architecture will also allow asynchronous operations of the functions as the external environment is asynchronous. Each function is described along with BB-Net test requirements in the following paragraphs.

A distributed CMES environment will focus development as it matures through extensive testing. With experimentation, dynamic control strategies will be developed and improved. The impact of overhead on parallelization will be monitored to determine the optimum granularity for distributing this application.

4.5 CONTROL ISSUES

The blackboard paradigm provides control knowledge and opportunistic control. The motivation for this paradigm results from control requirements of large complex knowledge-based system, especially in situations where the control decisions depend on the solution state and also where control knowledge is difficult to elicit. Strategic knowledge (knowledge about which tactics to apply given a situation) are usually very difficult to elicit from experts doing complex tasks. As a consequence, BB-Net architectures allow explicit representation of control knowledge and permit flexibility in rapid prototyping and incremental development.

BB-Net provides a method of incrementally allocating distributed processing resources to expert system tasks. Through experimentation in the CMES/BB-net testbed, both domain dependent and independent strategic knowledge will be developed and placed in the C^3I Meta Controller. A high level set of communications standards, protocols, and control knowledge representations will also be developed and placed in the C^3I Meta Controller. For example, tasks need to be allocated not only on the basis of computational cost and goal dependencies, but also on the potential benefit of task execution based on the current solution state, the predicted results, and associated confidences.

Providing this type of distributed architecture will result in a highly survivable system. If there are hardware problems with a particular processor the processing of tasks will shift to a different processor. If one knowledge source is producing faulty data, that knowledge source, predicted results and associated confidences will be reduced resulting in lower probabilities of tasking that knowledge source. This results in a higher total system performance and reliability.

4.6 CONTROL ISSUE TEST REQUIREMENTS

Dynamic control strategies are required within each function and between functions. The first step in developing these strategies is the generation of detailed state transition diagrams for various scenarios.

The data that each of the major functions is processing determines the processing resource priority of that major function. It is important to continually evaluate the urgency of providing more processing resource to high priority functions. As this evaluation is performed, the controller can adjust the order of tasks on the agenda.

1) Profile Update

Control Issue Test Requirements: **An input data stream is used to update frames representing the threat model. Due to the volume and speed in which new information and reports arrive, more than one machine must be available to accept incoming data. With an adaptive control architecture, Profile Update tasks will be distributed to available processors and lower priority tasks will be delayed when processors are busy.**

2) Situation Assessment

Control Issue Test Requirements: **There are two areas in which the dynamic control strategy and flexible processing resource allocation capabilities will improve the Situation Assessment function:**

1. As information on high priority TAGs is passed to the planning function, low priority TAGs are processed in the background.
2. Clearly, as the information about a particular TAG increases, the plan to apprehend that TAG should improve. The goal here is to determine what type and amount of knowledge will produce a successful plan and when adding more knowledge will only produce trivial improvements.

3) Adaptive Planning

Control Issue Test Requirements: **For testing distributed processing we will adjust resource levels and increase the number of TAGs simultaneously planned against, and distribute the planning functions over several nodes. Also, the global control function will aggregate the results of local planning enabling the planning testbed to analyze decisions based on both global and local considerations.**

Dynamic control strategy is important to the Adaptive Planning function. If there is a TAG with a high suspicion rating near the interdiction border, for example, the immediacy of handing the plan to the interception/apprehension team is more important than a perfect plan. Contingency plans can be generated after the interception team is on its way to evaluate system planning performance in situations requiring adaptive control. However, if there are only low suspicion TAGs near the border with medium suspicion TAGs a bit further away and the highest suspicion TAG farthest away, it becomes important to provide a very efficient plan which conserves the correct amount of resources for the high priority tag while effectively monitoring and/or apprehending the close range TAGs.

These experiments will use BB-Net's abilities to represent control knowledge and adaptive control features in adaptive control for the flexibility required in CMES.

4) Performance Assessment

Control Issue Test Requirements: This function will evaluate both the CMES tool and the BB-Net environment by measuring the volume and speed limits in incoming data, by determining the accuracy of Situation Assessment predictions, and by comparing results of allocation plans. As CMES becomes distributed, experimentation with allocation of processing resource to CMES functions will occur. The performance assessment function will provide measures and insight into the effect of varying processing resources and execution times over CMES functions.

5 SUMMARY

Two of Lockheed's internally developed projects, CMES and BB-Net, apply expert system technology and blackboard architecture techniques to C^3I applications. These technologies are developed within a system analysis discipline and will be used to explore specific applications in Lockheeds developing C^3I Laboratory.

CMES explores the use of expert system data structures, flexible processing, and sophisticated user interaction with respect to Monitoring, Situation Assessment, Adaptive Planning, and Performance Assessment.

BB-Net explores control and communication issues associated with distributing the expertise associated with Detection, Identification, Tracking, and Engagement.

The C^3I Laboratory is being developed as a collaborative problem solving environment to address the different aspects of specific C^3I applications while maintaining a global perspective.