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MAN-MACHINE INTERFACE ANALYSES FOR BOMBER FLIGHT MANAGEMENT SYSTEM (U)

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FOR THE COMMANDER

Walter Summers

WALTER C. SUMMERS
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The research reported in this document represents a concept definition study directed to exploring the MMI issues inherent in the development and integration of an FM avionic subsystem into a manned, penetrating bomber weapons system. The report addresses four specific FM/MMI objectives: (1) Develop and document "optimum" FM/MMI conceptual display formats; (2) Integrate a laboratory (i.e., non-flyable) software development/demonstration FM processor into DET 1 AL's Strategic Avionics Battle-Management Evaluation and Research (SABER) advanced conceptual bomber crew system simulator; (3) Conduct a laboratory, part-mission demonstration of FM avionics concept in the SABER facility; (4) Provide consultative support to government and industry for review and critique of FM/MMI conceptual dislay formats.

This report documents the initial (Concept Definition) phase of the design of "optimum" flight management display formats. The intent is to lay the foundation for an information requirements analysis for an FM system and subsequent design of a conceptual MMI.

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PREFACE

This effort was conducted under exploratory development Program Element 62202F, Work Unit 7184 10 44, "Advanced Strategic Cockpit Engineering and Research," by the personnel of the Crew Station Integration Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Mr Gilbert G. Kuperman was the Work Unit monitor and provided technical direction to the team. The effort was supported by the personnel of Logicon Technical Services, Incorporated, Dayton, Ohio under Contract No. F33615-89-C-0532. Mr Robert Linhart was the Air Force Contract Monitor.

The effort was performed in support of Strategic Flight Management Project (Program Element 62201F) being conducted by the Control Systems Development Branch, Flight Controls Division, Wright Laboratories.(WL) Ms Judith Probert is the Project Manager.

The authors wish to thank Ms Probert, Mr Bruce Clough, and Mr J.B. Schroeder (WL) for their participation in this concept definition analysis. Their expertise and understanding in the area of aircraft flight control provided valuable insights into the functional requirements for a flight management system. Appreciation must also be expressed to Lt Col William R. Hard and Lt Col David Bostelman (ASD/XRZ) and to Mr Ronald Kaehr (WL/AAR) for their support and encouragement during the course of the research and for their willingness and ability to share their understanding as to the possible application of a flight management avionics subsystem to evolving Air Force mission requirements.

Thanks are also due to the personnel of the Boeing Defense and Space Group, Seattle, Washington, who are supporting WL in the development of a flight management concept integration study, and who freely shared their knowledge and plans, and to the personnel of Titan Systems, La Jolla, California, subcontractor to Boeing in knowledge engineering for mission planning and mission management execution, who provided insight into flight management scenarios and possible tactical doctrinal implications of automated flight management avionics. Gratitude must also be expressed to Capt Daryl Hauk (ESD/SZ K) who provided insight into the mission planning implications of the conceptual system, and to Maj D. Hobbs (SAC/XRHN) and Maj J. Debnam (SAC/XRFF) who served as our points of contact at Headquarters, Strategic Air Command, Offutt Air Force Base, Nebraska.

The authors also wish to thank Dr Lawrence Wolpert, Logicon Technical Services, Inc. (LTSI), for review of this manuscript and his many helpful comments and suggestions.

TABLE OF CONTENTS

LIST OF FIGURES

GLOSSARY

ALCM	Air Launched Cruise Missile
AL	Armstrong Laboratory
AL/HED	Armstrong Laboratory/Human Engineering Division
AP	Aim Point
CAT	Cockpit Automation Technology
CCCD	Crew-Centered Cockpit Design
COMINT	Communications Intelligence
DET 1 AL	Detachment 1 Armstrong Laboratory
DOB	Defensive Order of Battle
DTED	Digital Terrain Elevation Data
ECM	Electronic Countermeasures
ELINT	Electronic Intelligence
ELS	Emitter Location Subsystem
ESM	Electronic Support Measures
EXCM	Expendable Countermeasures
FCS	Flight Control System
FM	Flight Management
ICBM	InterContinental Ballistic Missile
IDEF0	Integrated Computer-Aided Manufacturing (ICAM) Definition
INS	Inertial Navigation System
IOC	Initial Operational Capability
MILSTAR	Military Strategic Tactical And Relay

MMI	Man-Machine Interface
OBMM	On-Board Mission Manager
OOB	Offensive Order of Battle
OSD	Operational Sequence Diagram
PVI	Pilot Vehicle Interface
RT	Relocatable Target
RTAPS	Relocatable Target Adaptive Planning System
RWR	Radar Warning Receiver
SABER	Strategic Avionics Battle-Management Evaluation and Research (simulation facility)
SA	Situational Awareness
SAC	Strategic Air Command
SIOP	Single Integrated Operations Plan
SLBM	Submarine Launched Ballistic Missile
SRAM	Short Range Attack Missile
TA	Terrain Avoidance
TF	Terrain Following
VOD	Vertical Obstruction Data
WL	Wright Laboratory

Section 1

INTRODUCTION

The strategic mission has become much more complicated due to improvements in enemy tactics, equipment, and communication. Advancements in air-to-air and surface-to-air threats require enhanced threat detection and avoidance capabilities for all airborne platforms. Relocatable targets (RT) of all classes are increasing in number and mobility, impacting fuel, payload and mission management requirements. The mobility of targets and threats paired with real-time intelligence updates constantly redefines the strategic environment.

This changing environment forces aircrews to assess unplanned situations and perform adaptive planning throughout the mission. The crew must monitor and interpret incoming information from a variety of sources, monitor system and mission status, determine vulnerability to threats, and replan the mission. It is unlikely that the aircrew will be able to perform all of these functions in real-time without the assistance of expert systems. Therefore, on-board adaptive mission planning systems are becoming essential to the success of the mission. Mission planning systems would be responsible for managing intelligence updates, target status, threat activity, and mission timing and status.

OPERATIONAL REQUIREMENTS

The purpose of on-board mission planning systems is to maximize an aircraft's mission effectiveness, survivability, and flexibility. Mission planning will be most valuable when responding to unplanned events. The operational requirements include: real-time problem solving, real-time processing of incoming intelligence data, system status monitoring, and route planning.

The mission planning system should have the capability to incorporate incoming target data and threat data with previously defined data base information. Threat characteristics from incoming sensors will also be monitored and assessed. When an event is determined to warrant a change to the current mission plan, the mission planning system will oversee the change. Mission replanning would include route adjustments, retargeting, weapon reassignments, and aircraft configuration changes.

Another requirement of the mission planning system will be to compute changes based on aircraft constraints, such as timing, fuel, and weapons. The mission planning system will depend on knowledge-based algorithms to construct route plans in line with aircraft constraints, in addition to mission data.

MAN-MACHINE INTERFACE

Operational requirements for flight management systems impose unique challenges for design of crew stations. Welch (1982) and Reuss and Kobarg (1982) projected trends in operational mission requirements for battle management that illustrated human engineering needs of crew stations. They noted that the trend in requirements would call for flight management rather than operation in mission context. The focus of their concern was function and capability requirements for offensive and defensive crew stations, respectively. They, in effect, conceptualized flight management systems and called for "total integration" of the crew with displays and systems. Kuperman and Wilson (1986) synopsized the Welch, and Reuss and Kobarg White Papers and suggested guidelines and design concepts for an engineering research simulator dedicated to the assessment and refinement of advanced manned bomber crew station concepts, in light of these new battle management concerns.

Hutchins, Neil, and Lind (1991) tested pilot performance and workload in a prototype avionics software system, Intelligent Air Attack System (IAAS), to evaluate the usefulness of artificial intelligence systems in military cockpits. An F/A - 18 - like aircraft simulator was used in a full-mission, war-at-sea mission scenario. The results from the study indicated improved performance using the IAAS system.

However, operator information requirements in an automated decision support environment, such as an FM system, remain unclear. There are two primary issues of concern in the design of an "optimal" man-machine interface (MMI) for FM: crew situation awareness and workload. These concerns speak to the need to tailor information displays to the needs of the crew member and to the priorities of mission phase. What information must be available to the operator at critical decision points and how that information is most effectively presented are the overriding questions that must be addressed in the design of FM MMI.

PURPOSE

The research reported in this document represents a concept definition study directed to exploring the MMI issues inherent in the development and integration of a FM avionic subsystem into a manned, penetrating bomber weapons system. The Flight Controls Branch of the Wright Laboratory (WL) is pursuing the exploratory development of such a subsystem through a series of contracts with the Boeing Defense and Space Group, Seattle, Washington. The Crew Station Integration Branch of the Armstrong Laboratory (DET 1, AL/HED) was requested to support this effort in the area of MMI. The DET 1, AL was requested to address four specific FM/MMI requirements. The following requirements define the overall AL/HED project objectives for FM:

1. Develop and document "optimum" FM/MMI conceptual display formats.
2. Integrate a laboratory (i.e., non-flyable) software development/ demonstration FM processor into DET 1, AL's Strategic Avionics Battle-management Evaluation and Research (SABER) advanced conceptual bomber crew system simulator.
3. Conduct a laboratory, part-mission demonstration of FM avionics concept in the SABER facility.
4. Provide consultative support to WL during the review and critique of Boeing Aircraft Company-generated FM/MMI conceptual display formats.

This report documents the initial (Concept Definition) phase of the design of "optimum" flight management display formats. The intent is to lay the foundation for an Information Requirements Analysis for an FM system and subsequent design of a conceptual MMI.

CONCEPT DEFINITION PROCESS

The Concept Definition process, as a proposed approach to FM MMI display development, is shown in Figure 1-1. Figure 1-1 illustrates four major phases in conceptual design and development of "optimum" prototypical display formats. The four phases are patterned after Crew-Centered Cockpit Design (CCCD), formerly named Cockpit Automation Technology (CAT), advanced crew system design methodology (Aretz, 1984). Information and conceptual background sources for this effort were: FM System Requirements Specifications, by Boeing (Ray, 1990); WL program planning materials (Probert, 1990), notes from AL/HED-WL meetings, Boeing briefing material (Churchman, May 1990) and Wilber (1988, 1989).

The goal of mission management is to provide aircrews with the necessary airborne management control and decision aids. The highly dynamic mission environment demands that a mission management system adapt to these changing conditions. The high volume of information available in this dynamic environment is continuously being updated and must be rapidly evaluated and integrated. At the same time, real-time adaptive flight management decisions must be accomplished utilizing large numbers of changing sometimes fuzzy decision criteria. Decision aids that embody current doctrine and knowledge rule bases are needed.

To facilitate this, artificial intelligence techniques have become the major focus of On-Board Mission Managers (OBMM) and FM systems. Knowledge-based approaches to route planning (Wilber, 1988, 1989) and threat avoidance (Wilber and Dryer, 1988) are among efforts to define and develop these systems. FM systems manage incoming data, current mission status, and in addition, compute and enact alternate trajectories (Churchman, 1990 and Ray, 1990).

General Dynamics, Convair Division, has recently begun work on a newly initiated program for Wright Laboratories (WL) that will address the need for an intelligent system for real-time targeting and adaptive flight management planning. This project will focus on "Concept Development" and identification of system requirements (Storer, 1991). The following paragraphs define a "strawman" Concept Definition process that is based on these ongoing efforts and FM MMI concerns.

The first phase of the process, Function Analysis, is the focus of this report and will provide the foundation for subsequent analytic and design activities. Graphical descriptions of the concepts, function flow, information/data flow and prototypical mission event sequences characterize the Function Analysis.

Figure 1-1 is a diagram of the events that may occur during the Concept Definition phase of FM system development and also notes the steps in the process with a sequence of activities that addresses current program objectives. The sequence of suggested events begins with the operational requirements and terminates with a simulator demonstration of conceptual displays. The events are briefly outlined in the following paragraphs.

Function Analysis

Operational Requirements are the driving force in the development of flight management systems. In fact, during the entire Concept Definition process the emphasis is the testing of the consistency of these user provided system requirements with the evolving system. The requirements for FM were previously defined as respond, in real-time, to unplanned events, monitor and interpret information from a variety of sources, and replan mission route within aircraft constraints. Measures of merit are identified, based on these user requirements.

System Descriptions, for a conceptual system, will be based on requirements of an FM system, current technological developments, and avionics capability assumptions.

Mission Context describes a specific application of an FM system. Mission scenarios and event sequence descriptions were used to illustrate the functionality

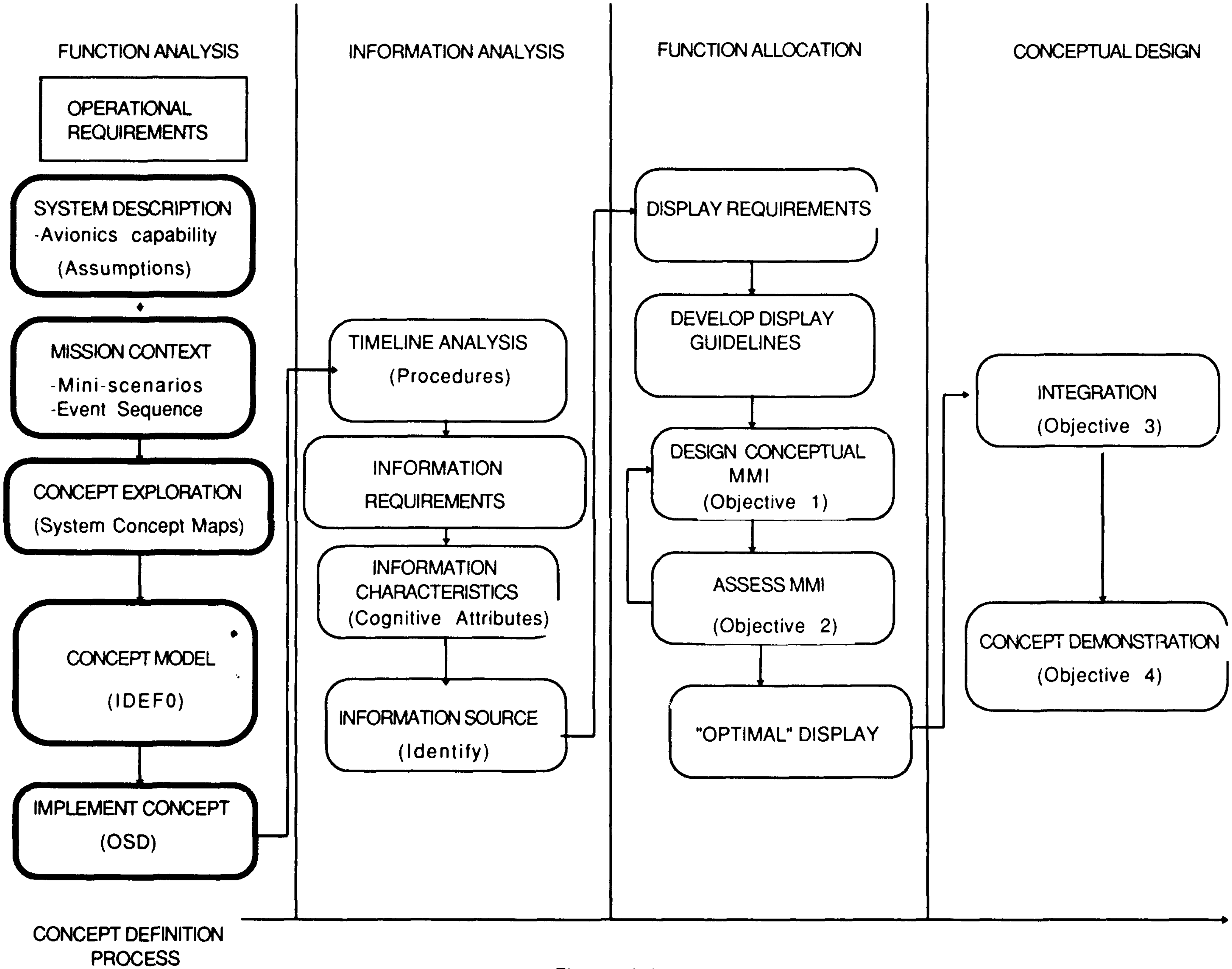

FUNCTION ANALYSIS
INFORMATION ANALYSIS
FUNCTION ALLOCATION
CONCEPTUAL DESIGN
OPERATIONAL REQUIREMENTS
SYSTEM DESCRIPTION
-Avionics capability
(Assumptions)
MISSION CONTEXT
-Mini-scenarios
-Event Sequence
CONCEPT EXPLORATION
(System Concept Maps)
CONCEPT MODEL
(IDEF0)
IMPLEMENT CONCEPT
(OSD)
TIMELINE ANALYSIS
(Procedures)
INFORMATION REQUIREMENTS
INFORMATION CHARACTERISTICS
(Cognitive Attributes)
INFORMATION SOURCE
(Identify)
DISPLAY REQUIREMENTS
DEVELOP DISPLAY GUIDELINES
DESIGN CONCEPTUAL MMI
(Objective 1)
ASSESS MMI
(Objective 2)
"OPTIMAL" DISPLAY
INTEGRATION
(Objective 3)
CONCEPT DEMONSTRATION
(Objective 4)
CONCEPT DEFINITION PROCESS

Figure 1-1

of FM. These scenario descriptions and projected sequence of events are independent of system constraints, i.e., are technology-free and platform-independent. Specific unplanned mission events, such as a pop-up threat, RT search, and deconfliction, address the need for on-board planning capability.

Concept Exploration for this project was achieved with semantic maps that represent FM system "things", i.e., objects, attributes of objects and relationships between objects. Important key concepts are identified and graphically represented.

Concept Model, the major focus of current effort, is a graphical description of system activities, information flow and subsystem interdependencies. It was accomplished with IDEF0 (a structured analysis and design technique, developed to represent systems, and system functions).

Implement FM Concept is the culmination of the function analysis stage in concept definition. Operational sequence diagrams (OSDs) represent an overlay of FM technology concept within mission context. (The OSDs are graphical representations of the information-decision sequences that occur within a specific scenario in the context of the FM system.) For example, the assumed FM avionics system and system capabilities are reflected in the diagrams in terms of system response to a specific unplanned event, such as a pop-up threat. OSDs serve as an initial definition of the crew system control inputs and corresponding information display responses for the conceptual FM subsystem.

Information Analysis

The second phase of a concept definition process, as represented in Figure 1-1, speaks to the need to identify the information required for successful accomplishment of mission objectives. A structured analysis is performed to assure the system developer that all information requirements are identified.

Timeline Analysis is, in effect, an initial step in a task analysis. It places mission events and procedures in context of the operator-in-the-loop. At this point in the

Information Analysis stage, consideration is given to the operator in the context of the mission and interaction with the total aircraft system including the FM subsystem. Operator functions and activities are examined in mission context. The mission mini-scenario is decomposed and events are represented on a timeline in terms of operator functions, tasks, and decisions. (The OSDs developed during FM Function Analysis reflect the unplanned event in mission context. However, they address only FM system functions. Operator response is noted but, in general, disregarded as an FM subsystem. At the Information Analysis stage, modeling the operator in a "strawman" baseline system achieves a finer-grained level of detail of activity description).

Information Requirements are identified based on the timeline analysis. The timeline analysis reflects operator tasks and decisions. Information needed to accomplish those tasks and effect mission decisions can be identified at an usable level of detail.

Information Characteristics refer to identification of information in terms of cognitive attributes, stimulus-response compatibility, visual, and spatial presentation. At this stage in the process, it becomes imperative to begin to address information requirements in terms of human-engineering requirements with regard to presentation media, and display attributes.

Information Sources, such as the environment, sensors, external C2, etc., impact decisions about display requirements and are identified during the Information Analysis phase.

Function Allocation

Display Requirements include identification of information that needs to be displayed, the amount of information, the data update requirements, and the timing of the information presentation.

Develop Display Guidelines for design of the MMI. Specific criteria for display parameters and configurations are based on a combination of display requirements and human engineering concepts.

Design of a Conceptual MMI utilizes the display guidelines specific to FM functional requirements (which may also be applicable to MMI, in general). These guidelines impact display configuration and allocation of functions.

Assess MMI. Ongoing and iterative assessment of conceptual design of "optimal" displays investigates adherence to display guideline requirements and tests for logical consistency and completeness of the design concept.

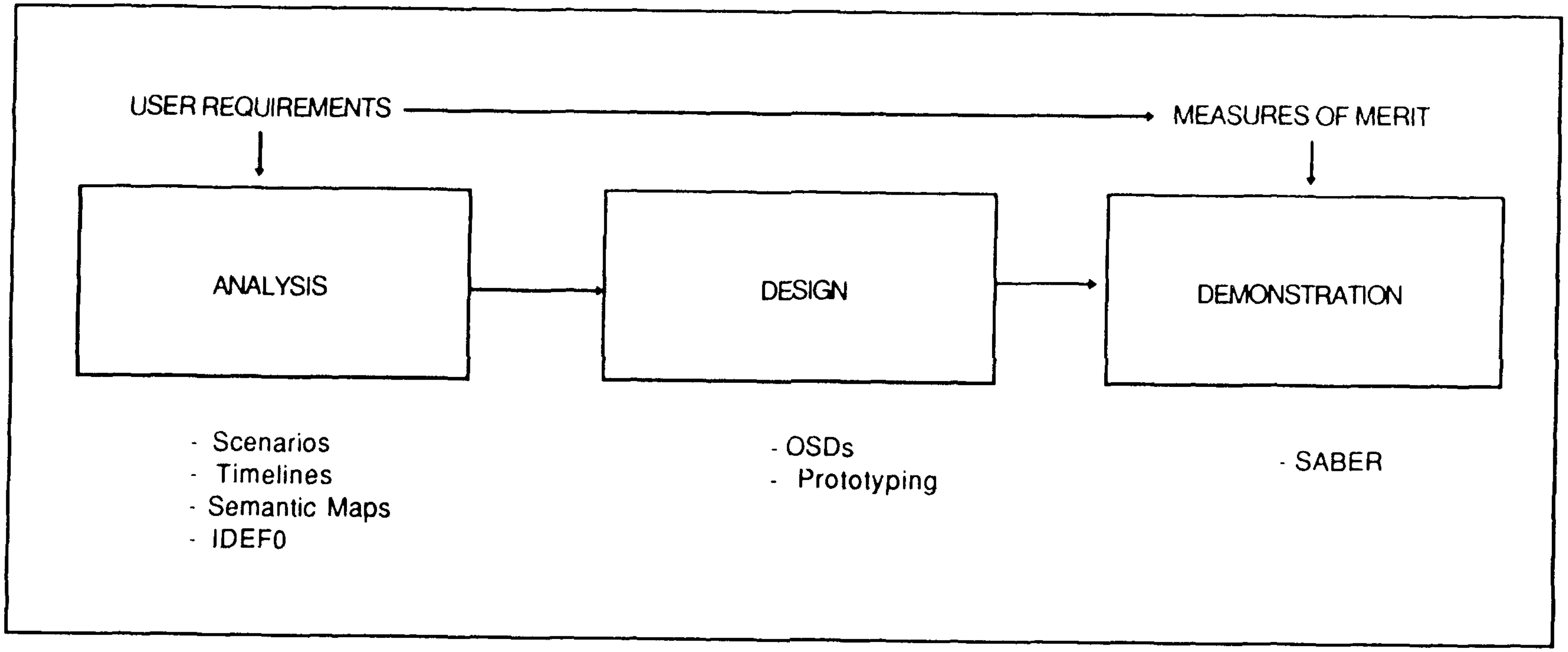
"Optimal Display" is the result of the Function Allocation stage of the Concept Definition process. An "optimal" display is the outcome of the iterative steps that precede it. The design of conceptual MMI and subsequent assessment of the MMI in mission context occurs in a feedback loop that results in a "simulator ready" display configuration that concurs with display design guidelines.

Conceptual Design

Integration of the display configuration and mission and avionics software into the Strategic Avionics Battle-Management Evaluation Research (SABER) (Kuperman and Wilson, 1988; Wilson and Kuperman, 1988) simulation facility culminates the Concept Definition process and provides the conceptual prototype for test and evaluation of the logic and consistency of the FM/MMI concept with user provided requirements.

Concept Demonstration of the MMI is an application of measures of merit. Measures that address mission effectiveness, system flexibility, and platform survivability are the focus of performance testing during Concept Demonstration. Measures of effectiveness and performance address the user requirements that have been the focus of the Concept Definition process.

Figure 1-2, Concept Demonstration, reflects a mapping of the tools used in the process leading to crew station conceptual design and refinement. The scenario descriptions, timelines, semantic maps, an IDEF0 model of the system and OSDs illustrate and define the functionality of FM in which user defined requirements drive the design and evaluation of FM MMI.



CONCEPT DEMONSTRATION

FIGURE 1-2

SUMMARY OF REPORT

SECTION 1: Introduction

The introduction defines the purpose of the report in the context of the overall AL/HED objectives that were defined by FM project requirements. In addition, the process proposed for accomplishing those objectives is defined.

SECTION 2: System Description

Section 2 presents a brief overview of proposed FM functional capabilities. Assumptions regarding those capabilities and the state-of-the-art avionics and software capabilities needed to fulfill user requirements are addressed.

SECTION 3: Mission Context

Section 3 consists of prototype part-mission scenarios representing user requirements in mini-scenarios in a technology-free context. Mission events are initially presented graphically without the constraints of being associated with a particular avionics capability. Event timelines represent the part-mission scenarios in context of time flow sequence.

SECTION 4: Conceptual System

Section 4 contains a conceptual description of FM subsystem objects, attributes and relationships, independently represented using a knowledge representation tool, semantic maps. In addition, the functionality of the FM conceptual system is graphically represented in Section 4 in an IDEF0 model.

SECTION 5: Concept Implementation

Section 5 consists of representations of the mini-scenario in the context of the conceptual system. OSDs represent the events in the prototypical mini-scenarios as they occur in sequence, and as the events are acted upon by the system and ancillary subsystems.

SECTION 6: Conclusions and Recommendations

Section 6 reviews project objectives and describes how the products of the current effort address those objectives. In addition, suggestions for ongoing support of FM/MMI Concept Definition are addressed.

Section 2

SYSTEM DESCRIPTION

The goal of mission management is to provide aircrews with the necessary airborne management control and decision aids. The highly dynamic mission environment demands that a mission management system adapt to the changing conditions. To facilitate this, artificial intelligence techniques have become the major focus of On-Board Mission Managers (OBMM) and FM systems. Knowledge-based approaches to route planning (Wilber, 1988; Wilber, 1989) and threat avoidance (Wilber and Dryer, 1988) are among efforts to define and develop these systems. FM systems manage incoming data, current mission status, and in addition, compute and enact alternate trajectories/flight paths (Churchman, 1990 and Ray, 1990). The following paragraphs present a brief discussion of the framework used for this Conceptual Definition of FM systems.

FLIGHT MANAGEMENT

A Flight Manager consists of a set of subsystems designed to perform autonomous inflight tactical mission planning in response to unplanned events. "The system will compute and enact an alternate, flyable trajectory within the constraints of aircraft limitation, time, fuel, weapons effects and survivability" (Churchman, 1990). That is, FM computes new solutions (i.e., reroute an aircraft) to unplanned events and provides the crew with optimal solution decision-aiding.

In beginning this Concept Definition, it was assumed that the trajectory replanning capability of FM would <u>not</u> be fully automated. Rather, an optimum replan would be accomplished in response to an unplanned event or deviation from the preplanned mission. The recommended plan would be presented to the crew for acceptance, and if adopted, would result in the generation of flight control command cues in the flight instrument displays. Safety of flight and (initial) user acceptance were the reasons underlying this assumed approach for FM mechanization. In effect, the FM, as currently envisioned, will function as a real-time decision-support system.

It is expected that the FM will make a major contribution to mission effectiveness and aircraft survivability, even without totally automated mechanization. The FM will, as a minimum capability, be able to quickly identify in-flight situations which require adaptive replanning. It will rapidly explore a wide variety of possible alternative tactical responses, inform the aircrew of both the triggering event (including its implications with respect to the objectives of the mission plan) and the recommended response. It will also facilitate the adaption of the crew decision, provide updates (feedback) of the response tactic effectiveness to the aircrew, and coordinate multiple subsystems in affecting the response.

The objectives of FM are to maximize mission effectiveness, survivability and flexibility by responding rapidly and optimally to unplanned events. The functions required of FM to meet these objectives include situation assessment, data base updates, threat avoidance, aircraft redirection and trajectory following. FM will receive information about the unplanned event, analyze its effects on mission objectives and aircraft survivability, and compute and present the optimal solution(s) to the crew. Figure 2-1 (Probert, 1990) illustrates the interactions among the FM subsystems and provides a brief description of their functionality. FM subsystems include: Mission Strategist, high speed data bus, Data Bases, Threat Manager, Trajectory Manager, Trajectory Follower, and Pilot Vehicle Interface. A brief discussion of these subsystems and their functions will preface the more in-depth Concept Definition that was the result of this effort.

The Mission Strategist functions as the the system executive in that it controls the FM subsidiary functions of Threat Manager, Trajectory Manager, Trajectory Follower, and the data bases. Furthermore, as situation monitor, the Mission Strategist performs situation assessment. Situation assessment is defined as real-time monitoring of mission timing (which includes waypoint timing, search area entry points, time of arrival at missile launch, weapon release points), the route plan, aircraft position, vulnerability, system status (fuel and weapons) and aircraft status. In addition, the Mission Strategist assesses damage on targets and monitors force redirection. Knowledge-based rules are applied by the Mission Strategist to impose thresholds and prioritize and execute other FM processes.

A high speed Data Bus provides the data flow capabilities between the Mission

Strategist and ancillary FM subsystems. That is, it is the communication channel between FM subsystems and data bases, and in addition, provides a communication link to non-FM systems. Non-FM systems include: electronic support measures (ESM), radar, controls and aircraft communication systems. Figure 2-1 (Probert, 1990) illustrates the functionality of the high speed data bus in relation to the Mission Strategist and the other FM subsystems.

The Threat Manager determines aircraft position and trajectory vulnerability and provides threat situation updates to the Mission Strategist. In doing so, the Threat Manager assesses ownship signature and threat parameter data, and makes comparisons to the threat data base. Based on these calculations, it controls counter-measures by utilizing ECM and EXCM or issuing threat avoidance requests to the Mission Strategist. Interface with the threat sensor data manager, evaluation of raw sensor data and control of countermeasures are the primary functions of the Threat Manager.

FM Data Bases are continuously refreshed with system and non-FM system data including aircraft performance (nominal and degraded), mission plan (route, timing, speeds, aim points, targets, search areas), DTED, VOD, RFPs, threats (OOB and DOB), timing, deconfliction, geopolitical, ownship signature, weapons, target, waypoint, and threat. These FM data bases are estimated to contain approximately 4GB of uncompressed data.

The Trajectory Manager functions to calculate new routes using Strategic Air Command (SAC) tactics that are based on the mission objectives and tacit knowledge about how to enhance survivability in an uncertain environment. The functional requirements for trajectory generation are terrain following/ avoidance, threat avoidance, obstacle avoidance, deconfliction, fuel optimization, terrain-referenced navigation,15and navigation updates. New routes based on these tactical criteria are developed by the Trajectory Manager. Furthermore, the Trajectory Manager updates the mission plan and calculates new optimized routes based on the threat situation. It computes threat avoidance, or threat minimization, fuel, time, and other deviations, using weighting coefficients that have been received from the Mission Strategist. Data utilized for generation of new routes reside in the FM data bases and include: geopolitical, tactical

FM TECHNICAL APPROACH

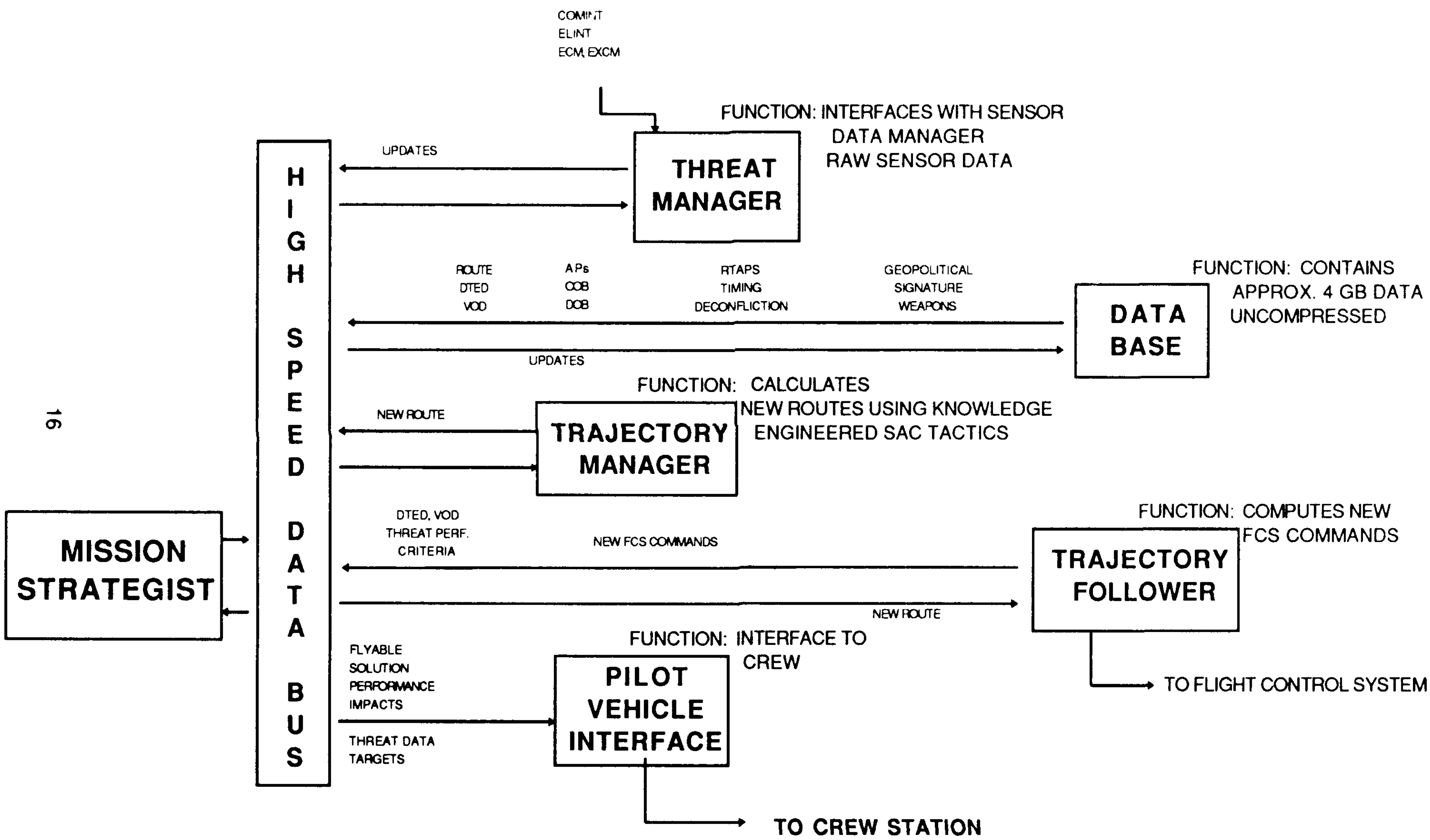


FIGURE 2-1

doctrine, timing (waypoint, tracking), route, DTED, VOD, threat capability criteria, weapons, targets, mission plan, search areas, recovery bases, and aerial refueling.

The Trajectory Follower computes flight control commands to provide decision-aiding to the flight crew. Trajectory following may or may not be auto-coupled. That is, the Trajectory Follower provides steering cues and/or auto options to the Pilot Vehicle Interface (PVI). In addition, the Trajectory Follower provides updates to the data bases. Flight Control System (FCS) commands are based on aircraft parameters. The FCS utilizes the aircraft model to develop the commands and tracking functions that are used to identify threshold deviations.

The Pilot-Vehicle Interface, providing crew situation awareness, presents the flight crew with information for situation assessment and decision-making. In fact, the PVI subsystem is the major focus of attention for an information requirements analysis, as the information presented to the flight crew is essential for system acceptance and effectiveness. Decisions for accepting or not accepting new solutions (trajectory functions) and flight control reside with the flight crew and are based on information available to them at the PVI. The PVI receives information from the FCS (Trajectory Follower), Threat Manager, Trajectory Manager, and the Mission Strategist.

ASSUMPTIONS

In order to perform concept definition analysis of an automated FM system, the operational capabilities of the host air vehicle had to be identified. The following items serve to describe the assumptions regarding implementation dates and avionics capabilities made in initiating the analysis:

Initial Operational Capability (IOC): An IOC of 1997-2000 was selected. This decision, together with the implicit assumption of a 1992 technology availability date, determines the level of avionics maturity to be expected in the host air vehicle.

Avionics Subsystems: An avionics capability similar to that represented by the B-

1B strategic bomber was selected to serve as a model with respect to the types and general capabilities of the on-board avionics subsystems with which the FM system would be expected to operate. Key avionics were felt to include:

Electronic Warfare:

Radar Warning Receiver (RWR) The RWR consists of a set of receiving antennas, data bases, and signal/data processors that detect, classify/identify and locate the source of radio frequency emissions. Data bases include both the characteristics of enemy threat system radars (surface-to-air artillery and missile acquisition and guidance radars, air-to-air acquisition and guidance radars, early warning search radars, and ground controlled interception tracking radars) and the intelligence-derived defensive order of battle (DOB) data base (i.e., threat types and presumed locations or operating areas). The DOB data base was employed during ground-based planning. The planned aircraft route was originally established to avoid significant exposure to the most severe threat systems. During the course of the mission, the operator monitors the RWR display of active emitters and attempts to correlate emitters with DOB sources. Inconsistencies (i.e., an emitter with no correlated DOB site) are potential threats to the aircraft and must be evaluated in terms of exposure duration, threat lethality, and aircraft vulnerability. "Pop-up" threats may be negated through some combination of active countermeasure application (flare or chaff dispensing and jamming) and aircraft maneuvering (avoidance or evasion).

Navigation:

Inertial Navigation System (INS) This subsystem serves to provide the platform with an inherent capability to estimate current geographic location. The estimate may be corrected, if in error, or refined by performing a navigation update. Radar, for example, might be used to image a fixed landmark whose latitude, longitude, and elevation are known (and stored in the FM aimpoint data base). If the aircraft's INS-based estimate of current position were perfect (i.e., corresponding to the actual location), then the landmark would appear in the center of the radar image display. If the estimate were in error, then the landmark would appear off-center. A radar display cursor, which initially appears in the center of the display, is used to perform the update. The operator refines the cursor position so that it overlays the landmark's radar image. He then designates this position to the navigation computer which adjusts the estimate of aircraft position.

Multi-mode Radar: The aircraft radar set is used to image radar fix-taking points and preplanned targets. Radar modes include real beam and high resolution synthetic aperture processing.

Piloting:

Pilot Relief Modes The baseline aircraft was to be provided with radar-based, automated terrain following (TF). An altitude-hold capability was assumed to be an adjunct of the TF mode. A heading-hold capability was assumed to automatically control the aircraft's heading with respect to the next preplanned destination point.

Electronic Emission Control (EMCON) Terrain avoidance flight without using radar emitting equipment. DTED data base is utilized.

Avionics Upgrades By the IOC date, it was assumed that certain preplanned product improvements had been made to the baseline aircraft (independently of the FM enhancements). These upgrades were assumed to include:

Navigation:

Emitter Location Subsystem (ELS) An ELS capability was assumed which would allow the bomber to more rapidly and accurately estimate the position (bearing and range) of the threat system radars. This capability would provide threat data of sufficient timeliness, accuracy, and resolution to make FM-based responses meaningful. The ELS would be a subsystem or submode of the RWR capability.

Piloting:

Additional Auto-Pilot Modes An automated terrain avoidance (TA) capability was assumed to have been added to complement the TF mode. An automated throttle control was assumed which would allow the aircraft to adjust engine power settings in response to deviations from planned arrival times at route waypoints.

Other:

Connectivity The Military Strategic Tactical and Relay (MILSTAR) constellation of communications satellites was expected to be in operation by the IOC date, and the bomber was expected to have been equipped with a MILSTAR terminal. MILSTAR would afford a reliable, secure, two-way communications channel with higher headquarters. MILSTAR would allow the bomber to receive emergency action messages (execution/termination) and force direction messages and, also, to transmit strike reports and other informational messages. In the context of a future FM capability, MILSTAR might be employed to update the mission plan based on more recent intelligence estimates and data.

"Glass Cockpit": The aircraft crew station was assumed to have been refined toward the goal of a "paperless" or "glass" cockpit. Multiple, multifunction displays provide for increased mission flexibility, improved information transfer, enhanced crew situational awareness, reduced crew workload, and eliminate the need for numerous panel-mounted, electromechanical controls.

Data Processing Requirements Projected technology for FM (Churchman, 1990) for 1995 suggests ADA-based single processor, 30 -100 million instructions per second (MIPS), mass storage devices, and >50Mb/sec databus. Hardware evaluation and risk assessment determined from low to medium risk for these technologies.

One global assumption is that the degrees of freedom available to the FM subsystem are quantified by the current mission planning policy for deconflicting penetrating bombers. If a bomber achieves each planned waypoint within a navigational accuracy of a few miles and a timing accuracy of several minutes then, presumably, it will neither interfere with other strike events/platforms or in turn be interfered with. Departure from these temporal and geographic parameters incur an unspecified penalty termed "assumed risk". With regard to a future FM system, assumed risk would be reflected by increasing assessed costs/penalties in a manner proportionate to the magnitude of the deviation from the deconfliction parameters.

Section 3

MISSION CONTEXT

MISSION REQUIREMENTS

In order to explore the functional implications of an FM capability, and, hence, to identify the aircraft integration and MMI requirements, mission requirements must first be identified. The mission selected for this FM/MMI analysis was that of a single aircraft performing an RT mission.

An RT is an asset or system which is intended to achieve survivability through mobility. Mobile intercontinental ballistic missiles (e.g., the Soviet SS-24 and SS-25 systems), mobile command posts, strategic aircraft, and troops out of garrison, are examples of RTs. The 1990 edition of Soviet Military Power notes that "the broad area available for deployment of both the SS-24 and SS-25 mobile systems and the use of concealment measures would complicate locating these systems in wartime." At the October 5, 1990 Strategic Relocatable Target Capability Program Office Briefing to Industry, the fundamental requirement was to locate and identify RTs. Sensors are required to support the RT location and identification of weapon system functions. The system must be capable of searching broad areas and of identifying concealed targets. This is a much more complex requirement than striking fixed targets (e.g., missile silos) whose positions are accurately known. A bomber performing a contrariety mission must, then, be more flexible than one attacking fixed targets.

Another mission requirement will be defeating enemy air defenses. Modernization of Soviet air defenses has been significant and may strongly impact evolving bomber missions. The 1990 edition of Soviet Military Power points out the rapid introduction of the modern SA-10 surface-to-air missile system (both fixed site and mobile versions) and the "improving Soviet air defense capabilities against low-altitude aircraft." Modern air defenses, including mobile systems which are deemed to be effective against low-altitude flight profiles, have posed a challenging problem to the survival of a penetrating bomber. The uncertainty of missile site location during mission planning and mission execution are significant components of this challenge.

Deconfliction to penetrating bombers is a term used in mission planning to refer to the need to route (in time and/or in space) penetrating bombers away from the detonations of ballistic and cruise missile warheads or other bomber-delivered weapons. The bomber must keep within the planned time/space window as it flies its planned route. Searching for RTs or avoiding mobile air defenses makes assuring deconfliction more difficult.

STRATEGIC BOMBER MISSION

The exploration and demonstration of an FM concept is in the context of a strategic bomber. The Strategic Flight Management Concepts for Large Aircraft Industry Review (January, 1989) states that fifty percent of the strategic targets in the 1990 time period will be mobile, and only 25 percent of the targets will be hard, fixed sites. Therefore, the location and targeting of relocatable targets has become a challenge to mission planners. Target search areas are developed based on RT deployment probability and bomber capabilities. The bomber's trajectories through the search areas are optimized to locate and target the maximum number of RTs.

Currently, bomber force missions are preplanned with turn points, navigation update points and fixed target locations. Coordination of time of arrival at these points for individual bombers within the force is critical in order to accommodate the deconfliction of forces. Mission planners also consider the target sites assigned to each bomber ensure deconfliction of the force. Therefore, an individual bomber must remain on course and each bomber must deliver weapons as scheduled to ensure weapon deconfliction and fratricide avoidance. In addition, communication within the force is limited, therefore, crews have minimal accessibility to updated information regarding the existence of threat, nuclear detonations, and weather.

FM will enhance the strategic bomber mission by increasing survivability, maintaining deconfliction requirements, and improving mission effectiveness.

Increasing the survivability of the bomber will include initiating threat avoidance procedures and insuring deconfliction. Deconfliction is achieved by rerouting a bomber to avoid nearby nuclear events. FM will assist in deconfliction by issuing flight commands which will keep the bomber on course and able to strike targets at the preplanned times. Maintaining the planned route ensures the safety of both the bomber and of nearby aircraft. FM will employ techniques to keep the aircraft on the planned route. FM will enhance mission effectiveness by optimizing the trajectory through a search area when the bomber's entry point deviates from that which is planned.

MISSION SCENARIOS

Purpose

FM demonstration and evaluation will address three priority issues of a bomber mission in a nuclear single integrated operations plan (SIOP). These issues are threat avoidance, deconfliction, and RT search. Scenarios addressing these issues were selected to illustrate the principle concepts employed by the FM system. The demonstration will characterize typical system reactions to unplanned events in the SIOP mission (Ray, 1990). Boeing has suggested three scenarios: avoidance of a "pop-up" threat, reroute around a nuclear event, and optimization of a trajectory through an RT search area. These three scenarios contain aspects of the bomber mission in which FM will play an essential role.

The purpose of these scenarios was to demonstrate FM functions. FM functions include threat detection and management, situation assessment, trajectory management (route planning) and following, and route adjustment management. The scenarios were broken down into events, and the functions of each subsystem were identified.

The scenario descriptions and functional requirements will be essential for development of the PVI. Before designing displays, the information required to perform an activity must be identified. Listing the events of a scenario and the capabilities of FM is a precursor to defining information requirements. The designer will examine the incoming and outgoing information for the sequence of events. The information needed by the crew at each event to perform their required activities will be determined.

The following sections include a brief description of each scenario as defined by Boeing (Ray, 1990). The functionality required of the major FM subsystems throughout the scenario have been identified. The subsystems are: Threat Manager, Mission Strategist, Trajectory Manager, PVI, and Trajectory Follower. The FM system also consists of data bases, that the subsystems call on for mission and tactical information, and a high speed data bus.

Threat Avoidance

A pop-up threat scenario was developed to demonstrate FM functionality to unexpected threats. In this scenario, one or more unexpected threats have been detected along the planned flight path. These threats have been classified as imminent. A threat is defined to be imminent when the aircraft, remaining on the planned route, will enter the lethal envelope of the threat. A description of the scenario and FM responses and functions follow.

An unexpected threat or multiple threats are detected in the vicinity of the planned flight path by the Threat Manager. The Threat Manager identifies the threat type and location. The Threat Manager then assesses ownship vulnerability and classifies the danger the threat poses to the current mission plan. The threat is determined to be imminent and a threat avoidance request is sent to the Mission Strategist.

The Mission Strategist is responsible for formulating strategies which are used to determine solution guidelines. Strategies are devised by computing weighting factors (costs and time) and mission objectives. Solution guidelines are then forwarded to the Trajectory Manager.

A set of candidate solutions are generated which maximize the survivability of the bomber by the Trajectory Manager. The bomber can either reroute to avoid the threat or minimize its exposure to the threat by using evasive techniques, both of which will require a change in the current bomber route. According to the current concept requirements, the optimal solution is presented to the crew within five seconds of the threat detection, via the PVI. The crew either accepts or rejects suggested optimal routes while the bomber remains on the planned flight path. The display is updated every five seconds, until the crew responds.

The crew response is sent to the Mission Strategist, which coordinates the responses of FM functions. If the proposed route is rejected, the Mission Strategist will again develop strategies and send them to the Trajectory Manager, which will proceed to develop and display another optimized route to the crew. This will continue until the crew accepts a route.

When a route is accepted, the new trajectory information will be updated in the data bases and sent to the Trajectory Manager. The Trajectory Manager will generate real-time flight control commands. These commands will be forwarded to the crew and to the Trajectory Follower. The Trajectory Follower tracks aircraft variables to meet quantified mission objectives. The Trajectory Follower also regulates control effector, flight director, or manual pilot commands. Information is transmitted to the crew, in a form that is dependent on the level of automation in aircraft control.

Deconfliction

Two types of deconfliction will be addressed in the demonstration: avoidance of another bomber's targets, that is, avoidance of effects from other Blue Force delivery systems and timely execution of weapon delivery. Timely execution requires avoidance of delivering weapons whose detonations will effect other Blue Force delivery systems. In the first case, replanning is required to avoid nuclear events along the flight path. Nuclear events could be a result of gravity bombs, Short Range Attack Missile (SRAM), Air Launched Cruise Missile (ALCM), Inter-Continental Ballistic Missile (ICBM), or Submarine Launched Ballistic Missile (SLBM) detonations. Carrying out weapon delivery as scheduled may require adjustments in routing or timing. The FM system will be responsible for overseeing these adjustments.

When the bomber is approaching a nuclear event, the Mission Strategist determines the threat window and computes weighting factors and mission objectives. If the threat is imminent, a route change request is delivered to the Trajectory Manager.

The Trajectory Manager normalizes weighting factors, generates candidate coarse (approximation) solutions, and selects an optimized trajectory. This trajectory is presented to the crew via the PVI. The crew evaluates the information and selects or rejects the proposed reroute. As in the case of the pop-up threat scenario, the Trajectory Manager updates the displayed route while the crew is making their decision. The crew response is sent to the Mission Strategist via the PVI.

If the proposed route is rejected, the Mission Strategist will recompute weighting factors and mission objectives and issue a route change request to the Trajectory Manager, which will send another route to the crew. This will continue until the crew accepts a route.

When the Mission Strategist receives a route acceptance from the crew, the current route is updated and sent to the Trajectory Follower. The same procedure is then carried out for generating and executing flight commands as described for the threat avoidance scenario.

For the second type of deconfliction, timely weapon delivery, the Mission Strategist monitors the bomber route and timing by comparing current status with the planned route in the data base. When a deviation is discovered, the Mission Strategist determines the mission objective function and formulates the solution which will result in timely weapon delivery. The changes needed are then sent to the Trajectory Manager.

The Trajectory Manager generates the new route and displays the information to the crew via the PVI. The crew makes a decision to accept or reject the recommended adjustments. The decision is transmitted to the Mission Strategist, which updates the data bases with the new information and prompts the Trajectory Manager to generate the control commands necessary. These commands are received by the Trajectory Follower and the crew, via the PVI.

Search for Relocatable Targets

A preplanned route through RT search areas is structured so the bomber will pass within sensor coverage of the most probable target locations. However, the actual entry points and times for entering the search areas may vary because of route replanning, aircraft drift or navigation error. The FM system will generate a route based on the actual arrival point to the search area.

When approaching the search area, the Mission Strategist monitors the upcoming arrival point and compares it with the preplanned arrival time. When there is a deviation from the planned route, the Mission Strategist generates a prioritized search plan, using information retrieved from the data bases. A route change request is sent to the Trajectory Manager along with mission objectives and cost functions generated by the Mission Strategist.

As in the previous scenarios, the Trajectory Manager generates candidate routing solutions and displays the optimized adjustment to the crew. Trajectory selection by the crew and control command generation are carried out in the same manner as those discussed in the other scenario descriptions.

EVENT SEQUENCE

Event Sequence diagrams are pictorial illustrations of the narrative scenarios. They provide graphic representations of mission context. The diagrams depict possible unplanned events and include the responses of FM and the crew to these events. These diagrams represent the preplanned route, the adjusted route, and the activities performed by the FM system and the crew. Descriptions of FM functions throughout the scenarios are included in Figures 3-1 to 3-4.

FM monitors the incoming threat data and detects a threat in the current flight path.

FM recommends a route change to the crew.
The route is continuously updated and presented to the crew.

The crew has the final decision regarding the new route.

FM generates the flight control commands for the new route.

FM monitors the manuever and continues to monitor incoming data and events.

FM initiates a turn short manuever which will regain time lost from the reroute.

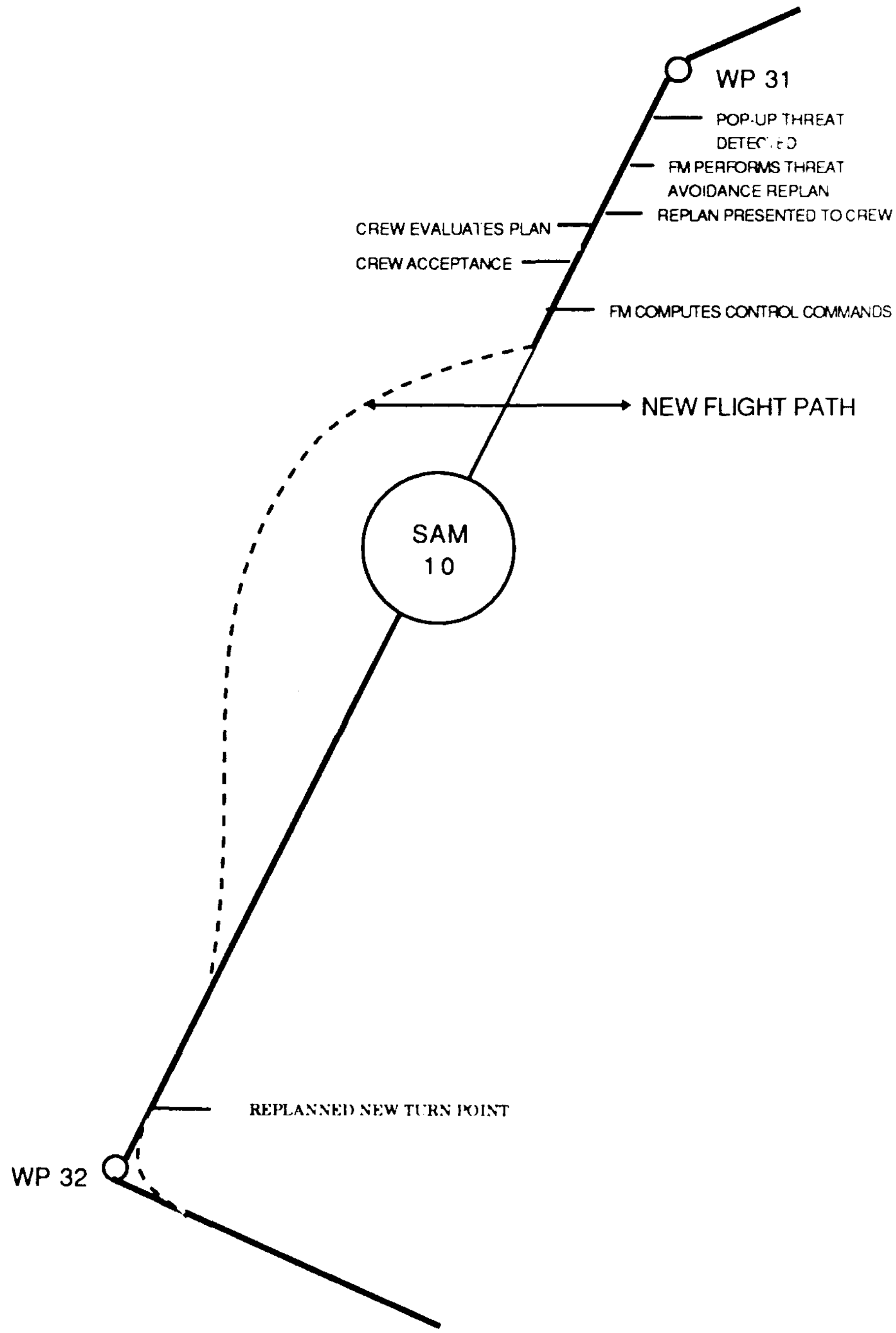


Figure 3-1 Pop-up Threat Scenario Event Sequence

FM monitors the planned route, current conditions and weapon delivery times.

FM determines the needed aircraft changes to meet the planned weapon delivery time. For example, adjust airspeed. The solution is presented to crew.

FM continuously monitors the current status and updates the crew display to reflect any changes.

The crew makes the final decision regarding the aircraft control.

FM manages the systems involved in reconfiguring the aircraft.

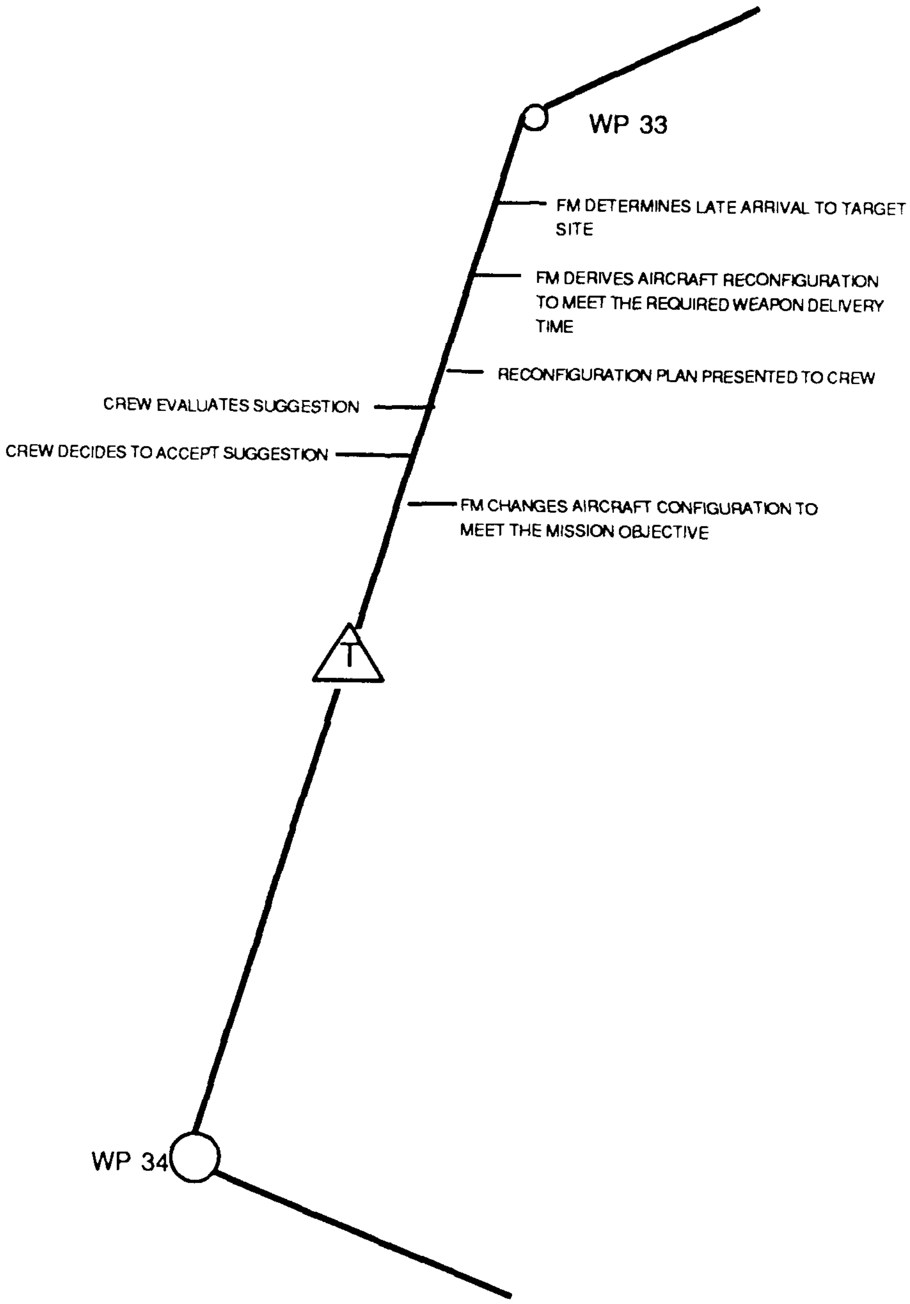


Figure 3-2 Deconfliction -- Timely Weapon Delivery Event Sequence

FM continuously monitors events and data base updates.

When another aircraft releases a nuclear weapon in the flight path, FM generates a new route to avoid the threat area.

FM presents the crew with the reroute and continuously updates the display based on current conditions.

The crew makes the final routing decision.

FM generates the control commands needed to fly the new route and manages the systems responsible for carrying out the control functions.

FM continues to monitor the events and the reroute.

FM initiates a turn short manuever which will regain time lost due to the reroute.

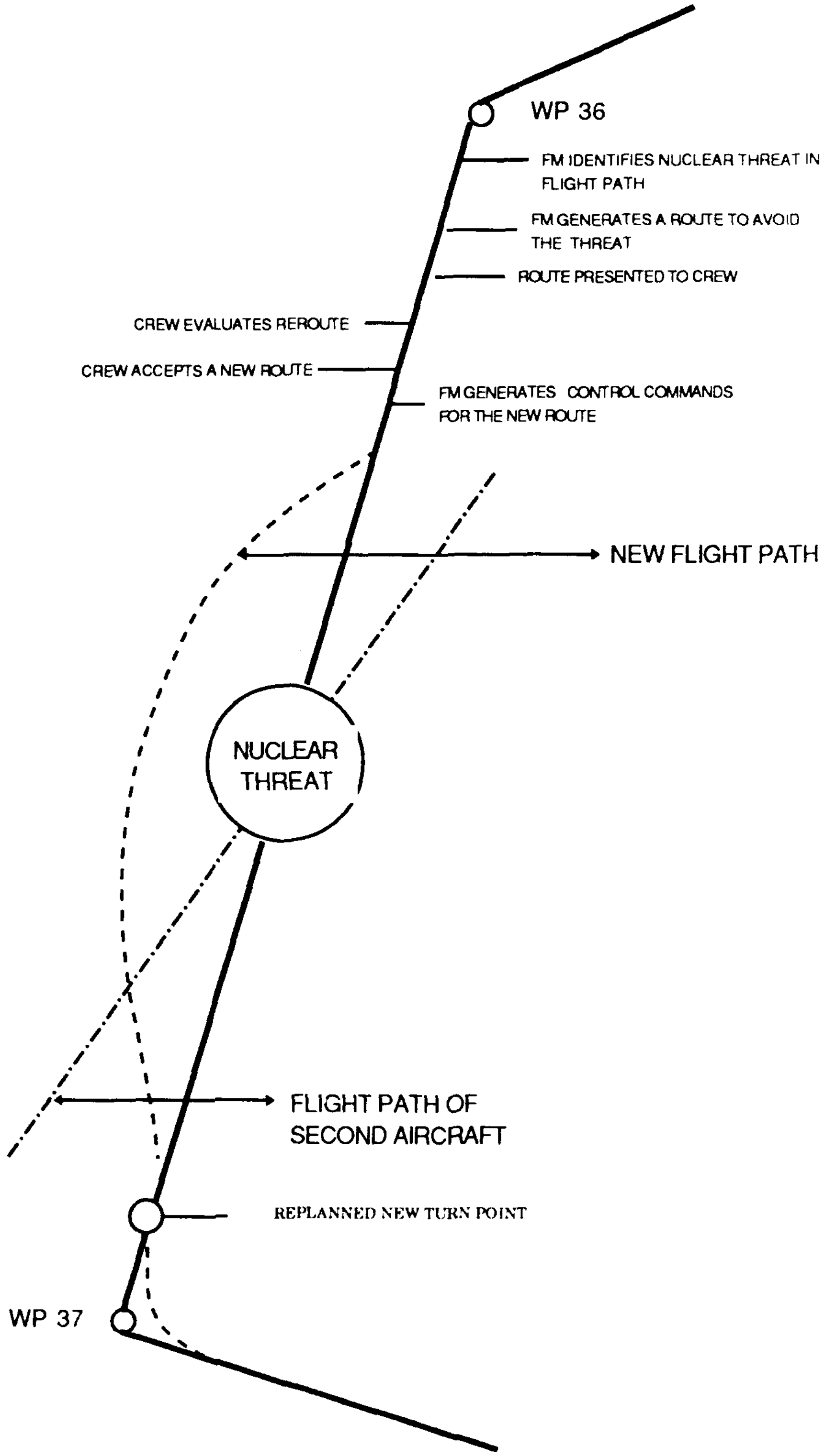


Figure 3-3 Deconfliction -- Avoidance of Nuclear Threat Event Sequence

FM monitors current location of the aircraft, the target area, and the planned route at all times.

FM determines that the entry point into the target area is not as planned (e.g. due to wind drift).

FM generates the optimal route through the target area based on target priority.

FM displays the route to the crew, which is updated while the aircraft continues to drift.

The crew makes the final routing decision.

FM is responsible for generating the control commands and monitoring the systems which carry them out.

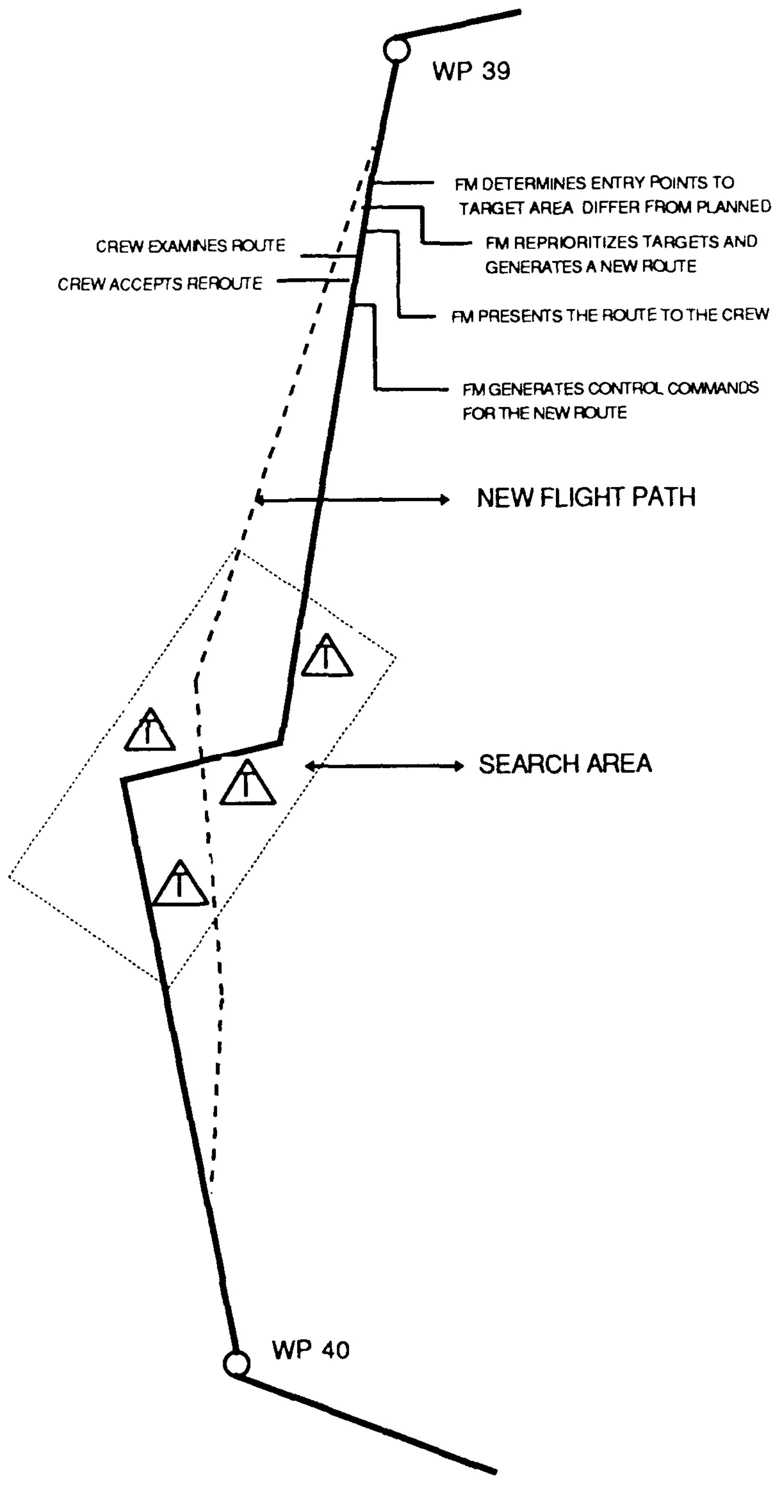


Figure 3-4 Relocatable Target Search Event Sequence

Section 4

CONCEPTUAL SYSTEM

OVERVIEW

Specifically, this discussion of the conceptual system will include the process of identifying: 1) system objects and attributes, 2) system functions, 3) specific subsystem activities, and 4) data flow through the system. Within the context of this effort, a "top-down" process was followed. The departure point was the statement of operational requirements as represented in the mini-scenarios and event sequence descriptions. The goal was to begin with a "requirements driven" perspective, rather than artificially impose possible constraints which might be inherent in a specific embodiment of FM avionics (i.e., a "technology driven" approach). This emphasis on "requirements" (rather than "technology") is hoped to result in a system concept definition which reflects both the needs and expectations of the eventual end-user. The intent is to lay the ground-work with a concept exploration of FM avionics and MMI for subsequent information requirements analysis based on prototypical mini-scenarios.

The goal of this Concept Definition is to provide a clear understanding of the system functional capabilities, activities and the functional dependencies of ancillary avionics subsystems, and more specifically, to provide the foundation with which to design and assess the system MMI. The concept definition is driven by user requirements and assumptions about avionics capability. This is the initial step in a process that will provide the basis for subsequent phases of the Concept Definition process.

The application of mission scenarios to define the functionality of an FM system facilitates an understanding of the information flow through the system and tests the logical consistency of the initial "strawman" concept definition. Once the operational concept is defined, the specific questions about operator information requirements can be addressed. For example, what are operators supposed to do? What information do they need to do it? How is that information most effectively presented? And what processes should/should not be automated? It is this Requirements Analysis that provides the foundation for design of optimum displays.

APPROACH

The initial focus of the FM Concept Definition was to develop a graphic description of the system, a model, based on the current system concept phase of development. There are several questions that will be answered using this approach. First, a definition of the functional characteristics of the system and its ancillary components will provide a foundation for an Information Requirements Analysis. Second, the model will illustrate the interaction of subsystems that occurs when replanning and rerouting the aircraft in response to unplanned events. Third, the flow of data and information through the system will be observed and the sources of information will be identified.

The immediate objective is to assist in development and evaluation of FM MMI for three scenarios: pop-up threat (avoidance), deconfliction (recover mission time and avoidance of a nuclear event), and relocatable targets (recover search area entry point). FM functional requirements may or may not differ for each of these three scenarios. Rather than develop a separate model to illustrate FM functions in each case, the system model will encompass functionality for all cases, simultaneously. For example, function requirements for the unplanned event of pop-up threat will include threat management, which may require activation of countermeasures. Countermeasures are not included in the scenario for deconfliction, or recover search entry point. Nevertheless, the model will include the function for all three cases as though these events occurred at the same time. This strategy will illustrate FM functional capability in broader perspective.

Function Analysis of FM, with its focus on information components, will be utilized in the development of optimum display and control configurations for the PVI. Demonstration of system responses to these unplanned mission events addresses FM function requirements of survivability, deconfliction, and effectiveness. Therefore, a scenario-driven, graphic description is the focus of this preliminary concept definition and will serve to identify FM functional and information requirements in order to refine the FM concept.

A dual approach was used to develop a model of FM *functionality and information* requirements. First, an overview of the system components, objects and relationships, took the form of semantic mapping. This consisted of identification of key ideas that related to system functionality. Based on available documentation, the objects/things of the system were identified. Attributes, relationships and actions on these objects were then identified at a very global level. This graphic description of the system was used as an object-oriented tool to describe the system in terms of its components (concepts), as well as their attributes and interrelationships.

Each of the FM subsystems that were identified in Boeing requirements documentation and WL program planning material was represented as a superordinate concept on a semantic map. That is, a semantic map was constructed for each major FM subsystem. Then, concepts subordinate and related (in some way) to the subsystem in question, were represented as nodes on the semantic map with relationships between the concepts being represented as links or connectors between the nodes. Identification of global characteristics of FM and understanding of the complexity of the FM problem was the major purpose of this activity.

FM subsystems, Mission Strategist, Threat Manager, Trajectory Manager, PVI (situation awareness), and Trajectory Follower, were examined independently in terms of what they do, what they contain, information needed, and sources of information. The data bases of an FM were considered as shared data bases between the subsystems operating as an internal and external data and information source. A high speed optical data bus is assumed for communication within FM and is inferred rather than explicitly included in the model. A brief description and background of semantic mapping is included below.

Semantic Maps

Semantic maps originated with Quillian's Semantic Networks (1969). They represent knowledge as a linked structure of objects or events illustrated as nodes.

These nodes are connected by links or arcs that represent relations between the objects and facts (Eberts and Brock, 1987). That is, semantic maps are graphic representations of a knowledge domain in that concepts (key ideas) are represented as nodes, and the links between those nodes represent relationships between the concepts. The meaning of a concept is reflected by its associations with other concepts. Furthermore, the objects (nodes) on the maps are exhibited in terms of being subordinate or superordinate to related objects. A semantic network may be seen as an hierarchical representation of the domain in question. For example, a concept represented on the map may have several related subordinate concepts that define the superordinate construct. The semantic network represents a schematic, so to speak, of the structure of the knowledge domain. A semantic network of the FM system was prepared as an initial step in the function requirements definition process.

This technique has recently been demonstrated to effectively develop concepts and understanding of system functionality. For example, McFarren (1987) utilized the semantic network approach in concept mapping, as an interactive technique, to aid communication between designers and system users, in order to identify the key concepts involved in solving a problem and to represent models of problem domains. Concept mapping was recommended as an effective tool to define the problem space in developing decision support systems (DSS).

A natural extension of this concept mapping methodology was used most recently as a knowledge acquisition tool (McNeese, Zaff, Peio, Snyder, Duncan, and McFarren (1990) to elicit expert knowledge from pilots. Expert pilots were interviewed in knowledge acquisition sessions and concept maps of several pilot's views of a target acquisition task were developed. It was found that while configurations of pilot concept maps differed, as would be expected, the key concepts and links represented a mental model of the target acquisition task that could be used for continued information analyses. This interactive development of concept maps of a tactical combat flight domain resulted in a summary concept map that incorporated multiple perspectives of expert knowledge.

The objectives for semantic mapping of the FM concept were twofold. First, this technique was used to understand the problem domain of flight management.

What was needed was to identify the global characteristics of the FM problem and solution. The overview of the system by semantic mapping the information known about system functions and requirements led to a better understanding of functional and information requirements. (At this time, the maps only represent concepts derived from existing documentation.) Parallel and subsequent concept definition was enhanced using this methodology.

The second reason for illustrating FM in semantic maps was that the veridicality of the FM model may be easily tested in continued interviews with the user community. Representing the domain in a semantic map was a way of developing a mental model of the system functionality. Semantic networks or variations thereof, such as concept mapping, have been used as a knowledge representation format because of the supposition that this is a reflection of the way people think. It has been suggested that individuals organize domain knowledge as concepts and relationships (Quillian, 1968). Therefore, representing the system as a network of concepts and links between them attempts to stay as close as possible to the way knowledge may be represented in memory.

The overall goals of semantic mapping are to identify the global characteristics of the knowledge domain, and also to understand the overall complexity of that domain. In addition, with the semantic mapping technique, nuances of the knowledge domain may be illustrated. That is, the dynamics of the system or environment can be represented.

Keeping in mind that the goal of the project is to elaborate and contribute to the FM system concept definition in order to identify the information requirements for FM MMI, constructing semantic maps allows for continued examination and revision by the user community as the concept definition evolves. Because the networks can be readily modified, review of the maps by expert users will result in finer detail in functional descriptions and also result in corrections or other modifications to the existing maps. The semantic maps can be further utilized as a knowledge representation tool to gain richer understanding of information requirements. By using semantic mapping as a tool to expand and represent knowledge of an evolving concept definition, incongruities between the initial concept of the system and mental models of users and system designers can be eliminated before the simulation is developed.

The concept definition of FM as reflected in the semantic maps is illustrated in Figures 4-1 to 4-5. Some of the characteristics of FM revealed in this structure will be discussed below. The discussion will present more of an overview of the maps rather than an extensive discussion of the concepts represented on the maps. It should be kept in mind that this was a preliminary effort at an object-oriented representation of the system. The semantic maps for this effort are intended to be utilized as a springboard for discussions and knowledge elicitation from the user community at a later stage. Nevertheless, developing system concept maps provides human factors engineers with a way to map the FM domain in terms of a "strawman" mental model that was based on the available documentation of the system, and that model aided in the additional graphic structured analysis of FM activities, IDEF0, as will be discussed in a later section of this report.

Concept Map Analysis

The general objective for development of a concept map of an FM subsystem is to illustrate its global characteristics and complexity. The information available on a map is observed by identification of the "key" concepts that make up the system and by noting the attributes and relationships associated with those concepts. The objects seen on each concept map fall into categories of system "things" and attributes, data or information, and events. The connecting links between the objects, or concepts, consist of actions performed on, or by, related objects.

Identification of "key" concepts has been the focus of FM semantic mapping. However, the method for identifying a "key" concept is heavily dependent on the objectives and perspective of the concept mapper (supporting the premise that user involvement is an important factor in defining conceptual systems). The specific objective for semantic mapping of the FM system has been to understand the system functionality as a means to approach identification of information requirements. Therefore, "key" concepts on the subsystem maps are found to be those that appear to represent the specific functions of the system. The meaning and understanding of those concepts is seen by the relationships with other

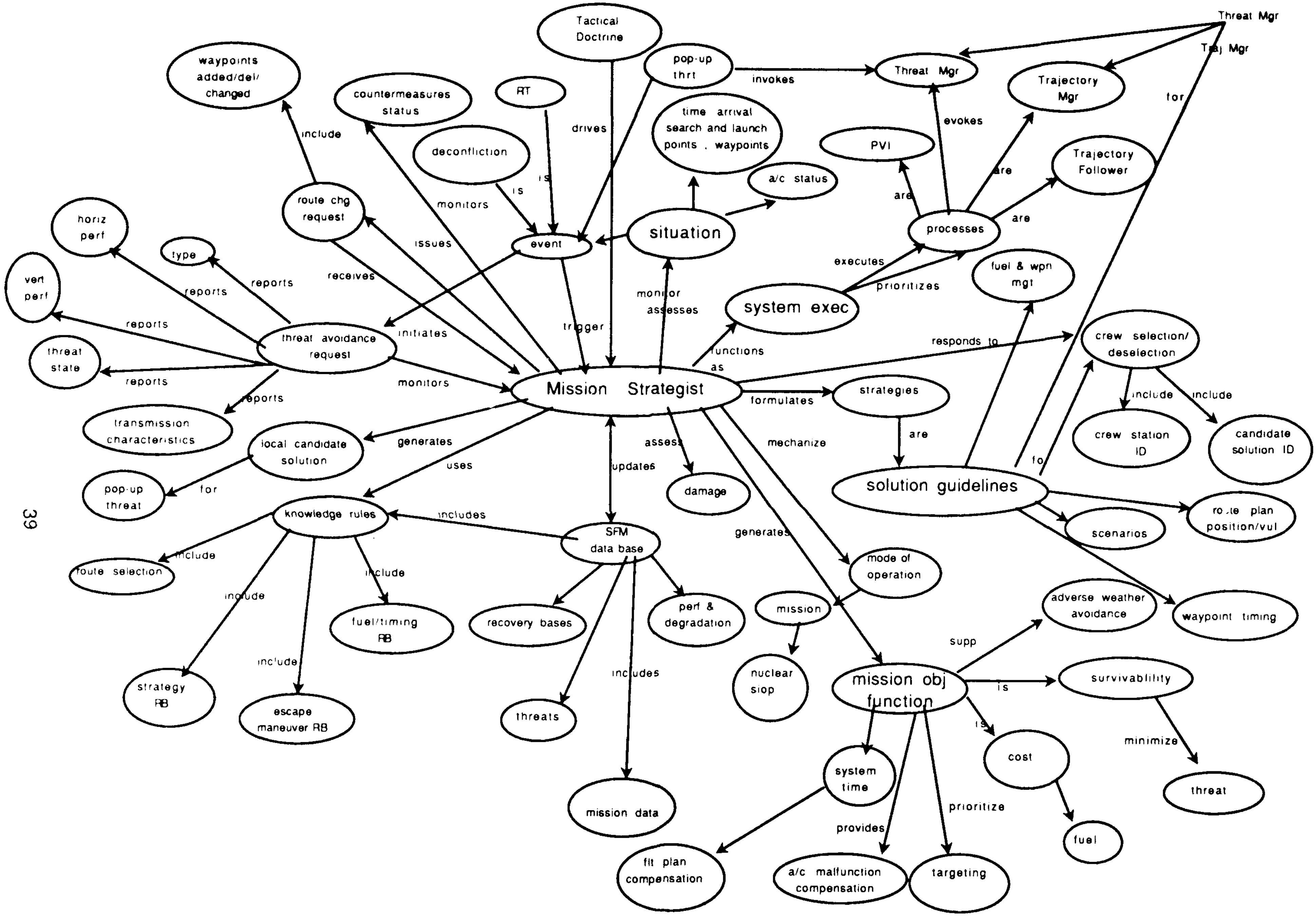


FIGURE 4-1 SEMANTIC MAP - MISSION STRATEGIST

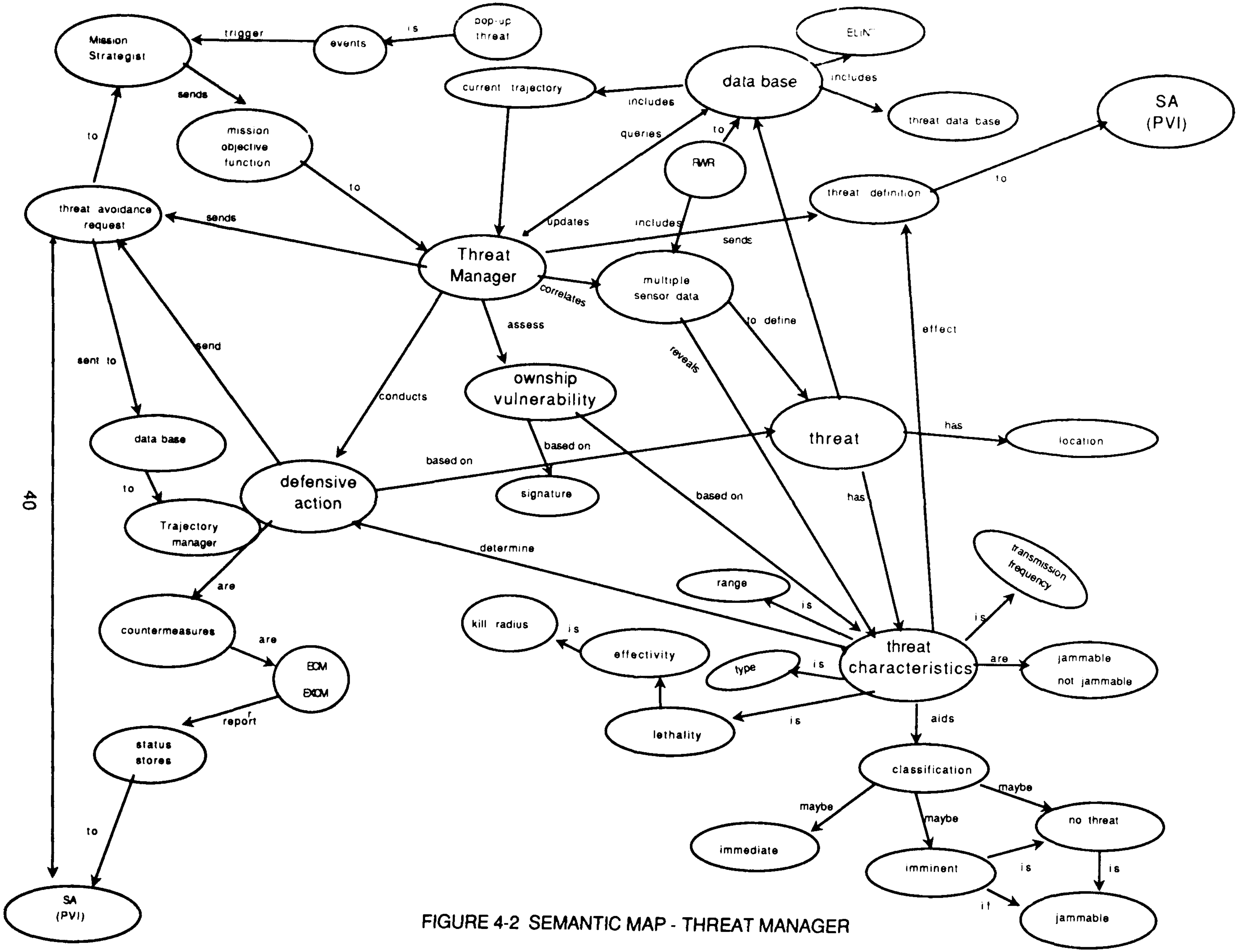


FIGURE 4-2 SEMANTIC MAP - THREAT MANAGER

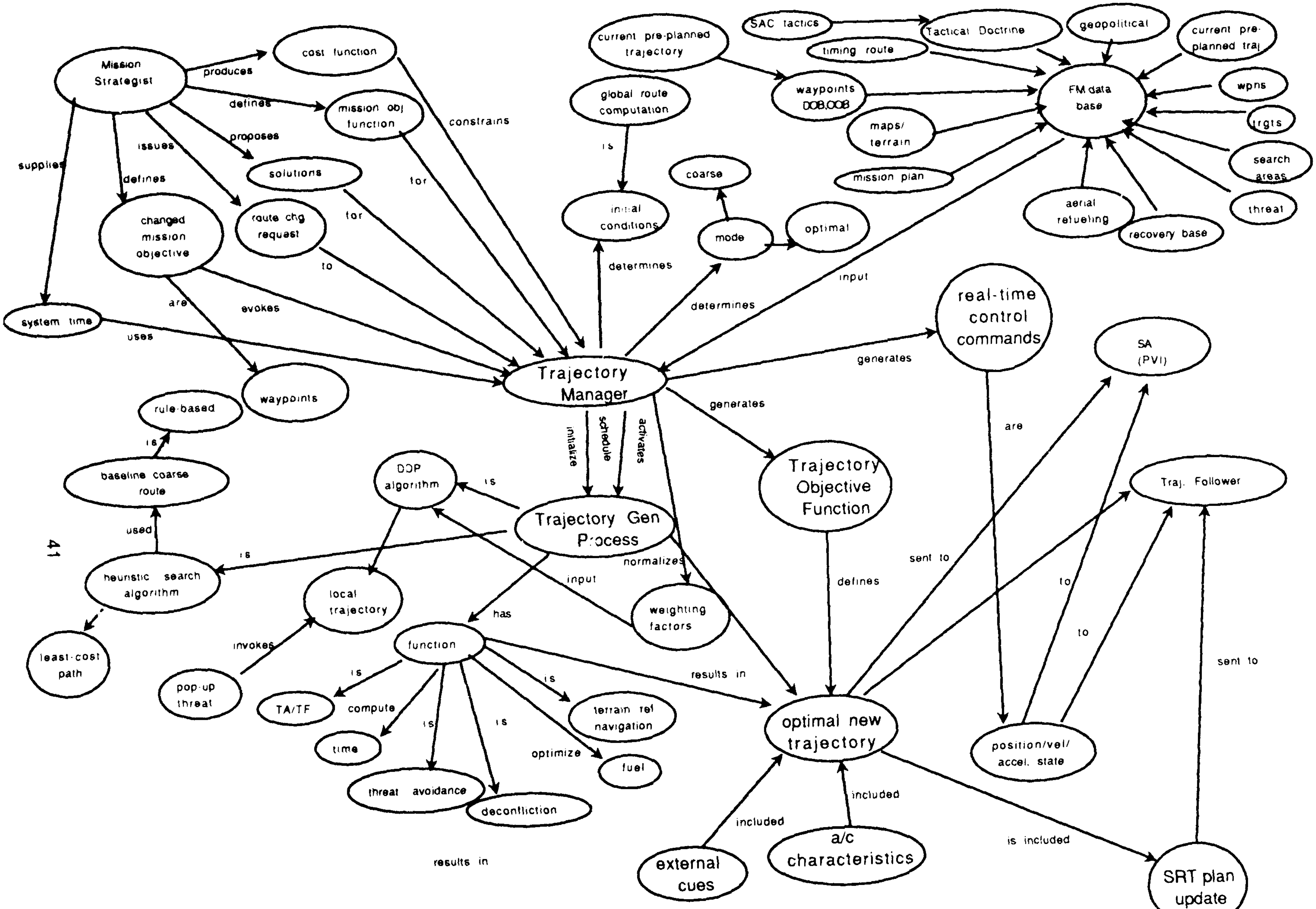


FIGURE 4-3 SEMANTIC MAP - TRAJECTORY MANAGER

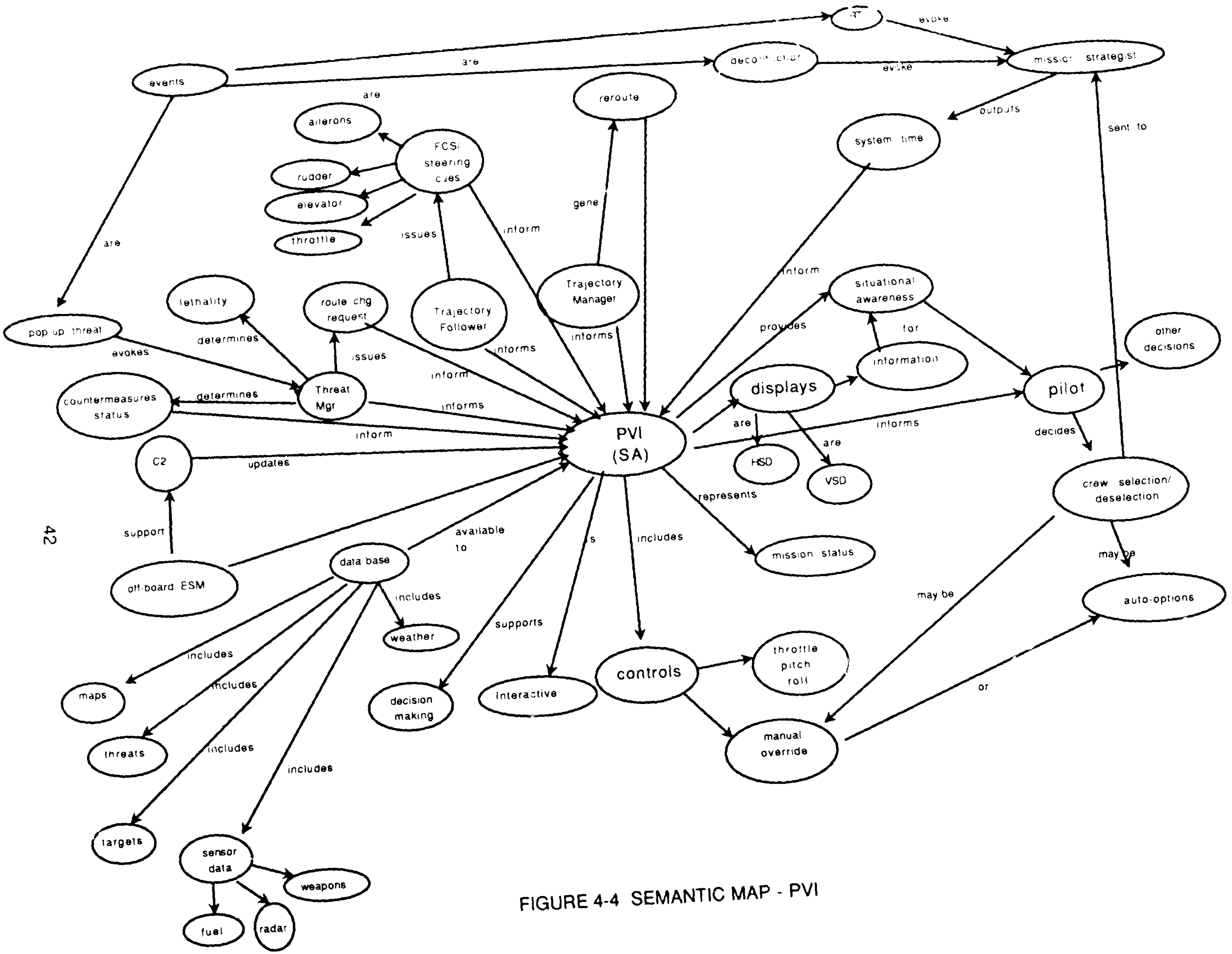


FIGURE 4-4 SEMANTIC MAP - PVI

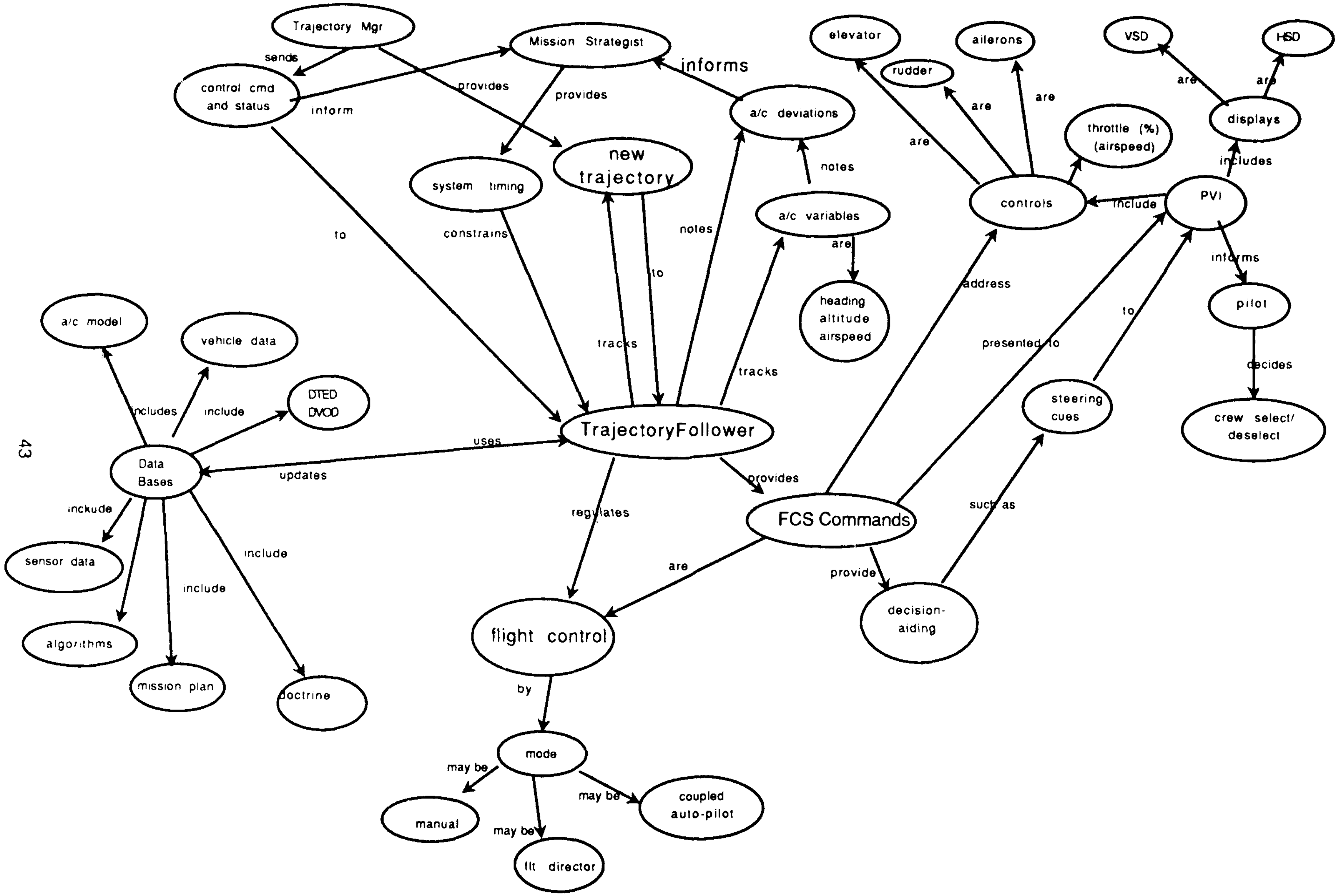


FIGURE 4-5 SEMANTIC MAP - TRAJECTORY FOLLOWER

concepts and connecting links to those key concepts. The maps are in a format that can be readily modified to accommodate additions or other modifications. The following paragraphs present a brief overview of the content of each subsystem map.

Mission Strategist

What information does the map contain?

Examples of the objects that are seen on the Mission Strategist Concept Map, Figure 4-1, that represent system "things" and attributes, data and information are **system executive**, **situation**, **solution guidelines**, **knowledge rules** and **mission objectives**. Also, links connecting concepts represent relationships between concepts, for example, the **knowledge rules** include the **strategy rule base** or **deconfliction** is an **event**. Furthermore, it is illustrated by the concept map that these key concepts contribute to definition of the functionality of the Mission Strategist. That is, the **Mission Strategist** functions as the **system executive**, it monitors the **situation**, generates **mission objectives**, and formulates **strategies** which are **solution guidelines**. In addition, information and decision criteria are identified at a global level. For example, the concept of **threat avoidance request** is shown to be related to the Mission Strategist in terms of input for Mission Strategist response. Information that is included in the threat avoidance request and available to the Mission Strategist is also illustrated in the concept map and seen as a subordinate concept to the Mission Strategist. Examples of such actions are: the **Mission Strategist** formulates **strategies** or the **Mission Strategist** uses **knowledge rules**.

Threat Manager

The objects shown on the Threat Manager Concept Map, Figure 4-2, that represent system "things" or objects and appear as key concepts are **threat**, **threat characteristics**, **ownship vulnerability**, and **defensive actions**. Attributes of these objects are also represented on the map. For example, **threat** has the attribute of

location, and **threat characteristics** has attributes such as **transmission frequency**, **type**, **classification**, etc. The connecting links between the objects on the map represent the relationships between the objects (key concepts). For example, the **threat** has **threat characteristics**; a **defensive action** is based on **threat**.

The map also shows that the **threat**, **ownship vulnerability** and **threat characteristics** are the objects (things and information) that lead to a key concept of **defensive action**. The interconnectedness of these concepts indicate the functional requirements of the **Threat Manager** to assess **ownship vulnerability** and conduct **defensive action** based on **threat**. Communication links between other subsystems are also indicated. For example, **threat definition**, and **threat avoidance request** information are both presented to the **PVI** for crew situation assessment as well as to the **Trajectory Manager** for rerouting, if required. The rest of the concept map of the Threat Manager consists of data and information utilized in the function of threat management.

Another way of viewing concept maps and their contents is to note the number of related or subordinate concepts that are connected to a particular concept. The concept of **threat characteristics** has more arcs or links connecting it to subordinate concepts and other key concepts, such as **defensive action**. At this stage in the concept mapping process, the dimension of number of links may reflect the fact that **threat characteristics** is a concept that impacts and drives the overall function of threat management. This information should be reflected in subsequent models of the threat manager and further impact scenario development and information requirements analysis.

Keeping in mind that this stage of the concept definition was to describe the subsystems at a global level, it can be noted that subordinate concepts on this map address only a level or two down in the hierarchy. For example, the concept of **mission objectives** that originates with the **Mission Strategist** provides the **Threat Manager** the constraints that lead to **defensive actions**. **Defensive actions** are shown to have two directly subordinate concepts of **countermeasures** and **threat avoidance requests** with **countermeasures** being **ECM** and **EXCM**. If this map were to continue down the hierarchy to address finer-grained detail, perhaps it would address rules or heuristics for utilization of countermeasures. As it is, the global description of the subsystem provides an overview of the Threat Manager characteristics and functions.

Trajectory Manager

The concept map for the Trajectory Manager, Figure 4-3, has two major emphases. They are the functional requirements of the Trajectory Manager and the data utilized to effect those functions. For example, the key concept of **optimal new trajectory** is illustrated as the result of the **trajectory generation process**. Also, there are three connections between the Trajectory Manager and other ancillary systems in FM. One, the Mission Strategist, is seen as the control to the Trajectory Manager in that **solutions**, changed **mission objectives** and those **mission objectives** evoke the trajectory management process. It is also illustrated on the map that the **Mission Strategist** produces **cost functions** that constrain the **Trajectory Manager**. The connections to two other subsystems by the **Trajectory Manager** are represented in terms of the Manager's output to the **Trajectory Follower** and information to **SA (PVI)**. The FM data bases have not been included in the model as an ancillary system due to their role as an information source and a communication link between subsystems. However, it is seen on the Trajectory Manager concept map that generating new trajectories in response to Mission Strategist requests is highly reliant on the multiple FM data bases for input. These data bases include: target prioritization data, map data, terrain elevation data, recovery base data, weapon data, fleet target data (offensive order of battle), mission waypoints, mission targets, and known threats (defensive order of battle data).

The major concept of trajectory management, **trajectory generation process**, is shown with a subordinate concept of has **functions**. These functions, of course, are related to the **optimal new trajectory** in that the functions will define the new trajectory.

Once again, it should be noted that these discussions of FM subsystems as defined in the concept maps, are only a cursory review and not inclusive of the map definition. A more in-depth review of the maps will be the focus of user involvement in the concept definition process.

Pilot Vehicle Interface (PVI)

There are several significant concepts illustrated on the concept map for the PVI, Figure 4-4, and they are **displays**, **controls**, **decision-aiding**, **situation awareness**, and **pilot**. The term PVI is used interchangeably with the situation awareness (SA) process. That is, the function of the PVI is to support the establishment and maintenance of situation awareness to the crew and to assist with critical situation recognition and decision-making.

The PVI interfaces with all the other FM subsystems, as seen on the map. In most cases, the relationships take the form of the PVI being the recipient of information from the other systems. An examination of the arcs (or links) between the concepts reveals that in most cases, the relationships pertain to informing or supporting, for example **decision-aiding**. Therefore, it can be assumed that the interchange of information for purposes of pilot/crew response is the major function of the PVI.

A noteworthy, dimension of the PVI concept map is the paucity of subordinate and related concepts to the already noted key concepts. Herein lies the focus of an Information Requirements Analysis. It is the information that needs to be presented on the displays to provide the pilot or crew knowledge with which to effect **selection/ deselection** and **other route decisions** that is missing from the current map. The output of all other subsystems is potential input to the PVI, as seen on the map. What remains to be determined is how that information should be presented at the PVI level of FM. The information available to the crew impacts the level of situation awareness. What is needed is knowledge regarding the parameters of the information required and an understanding of what "good" situation awareness is.

Trajectory Follower

The concept map for the Trajectory Follower, Figure 4-5, reveals a key concept of **flight control system (FCS) commands**. These FCS commands provide **decision-**

aiding such as **steering cues** to the **PVI** for management of aircraft **controls** and options of **flight control mode** which could be **manual**, **coupled auto-pilot**, or **flight director**. The functions of the **Trajectory Follower** are seen in the concepts of tracks **aircraft variables** and notes **aircraft deviations**. Another concept of tracks **trajectory** that was calculated by the **Trajectory Manager** confirms the functionality of the Trajectory Follower. Indirect links between the **Trajectory Follower** and other ancillary FM systems, such as the **Trajectory Manager** and the **PVI** are notable in the concept map, as well.

IDEF0

The above description of preliminary concept mapping of the FM system provides a foundation for continued analyses and definition of the functional requirements of the system, both by knowledge acquisition and a structured analysis and design technique. Throughout the next step (IDEF0 modeling) repeated references were made to the maps. The maps not only provided information about the global concepts of the subsystems, but also provided a test of the model's completeness and consistency.

The second part of our dual approach and the major focus of activity in defining the FM, was a description of the system in terms of a data management and information flow process. The vehicle for doing this was an IDEF0 model of the system. This modeling technique, Integrated Computer-Aided Manufacturing (ICAM) Definition (IDEF0) is an object-oriented system descriptive tool used primarily in the military and aerospace industry. A recent application of IDEF0 analysis was accomplished as part of the (CCCD) methodology (formerly Cockpit Automation Technology (CAT)) (Anderson, Ever, Green, and Wallace, 1990). The CCCD IDEF0 modeled the weapons system development process as it pertained to crew station design.

While semantic mapping provided a graphic global overview of the system in terms of its objects, attributes, relationships and functions, the IDEF0, represents a model of the system activities and data flow. An IDEF0 system description will allow an examination of information as a sequential process. FM, viewed as an information flow process, performs a sequence of activities with information used, managed, and output by those activities. Therefore, an attribute of the IDEF0 model is the ability to focus specific attention on information.

IDEF0, the military version of Structured Analysis and Design Technique (SADT) that was developed by SofTech during the early 1970s (Marca and McGowan, 1988), is a decomposition of the functional and informational components of the system from the top down. To be specific, the IDEF0 modeling process describes the system in terms of system and subsystem activities.

The IDEF0 model is a coordinated set of diagrams which illustrates FM from the point of view of human factors engineering. The diagrams illustrate FM system activities and interactions and data flow between subsystems. The model is a description of boundaries, behaviors and substance of FM. The boundaries of the model are defined by a single top-level box that is decomposed with subsequent decomposition continuing until all activities are identified in a hierarchical fashion. The IDEF0 analysis method was used to analyze FM in order to effect a *functional and informational* analysis of the system from the viewpoint of simulation planning and design of optimal displays and controls. The objective of the FM IDEF0 diagrams is to answer specific questions about what the system is supposed to do.

An IDEF0 analysis was developed subsequent to the initial concept maps described above. However, due to the complimentary nature of these techniques, several iterations of semantic maps occurred in parallel with the IDEF0 modeling. Each technique supported the other. FM IDEF0 provided a structured look at the system from the point of view of functionality, data flow, and interdependencies between functions. Semantic maps were not constrained by the structure imposed on IDEF0 system description, but instead allowed for the functionality to be represented without inferences about temporal considerations, data flow, or sequence of events.

Each IDEF0 diagram defines one specific topic. For example, diagram Node AO, Figure 4-7, defines the FM system at a top level. Each subsystem activity is defined with its information input, output, constraining factors and mechanisms.

Each box on AO will subsequently be defined at a finer level of detail. In other words, the hierarchical relationships are illustrative of parent/child diagrams. The parent functions are decomposed into 3-6 child functions or tasks. The level of detail and decomposition that occurs is determined by the initial declaration of the purpose of the model. The process continues until the questions about the system are explained in enough detail to accomplish the purpose of the model.

The IDEF0 model includes two graphic descriptors: boxes that represent activities, i.e., tasks that are performed by the system, and arrows that depict "things" of the system. The things of the system may be information, products of activities, or rules, etc. These arrows, in addition to representing system things, operate as connectors between activities. They illustrate the interdependencies, represent feedback loops between activities, and provide coherence of information flow through the system. The configuration of arrows to the boxes is a significant factor in understanding the IDEF0 diagram.

Arrows that enter the box from the left are input arrows. Input arrows represent things the activity will use or transform in the course of effecting the task under consideration. Activity constraints are represented with control arrows entering the box from the top. These constraints may be the rules or data that define the boundaries under which each particular activity occurs. Figure 4-6 provides an example of an IDEF0 box (adapted from Marca and McGowan, 1988).

According to IDEF0 protocol (Marca and McGowan, 1988), all activity boxes in the IDEF0 diagram must have at least one control arrow. However, it is not required to have input arrows for all activities. If there is doubt whether or not an arrow operates as input or a constraining factor, the decision is made to use the arrow as a control. Two other kinds of arrows are important in IDEF0 modeling, they are mechanism arrows and output arrows. The mechanism arrows enter the box from the bottom and define who is doing the activity or by what means the activity is getting done.

Not only do boxes have decompositions, arrows may also include several components, and those components may branch or join other arrows as input, output or mechanisms for activity boxes. Throughout the FM model, the

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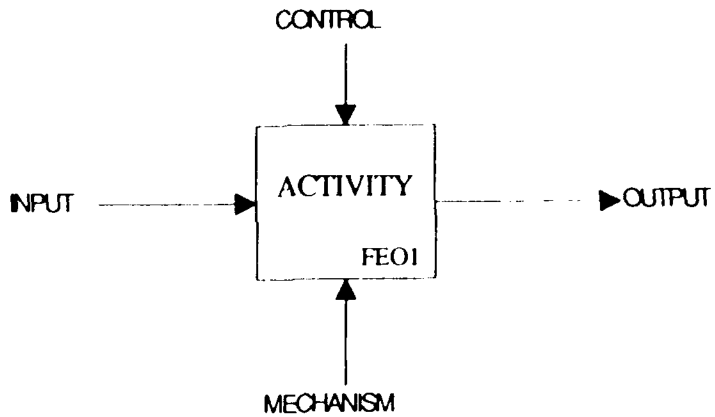

NODE:	TITLE: FIGURE 4-6 SAMPLE IDEF0 BOX	NUMBER:

mechanism for flight management is the FM System. Included within the FM System mechanism arrow and branching from that arrow are the subsystems. For example, Diagram A0, Figure 4-7, shows branches from M1 (Flight Manager) of Mission Strategist to determine mission strategy, Threat Manager is the mechanism for threat management, the Trajectory Manager is the mechanism for trajectory management, etc. Output arrows exit the box from the right and define the product of the activity. These output arrows will typically depict the source of input, control, or even a mechanism to subsequent activities or feedback loops to previous activities, thereby illustrating the interdependencies of activities within the system. In addition, the output arrow may represent a system output and be illustrated on the diagram as an output arrow (Ox).

The following collection of IDEF0 diagrams and narratives describe the conceptual FM system for three levels of decomposition.

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A-0 FLIGHT MANAGEMENT

The purpose of the FM model is to illustrate a conceptual definition of FM. In addition, the model will provide a foundation for MMI Information Requirements Analysis and subsequent development of optimum displays. FM is described from the perspective of human factors engineers. It is depicted as an onboard mission planning system, the objective of which is to respond to unplanned events with appropriate strategies that will accomplish mission objectives.

Input from FM data bases could include planned mission data, communication links, and incoming data from sensors, aircraft status information, threat and target update information and other intelligence data not available in the pre-flight plan. The FM system is illustrated in the model as the mechanism by which flight management occurs (mechanism arrow). Tactical doctrine (control arrow) is the overriding constraint that drives the FM system.

There are five output arrows that reflect results of FM activity. Countermeasures are the system response to immediate and imminent threat as determined by the system. FM determines and displays control effector commands to the crew. Situation awareness is provided to the crew on cockpit displays. A new route is computed, and continual information updates are fed back into the FM data bases

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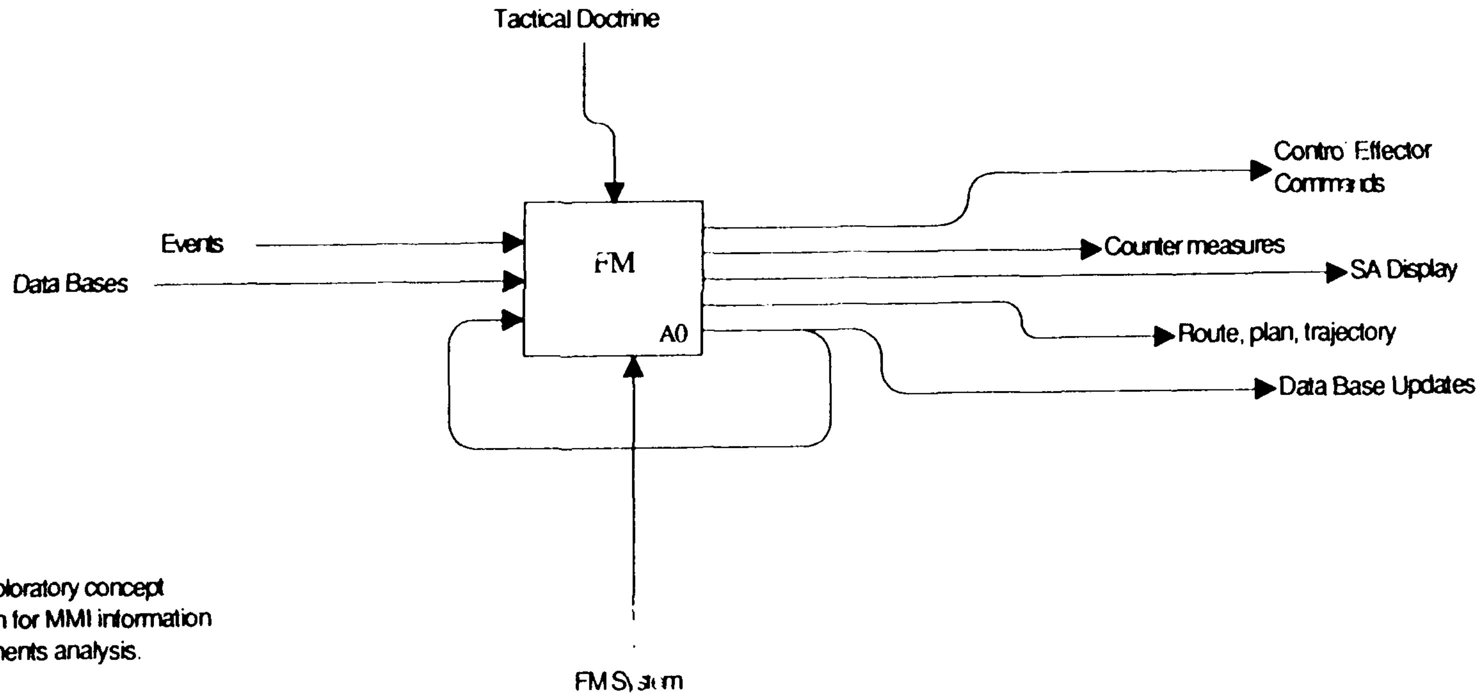

Purpose: Illustrate exploratory concept definition for MMI information requirements analysis.

Viewpoint: Human Factors Engineers

NODE: A-0	TITLE: -	FIGURE 4 - 7	NUMBER:

AO FM

FM activities are defined as the functional attributes of the specific subsystem components. There are five major functions involved in real-time onboard mission planning: determine mission strategy (box A1), threat management (A2), trajectory management (A3), manage the PVI (A4), and follow trajectory (A5). The Mission Strategist, represented by a branch of mechanism arrow M1, functions as the FM system executive that executes other processes in order to assure that timing and other objectives are met. Output, system time, from A1 provides control to all other processes that are represented on the diagram. Mission objective functions, cost and time, also are utilized as controls to threat management and trajectory management. (These functions are the perceived payoff and penalties associated with a mission). Data base updates are continuous throughout the process from activity box A1 through activity box A5.

Threat management (Box A2), accomplished by the Threat Manager, a branch of the M1 system arrow, detemines threat characteristics, based on threat parameters, threat mode of operation, and effects defensive actions in response to the threat. *Trajectory management* (Box A3) calculates coarse and optimal trajectories and generates real-time aircraft control commands for use by the Trajectory Follower to control the aircraft along the computed course. The Trajectory Manager branch of the M1 arrow, system, is the subsystem responsible for this activity. Management of pilot vehicle interface is the fourth activity illustrated in the FM parent diagram box A4 and it represents the situational awareness process requirements of strategic flight management. The SA process is represented as the mechanism for PVI activities. It is at this level of the FM that the crew information requirements and responses are effected.

Follow trajectory (Box A5) reflects the Trajectory Follower requirements to provide the flight directory display commands, manual or autopilot, to fly the path defined by the Trajectory Manager. This activity is managed by the subsystem, Trajectory Follower.

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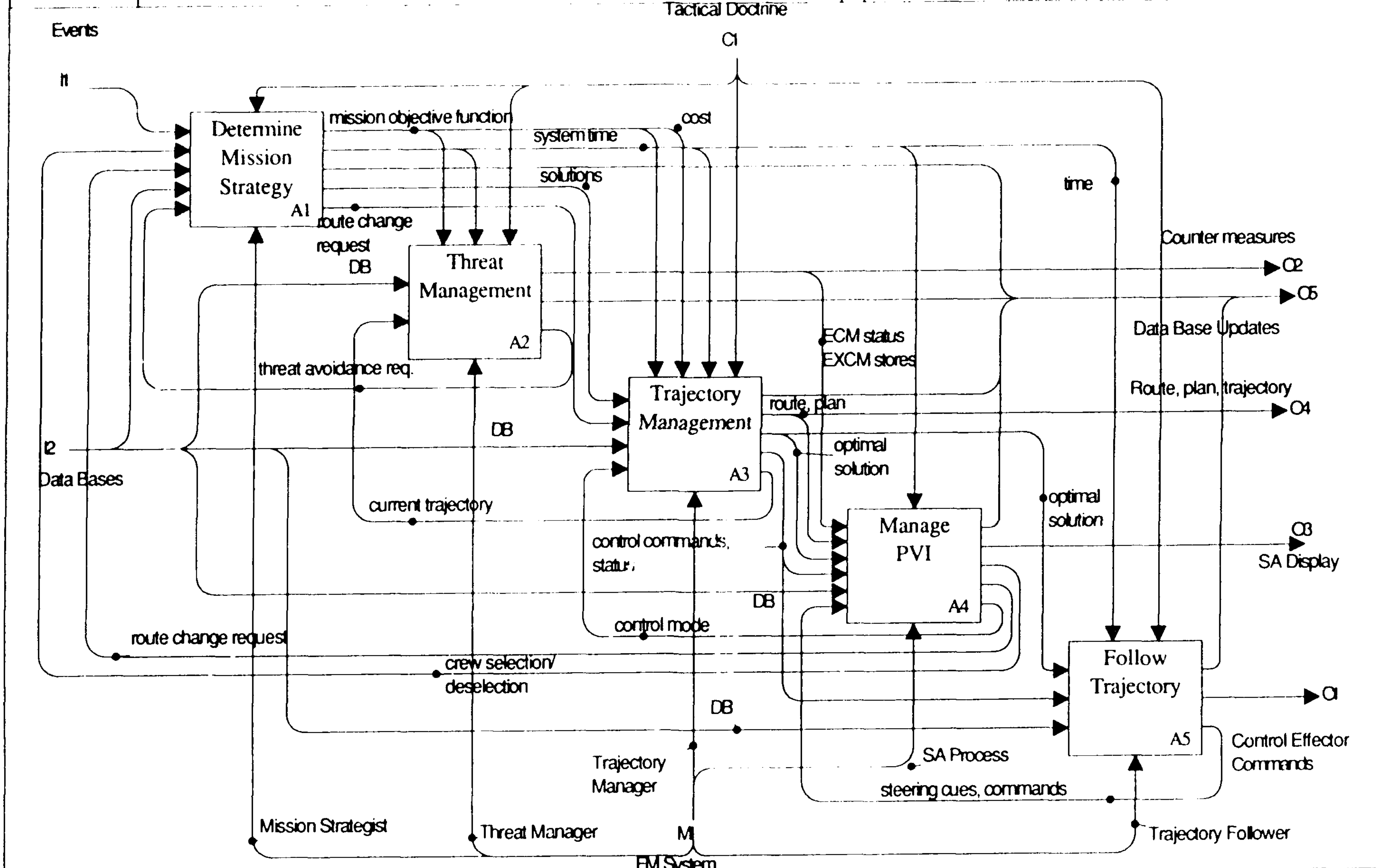


NODE: A0	TITLE: FM	NUMBER:

FIGURE 4 - 8

A1 DETERMINE MISSION STRATEGY

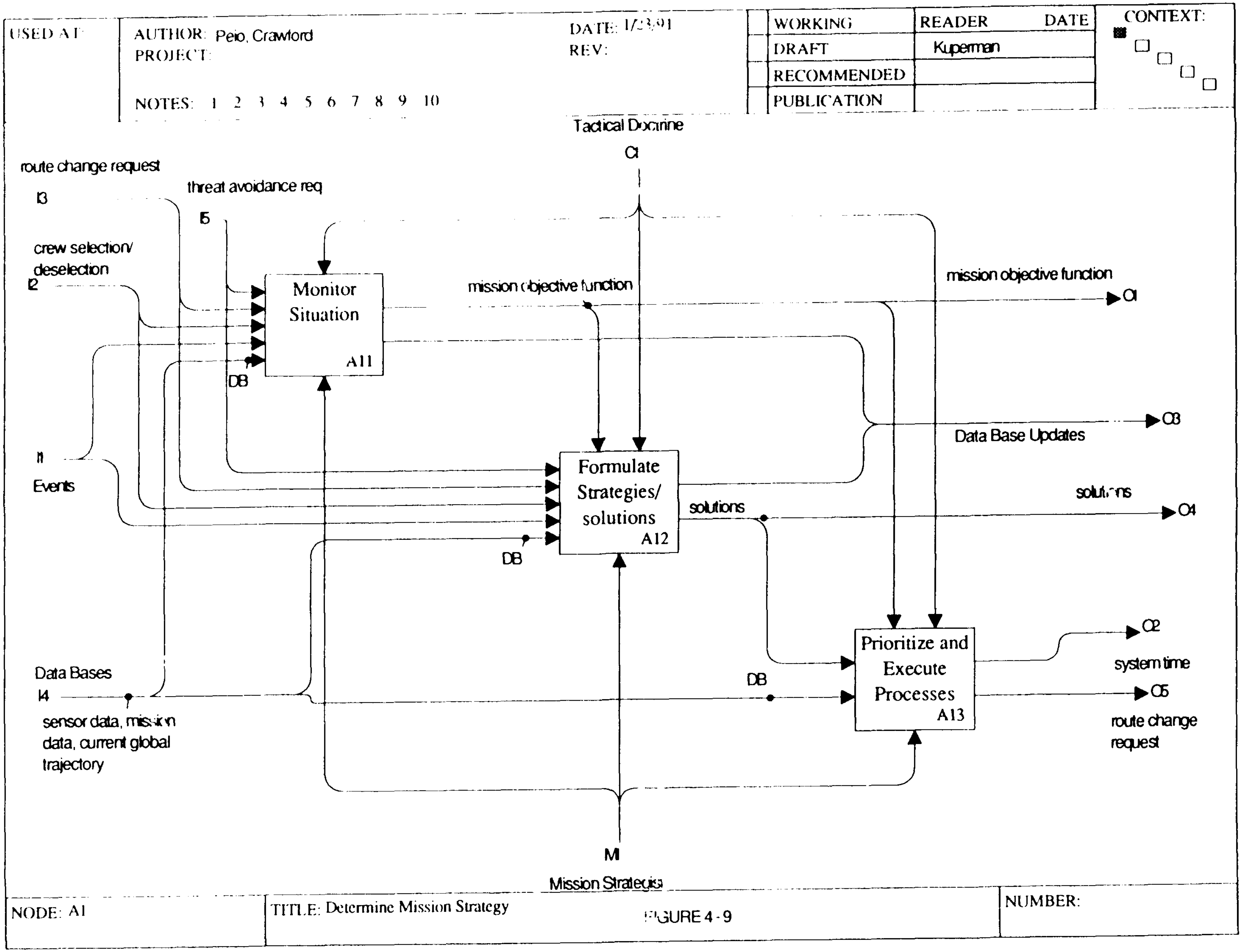
The Mission Strategist (M1) functions as the system executive and FM expert system that responds to mission events and updated data from FM data bases. Three activities are represented in the model to determine mission strategy. Box A11, monitor situation, reflects the Mission Strategist function to note and assess deviations from the preplanned mission due to unexpected events and to generate mission objectives for threat and trajectory functions to support: fuel/range, optimization; threat minimization; target prioritizations and adverse weather avoidance.

Data base input to this activity box includes: knowledge rules, mission data, current global trajectory, and sensor data. In addition, events, input I1, provide the impetus to initiate FM and the Mission Strategist functions. The IDEF0 model of the FM Mission Strategist suggests that monitoring the situation may be a discreet process. *However, it should be noted that monitoring* the situation is a continuous process throughout the mission and what is indicated on the diagram is that a specific event will serve as a catalyst for initiation of Mission Strategist functions.

The output of the monitor situation activity, mission objective function, (O4), is reflected in the model as a control arrow for *threat management and trajectory management. In addition,* this output arrow is represented as control for the activities of formulation of strategies and solutions (A12), and prioritizing and execution of processes (A13).

Knowledge rules, mission data, the pre-planned current global trajectory and sensor data are additional data base input for formulation of strategies and solutions to unplanned events as they are assessed by the Mission Strategist. The strategies and solutions generated involve guidelines for generating solutions in response to the unplanned event that may effect the mission plan. Both mission objectives and strategies are continuously provided as updates to the FM data base, output arrow O2.

Prioritize and execute processes (A13) is depicted on Node A1 of the IDEF0 diagram as the third box or activity. As the FM system executive, the Mission Strategist performs real-time execution of FM ancillary processes. Prioritization occurs in order to assure that the timing objectives of the system are met. Data base updates provide information to the Mission Strategist and strategic prioritization algorithms, which *reside in the subsystem,* are invoked based on this information. Mission objective and cost function output from box A11, as well as tactical doctrine (C1), operate as control to this prioritization process. Route change requests (O5)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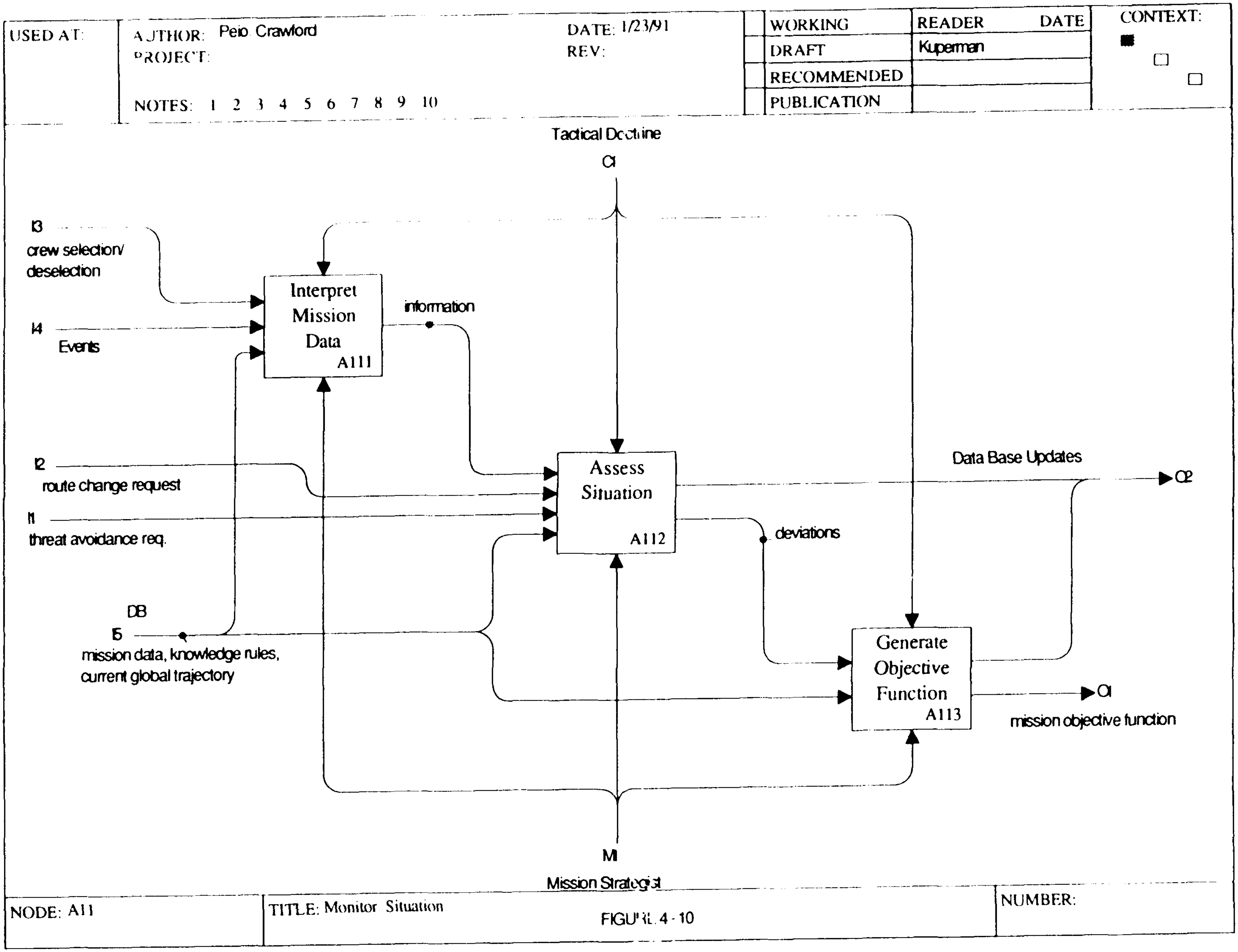
Tactical Doctrine
C1
route change request
I3
threat avoidance req
I5
crew selection/
deselection
I2
I1
Events
Data Bases
I4
sensor data, mission
data, current global
trajectory
Monitor
Situation
A11
DB
mission objective function
Formulate
Strategies/
solutions
A12
DB
solutions
mission objective function
O1
Data Base Updates
O3
solutions
O4
Prioritize and
Execute
Processes
A13
DB
O2
system time
O5
route change
request
M1
Mission Strategies
NODE: A1
TITLE: Determine Mission Strategy
NUMBER:
FIGURE 4-9

A11 MONITOR SITUATION

Further decomposition of box A11 reveals three activities associated with monitoring the situation by the Mission Strategist: interpret mission data (A111), assess situation (A112), and generate mission objectives (A113). Mission data input to the Mission Strategist from the FM data base will consist primarily of target prioritization data, map data, terrain data, recovery base data, weapon data and fleet target data for offensive order of battle. In addition, in order to interpret these data, knowledge rules and the current global trajectory are utilized by the Mission Strategist.

The resultant information based on the mission data interpretation serves the Mission Strategist in situation assessment (A112). There are two more input arrows to box A112 that provide additional information regarding the situation and they are threat avoidance request received from the Threat Manager and route change requests that are initiated at the PVI by the crew.

The third activity box on Node A11, monitor situation, addresses a major function requirement of the Mission Strategist, that of generating mission objective functions to support fuel/range optimization, threat minimization, target prioritization, adverse weather avoidance, target and flight plan, time constraints and aircraft malfunction compensation.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Tactical Doctrine
C1
I3
crew selection/
deselection
I4
Events
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information
I2
route change request
I1
threat avoidance req.
Assess
Situation
A112
Data Base Updates
O2
deviations
DB
I5
mission data, knowledge rules,
current global trajectory
Generate
Objective
Function
A113
O1
mission objective function
M1
Mission Strategist
NODE: A11
TITLE: Monitor Situation
NUMBER:

FIGURE 4 - 10

A12 FORMULATE STRATEGIES/SOLUTIONS

Four activity boxes are shown on Node A12 that indicate the Mission Strategist function requirement of developing solution guidelines for trajectory management and threat management. Knowledge rules, mission data and the current global trajectory are provided to the Mission Strategist by the FM data base. To formulate strategies, the Mission Strategist coordinates responses of other FM functions (A121), the Threat Manager, Trajectory Manager, PVI, and the Trajectory Follower. For example, responses from the Threat Manager, threat avoidance request (I1), the Trajectory Manager, route change request (I2), the PVI, crew selection/deselection (I3), and ongoing events (I4) are acted upon under the cons raint of the mission objective function (C1).

Activity box A122, evaluate trade-offs between mission parameters, is based on current mission data and cost and objective functions.

Compute weighting factors (A123) occurs as a result of the trade-off decisions. The optimal solutions are determined as a result of these trade-off weightings, according to the mission objectives.

The fourth activity box described on Node A12, generate scenarios (A124), notes the activity of the Mission Strategist to generate solution guidelines for updating the route plan solution.

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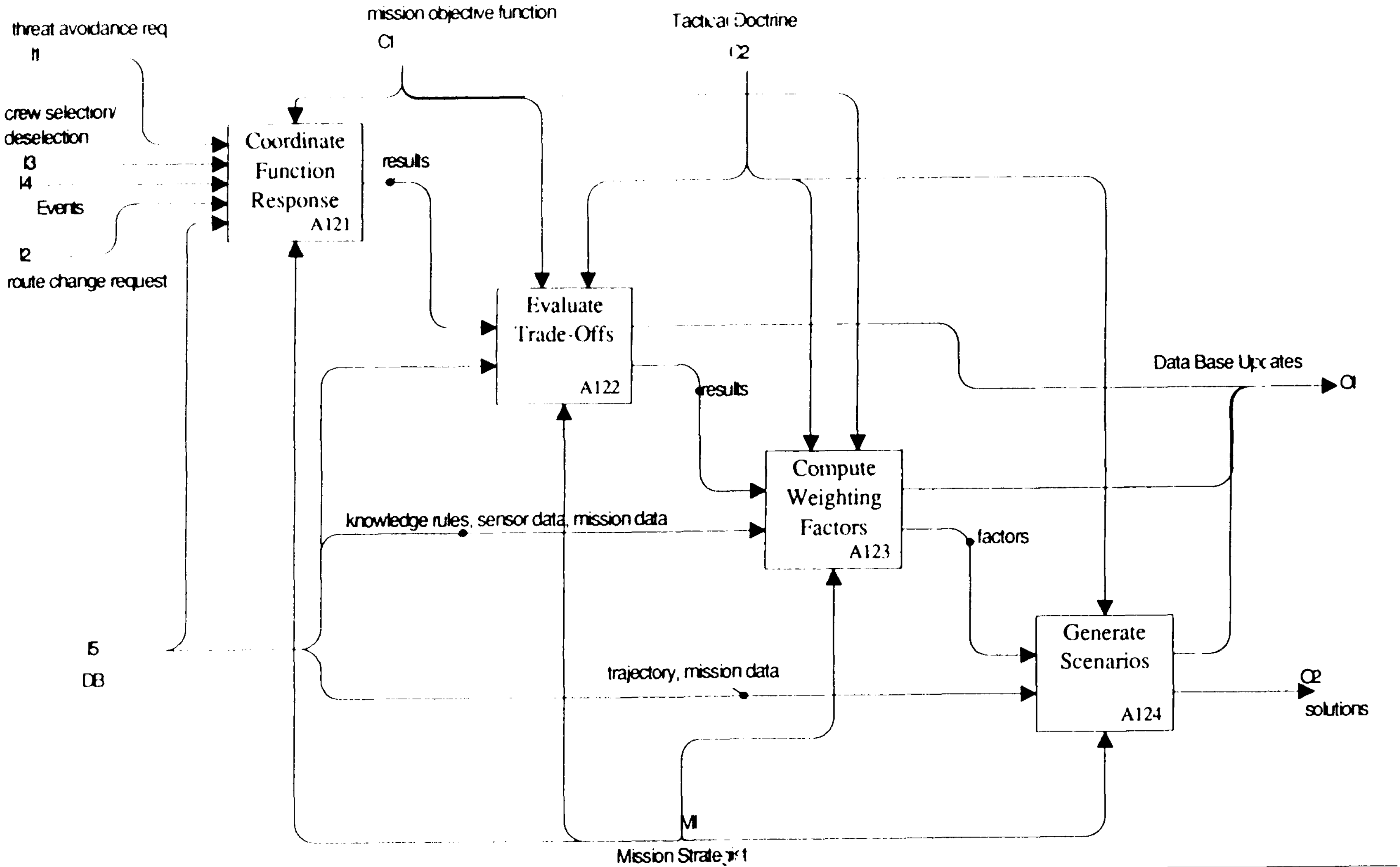

NODE: A12	TITLE: Formulate Strategies/ solutions	NUMBER:

FIGURE 4 - 11

A13 PRIORITIZE AND EXECUTE PROCESSES

Node A13 speaks to the Mission Strategist's role to evoke the ancillary subsystems for managing threat (A131), generating new routes (A132) and subsequently, updating the PVI (A133) system to provide the crew with system status information. Control arrow (C1) indicates the presence of the mission objective function operating as a control process for evoking the Threat and Trajectory Managers

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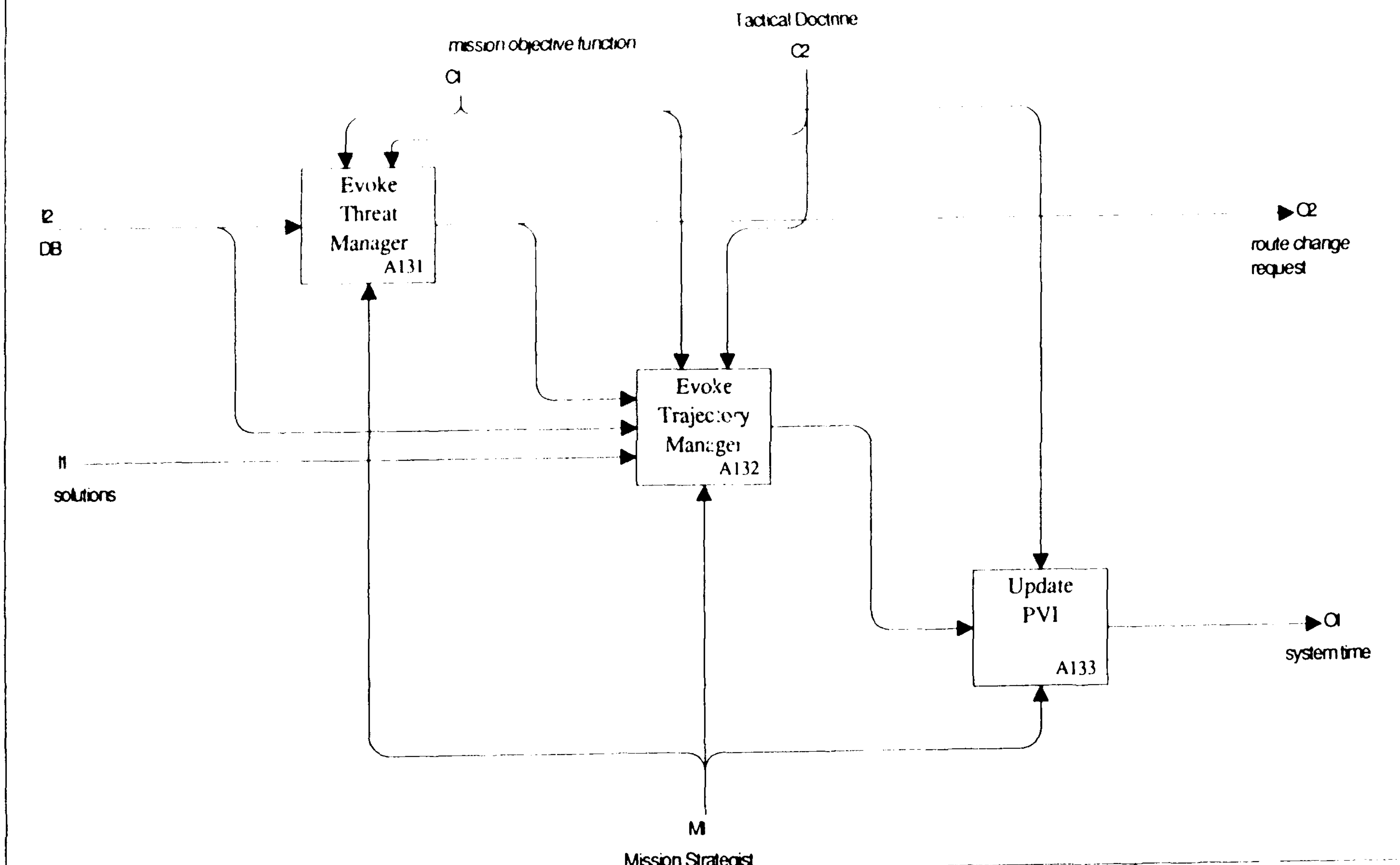
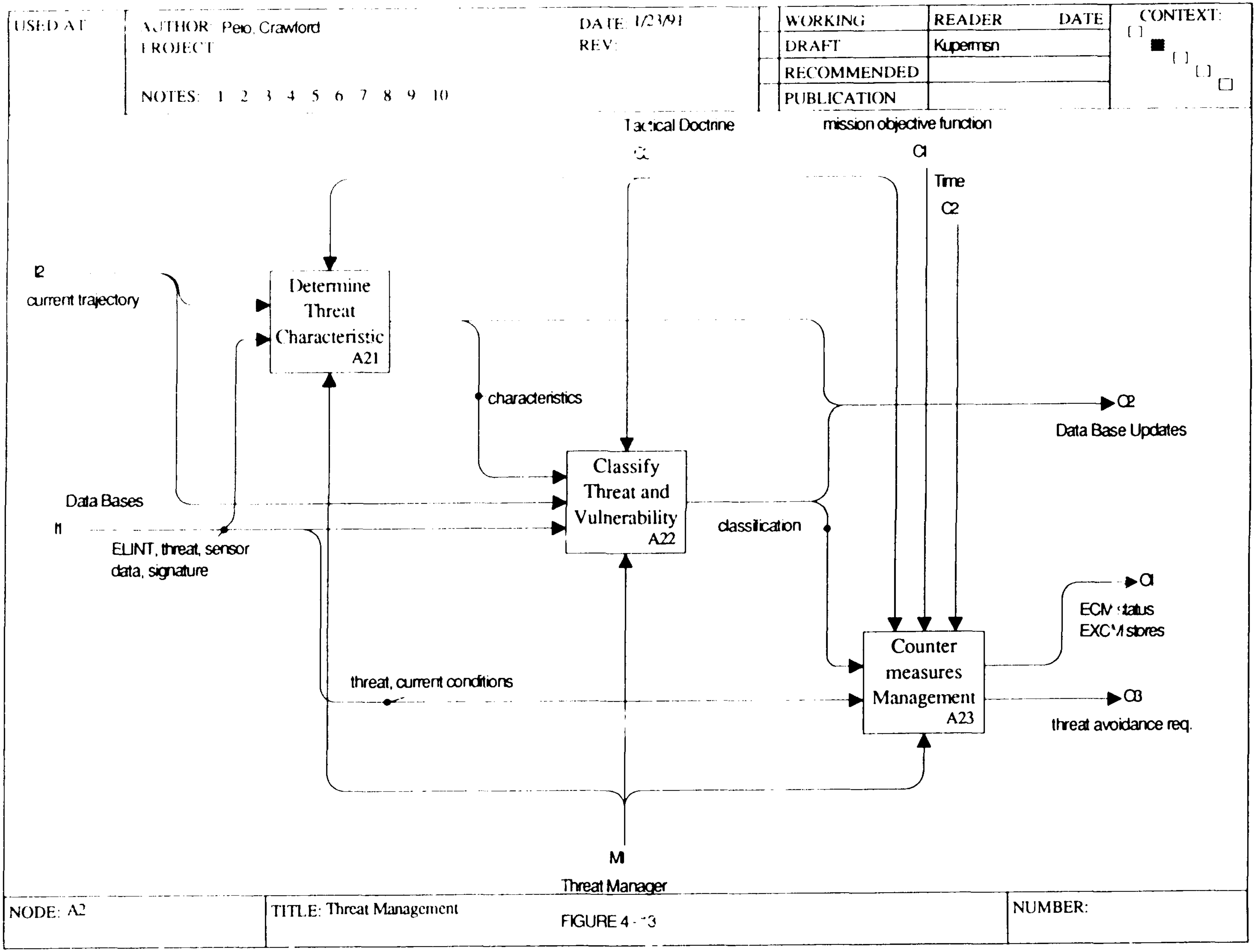


NODE: A13	TITLE: Prioritize and Execute Processes	FIGURE 4 - 12	NUMBER:

A2 THREAT MANAGEMENT

The IDEF0 model for Threat Management (A2) shows three activity boxes. The Threat Manager (mechanism arrow, M1) determines threat characteristics (A21), classifies the pop-up threat, assesses ownship vulnerability (A22), and manages countermeasures (A23). In order to determine threat characteristics, input from the FM data base (I1) includes threat, ELINT (frequency, power, level, mode and bearing of threat), and sensor data. This input is evaluated in order to both determine that a threat exists and to classify that threat. Depending on the threat classification results, a threat avoidance request (O3) may be issued by the Threat Manager. Tactical doctrine (C3), mission objectives (C1) and system time (C2) operate as controls for the Threat Manager's countermeasures management. Expendable countermeasures and electronic countermeasures are utilized, when appropriate, by Threat Manager. EXCM and ECM status is presented to PVI for situation assessment by the crew, (O1) in addition to updates to the data base (O2).



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READER
DATE
Kupermsn
CONTEXT:
Tactical Doctrine
mission objective function
C1
Time
C2
I2
current trajectory
Determine
Threat
Characteristic
A21
characteristics
Classify
Threat and
Vulnerability
A22
O2
Data Base Updates
Data Bases
I1
ELINT, threat, sensor
data, signature
classification
O1
ECM status
ECM stores
Counter
measures
Management
A23
threat, current conditions
O3
threat avoidance req.
M1
Threat Manager
NODE: A2
TITLE: Threat Management
NUMBER:

FIGURE 4 - 3

A21 DETERMINE THREAT CHARACTERISTICS

Detect threat (A211) reflects the Threat Manager capability to interpret threat emissions that can be detected by passive RWR and other sensor data systems in use by strategic offensive aircraft.
Once the threat presence is detected, the Threat Manager categorizes threats (A212) in terms of threat or sensor type, range, transmission frequencies and whether the signals are jammable or not jammable. In order to identify threat (A213), the Threat Manager interprets data detected by the ELINT system. (ELINT data are the emitter parameter files). These data are input to the Threat Manager from the data base. Finally, the Threat Manager locates threat (A214) in relation to the aircraft and does so using data input from RWR and ELINT system.

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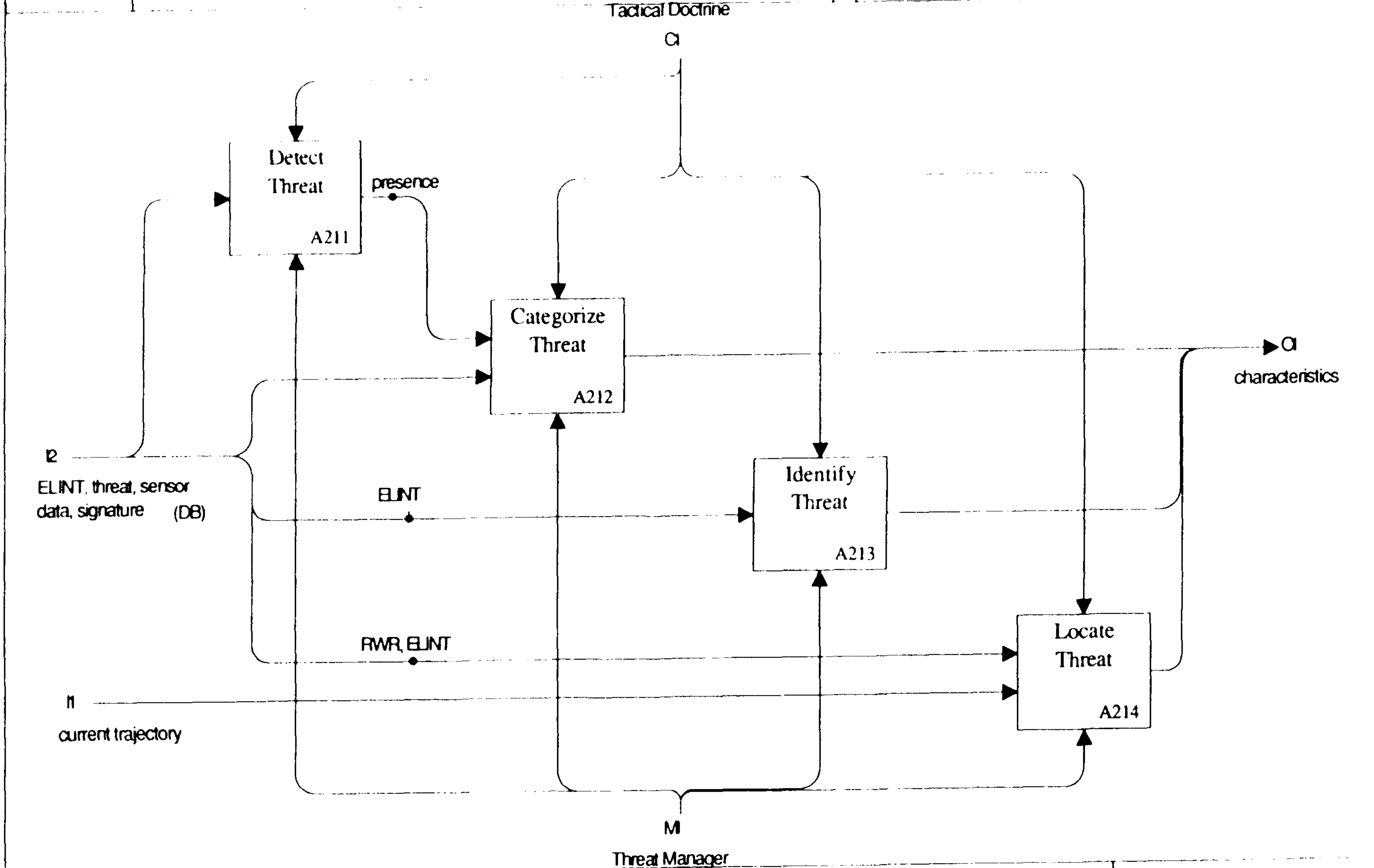
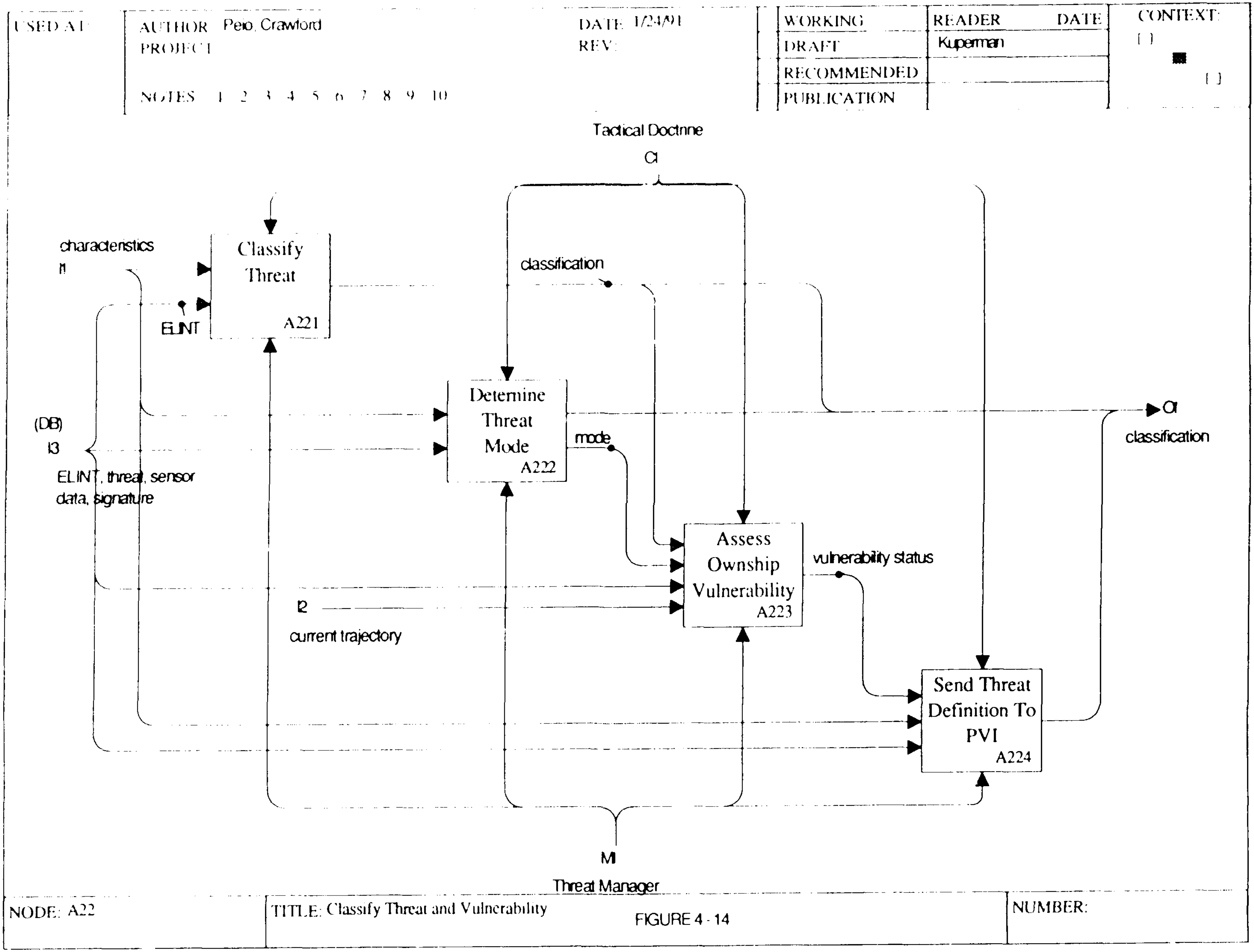


NODE: A21	TITLE: Determine Threat Characteristic	NUMBER:

FIGURE 4 - 14

A22 CLASSIFY THREAT AND VULNERABILITY

Threat characteristics, ELINT, sensor data, and ownship signature from the FM data base are the sources of information that allow classification of threat (A221) by the Threat Manager. Threats are classified in terms of degree, that is, immediate, imminent or no threat (jammable). (A threat is an immediate threat if ownship is within, or about to enter the lethal envelope of the threat. It is imminent when ownship will enter the lethal envelope if the projected trajectory is continued). In addition, threat mode (A222) is determined using the same input data. The threat mode of operation may be: search, track, or launch. Additional assessment of ownship vulnerability (A223) provides further information for threat classification and definition. Once the threat classifications are determined, this information is relayed to the Mission Strategist through the data base and the PVI for crew situation awareness (A224).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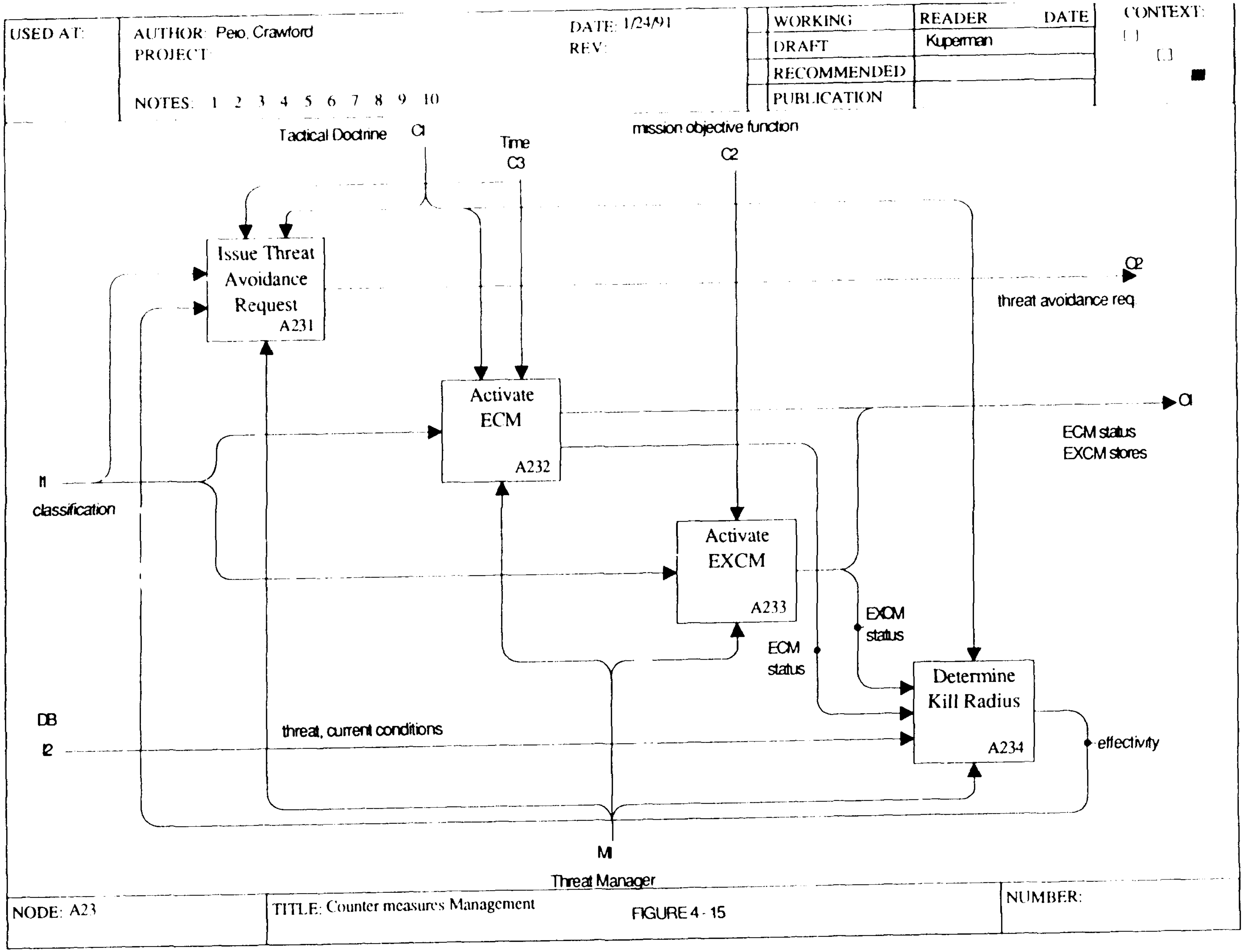
READER
DATE
Kuperman
CONTEXT:
Tactical Doctrine
C1
characteristics
I1
ELINT
Classify Threat
A221
classification
(DB)
I3
ELINT, threat, sensor data, signature
Determine Threat Mode
A222
mode
O1
classification
Assess Ownship Vulnerability
A223
vulnerability status
I2
current trajectory
Send Threat Definition To PVI
A224
M1
Threat Manager
NODE: A22
TITLE: Classify Threat and Vulnerability
NUMBER:
FIGURE 4 - 14

A23 COUNTERMEASURES MANAGEMENT

There are three options that the Threat Manager may effect in response to threat data. One is to issue a threat avoidance request (A231) to the Mission Strategist, second and third options are to activate electronic countermeasures (ECM) (A232) and to activate expendable countermeasures (EXCM) (A233). Threat effectivity is determined in terms of the kill radius (A234) of the threat. The information of threat effectivity is utilized as input for issuing threat avoidance requests, as is seen by the effectivity feedback arrow on the diagram. ECM status and EXCM stores information is sent to the PVI and continually updated in the FM data base.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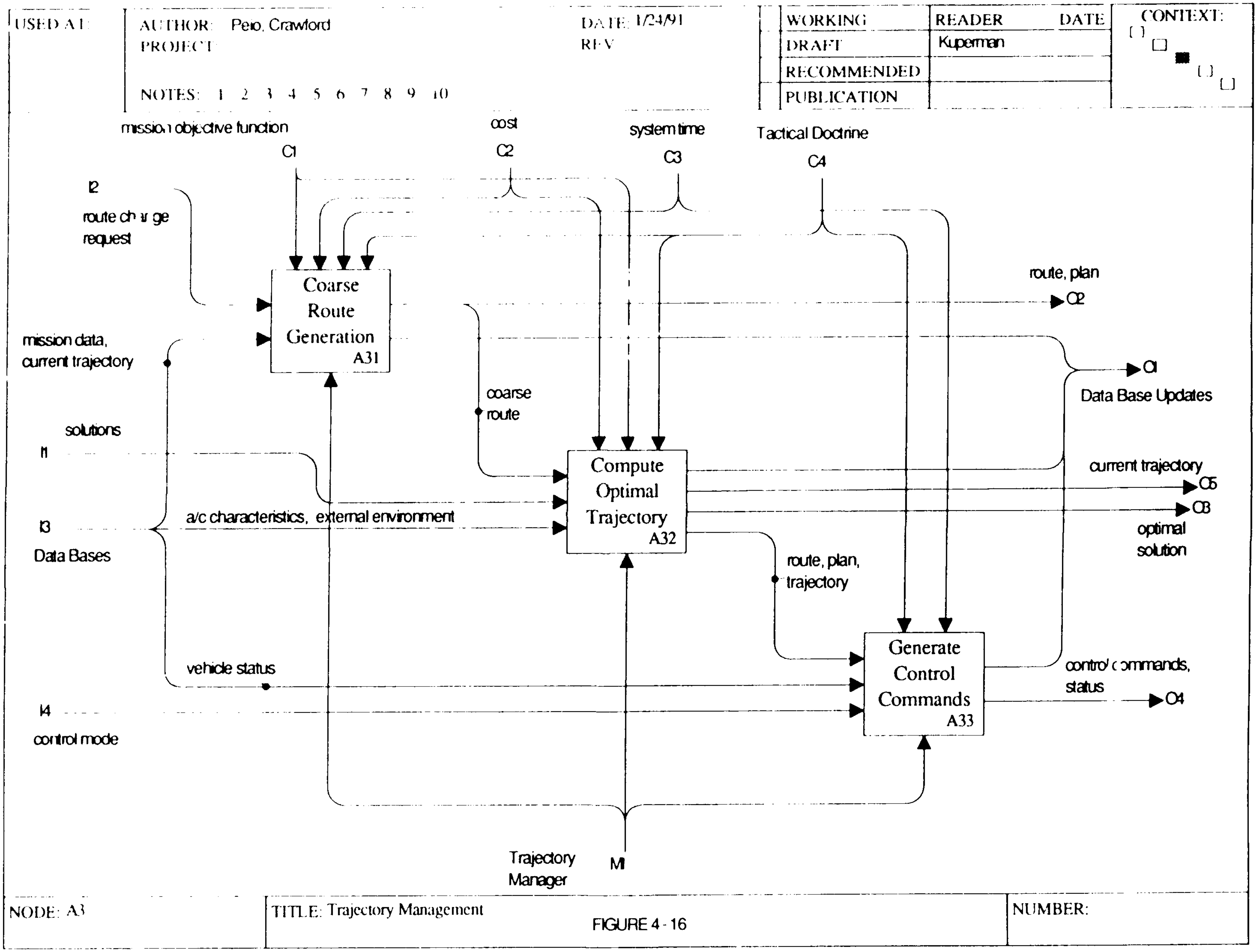
DATE
Kuperman
CONTEXT:
Tactical Doctrine
C1
Time
C3
mission objective function
C2
Issue Threat Avoidance Request
A231
Activate ECM
A232
Activate EXCM
A233
Determine Kill Radius
A234
C2
threat avoidance req
C1
ECM status
EXCM stores
I1
classification
EXCM status
ECM status
DB
I2
threat, current conditions
effectivity
M1
Threat Manager
NODE: A23
TITLE: Counter measures Management
FIGURE 4 - 15
NUMBER:

A3 TRAJECTORY MANAGEMENT

The functional requirements of FM trajectory management are : terrain following/avoidance, threat avoidance, obstacle avoidance, deconfliction, fuel optimization, and terrain referenced navigation. In order to satisfy those requirements, coarse route generation (A31) is initiated in response to route change requests. Mission objective and cost functions generated by the Mission Strategist (C2 and C3), as well as system time (C1), provide constraints for the coarse route generation process. The route generated at this level of trajectory management is a rule-based and heuristic approach that minimizes threat and may be part of the pre-flight plan. Input from FM data bases that includes pre-planned trajectory, and mission data, provides the data utilized by the Trajectory Manager for a new coarse route.

The next activity shown on the trajectory management process diagram is to compute an optimal trajectory (A32). This optimal route is based on additional data of aircraft characteristics and the external environment that is being continuously updated. In addition, local candidate solutions are provided to the Trajectory Manager by the Mission Strategist in response to a route change request. Control commands are generated (A33), based on the new optimal route. It is assumed that the trajectory management process is contingent on an accept or reject decision at the level of the PVI. As with all new information generated by FM subsystems, the data bases are updated for use by the system.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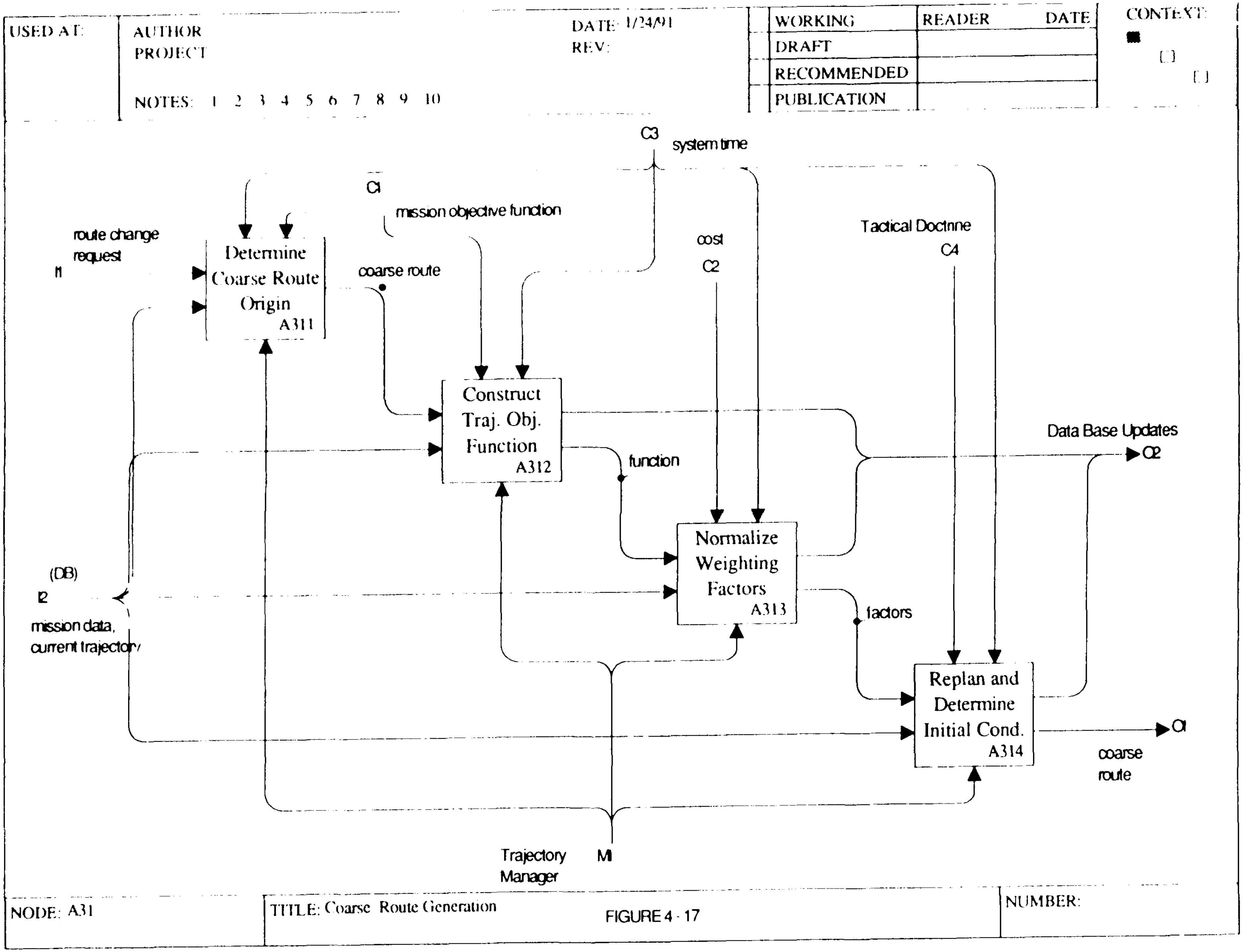
PUBLICATION
READER
DATE
Kuperman
CONTEXT:
mission objective function
C1
cost
C2
system time
C3
Tactical Doctrine
C4
I2
route change request
mission data, current trajectory
solutions
I1
I3
Data Bases
I4
control mode
Coarse Route Generation
A31
coarse route
a/c characteristics, external environment
Compute Optimal Trajectory
A32
route, plan, trajectory
vehicle status
Generate Control Commands
A33
route, plan
O2
O1
Data Base Updates
current trajectory
O5
O3
optimal solution
control commands, status
O4
Trajectory Manager
M1
NODE: A3
TITLE: Trajectory Management
NUMBER:
FIGURE 4 - 16

A31 COARSE ROUTE GENERATION

Coarse trajectories to known targets and around known threats may be computed in advance and reside in the FM data base and, therefore, may or may not be computed on-line in real-time. Four boxes are shown on diagram A31 that suggest activities that occur during route generation. Box A311, determine coarse route origin, refers to the decision by the Trajectory Manager whether a pre-planned coarse route will be the baseline route or a new coarse route must be determined on-line. The Trajectory Manager constructs a trajectory objective function in response to mission objectives determined by the Mission Strategist (A312), and it normalizes weighting factors (313) that were determined by the Mission Strategist as a result of determining the mission parameter trade-offs. In addition, the Trajectory Manager detemines initial conditions and replans trajectories based on changed mission objectives (A314).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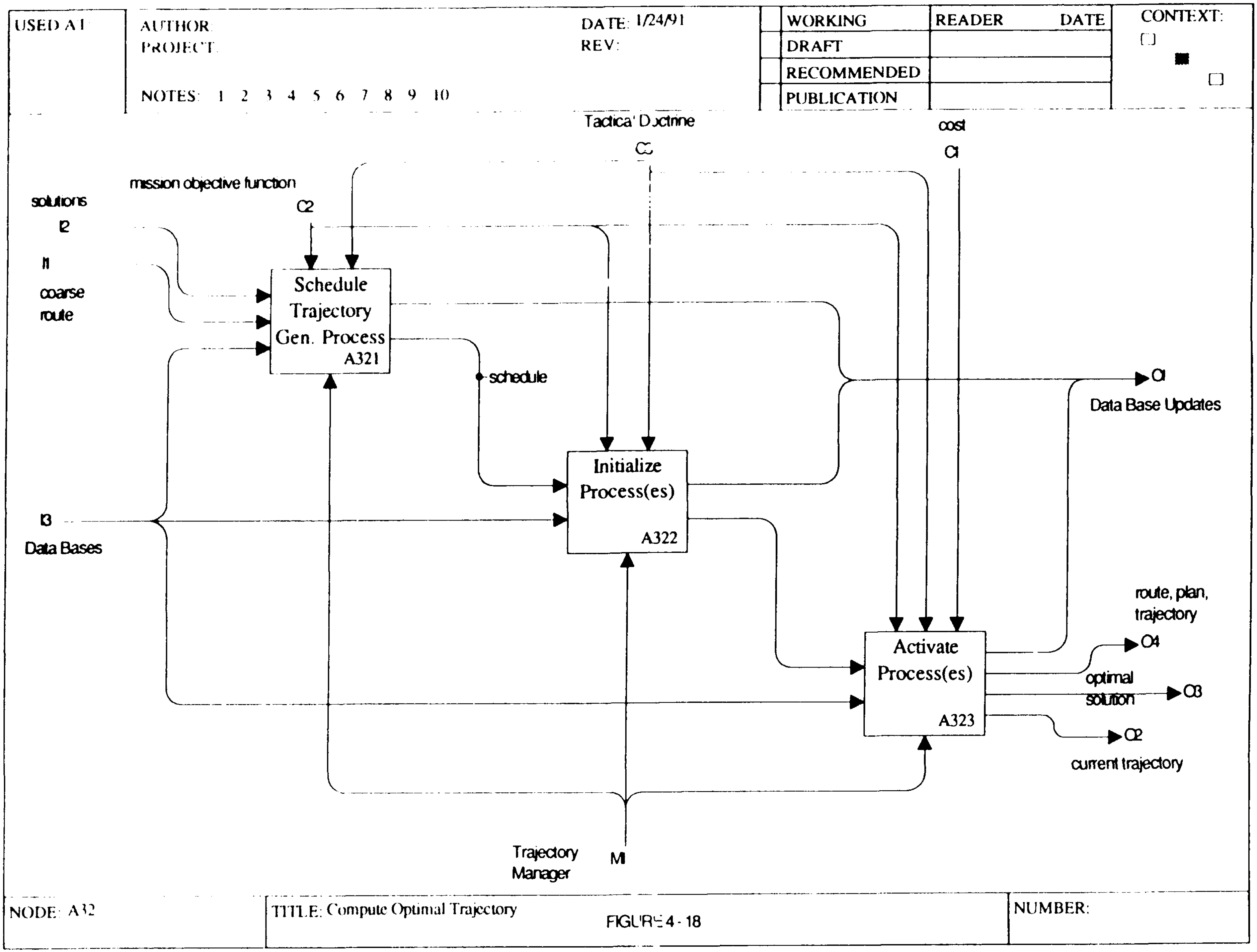
READER
DATE
CONTEXT:
C3
system time
C1
mission objective function
route change request
I1
Determine Coarse Route Origin
A311
coarse route
cost
C2
Tactical Doctrine
C4
Construct Traj. Obj. Function
A312
function
Data Base Updates
O2
Normalize Weighting Factors
A313
(DB)
I2
mission data, current trajectory
factors
Replan and Determine Initial Cond.
A314
O1
coarse route
Trajectory Manager
M1
NODE: A31
TITLE: Coarse Route Generation
NUMBER:
FIGURE 4 - 17

A32 COMPUTE OPTIMAL TRAJECTORY

Optimal trajectory generation by the Trajectory Manager includes scheduling the appropriate trajectory generation processes (A321), initializing those processes (A322) and activating the processes (A323) in order to generate a flyable trajectory, and a local candidate solution real time during the execution of the mission Trajectory generation processes are algorithms, rules and precomputed trajectories that include: A* Search Algorithm (A*); differential dynamic programming (DDP), SRT search update; expert system route planning; and precomputed test routes.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READER
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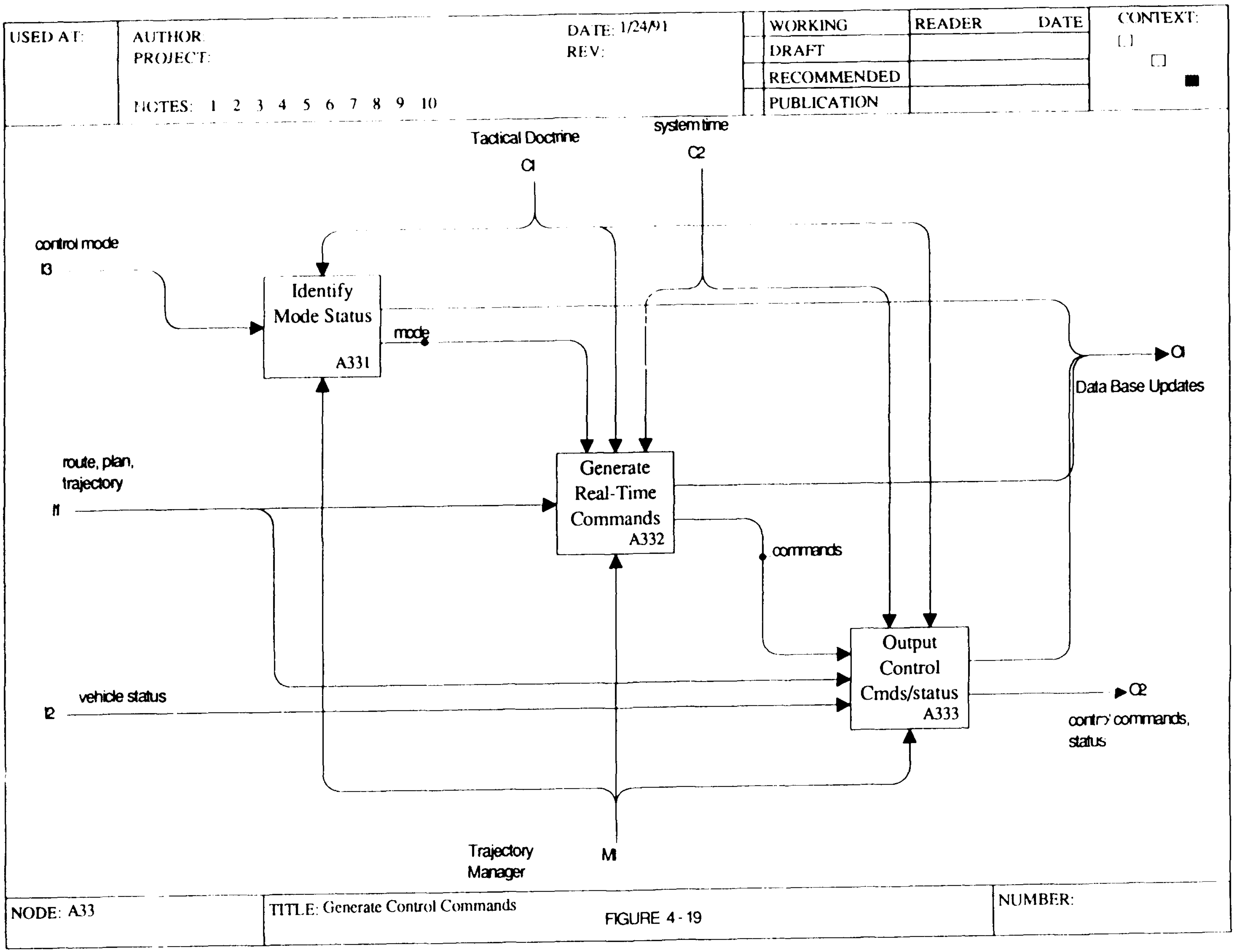
CONTEXT:
Tactical Doctrine
C3
cost
C1
mission objective function
C2
solutions
I2
I1
coarse
route
Schedule
Trajectory
Gen. Process
A321
schedule
Initialize
Process(es)
A322
O1
Data Base Updates
I3
Data Bases
route, plan,
trajectory
Activate
Process(es)
A323
O4
optimal
solution
O3
O2
current trajectory
Trajectory
Manager
M1
NODE: A32
TITLE: Compute Optimal Trajectory
FIGURE 4 - 18
NUMBER:

A33 GENERATE CONTROL COMMANDS

The IDEF0 diagram A33 has three activity boxes that address the Trajectory Manager function of generating control commands. Identification of control mode status (A331), either flight director, manual or auto-coupled is the first activity that is illustrated on the diagram. Generation of real-time commands (A332) indicates Trajectory Manager establishment of new heading and rate, altitude and rate, airspeed, pitch angle, and bank angle, % throttle and wing sweep during prosecution of the mission. These control commands and status are then output to the PVI, data bases, and the Trajectory Follower (A333).



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CONTEXT:
Tactical Doctrine
C1
system time
C2
control mode
I3
Identify
Mode Status
A331
mode
route, plan,
trajectory
I1
Generate
Real-Time
Commands
A332
commands
vehicle status
I2
Output
Control
Cmds/status
A333
O1
Data Base Updates
O2
control commands,
status
Trajectory
Manager
M1
NODE: A33
TITLE: Generate Control Commands
NUMBER:

FIGURE 4 - 19

A4 MANAGE PILOT VEHICLE INTERFACE

The process responsible for situation awareness includes management of cockpit displays and the information presented to the flight crew. Activity Box A41, information display, represents all the information presented to the crew on cockpit displays. System time, threat information, and trajectory data are required information. Also, relevant maps are presented, route change requests are updated, and countermeasures status, target data and sensor data are all provided to the PVI (situation awareness process). These mission status and decision-aiding data are part of the MMI requirements that support FM objectives of flexibility, effectivity and survivability.

In addition to providing information to the crew, providing control options (A42) are an integral part of the PVI. These control options operate as input to the PVI activity of "manage the selection/deselection" (A43). The crew response is introduced as an output at this level of the FM system. The output arrow O3 reflects the crew decision that is subsequently sent to the Mission Strategist in what is seen as a feedback loop on the diagram Node A0, FM. Additional situation updates to the Mission Strategist (A44) are represented as the final activity required by the situation awareness process (M1). The FM data base also receives updated information from PVI management.

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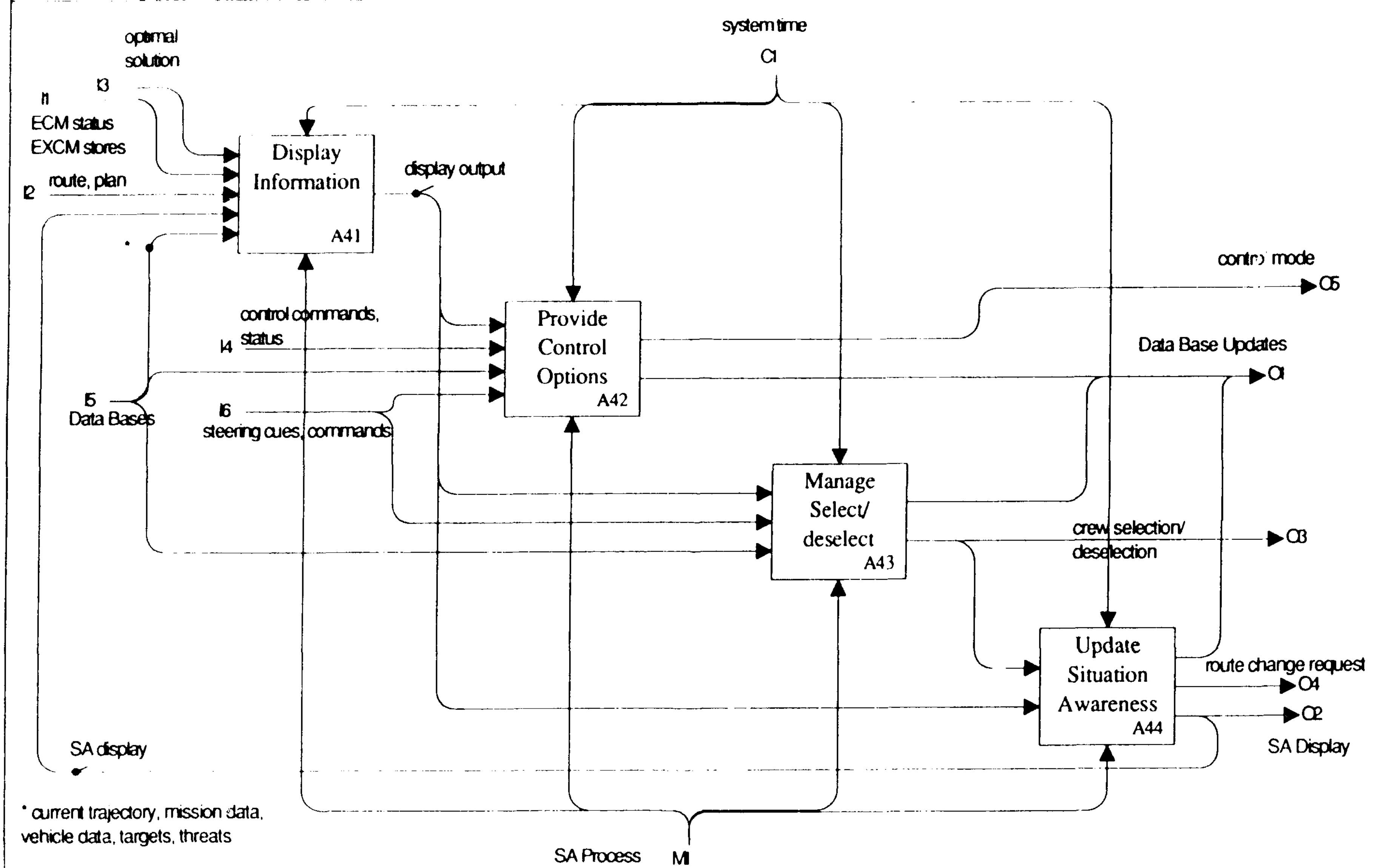

NODE: A4	TITLE: Manage PVI	NUMBER:

FIGURE 4 - 20

A41 DISPLAY INFORMATION

Continued decomposition of the information display can be reflected in the four activity boxes which, in effect, are representative of the four independent displays potentially available in the cockpit. The map display (A411) input includes optimal solution/trajectory (I1), route plan, system time, and current trajectory (waypoints targets and current aircraft position). A vehicle status display (A412) includes information input of engine and fuel status and other vehicle data. An aircraft status display (A413) includes ground speed, fuel flow, airspeed, altitude, vertical velocity, bank angle, heading, and system time. The defense display HSD (A414) includes system time, weapons status, ECM status, EXCM stores, maps, current trajectory, and mission data.

A42 PROVIDE CONTROL OPTIONS

N/A

A43 MANAGE SELECT/DESELECT

N/A

A44 UPDATE SITUATION

N/A

Activity boxes A42, A43, and A44 were not decomposed to a finer level of detail at this time. Although for design of the MMI, a decomposition would be required to effect a sufficient understanding of the FVI function and information requirements.

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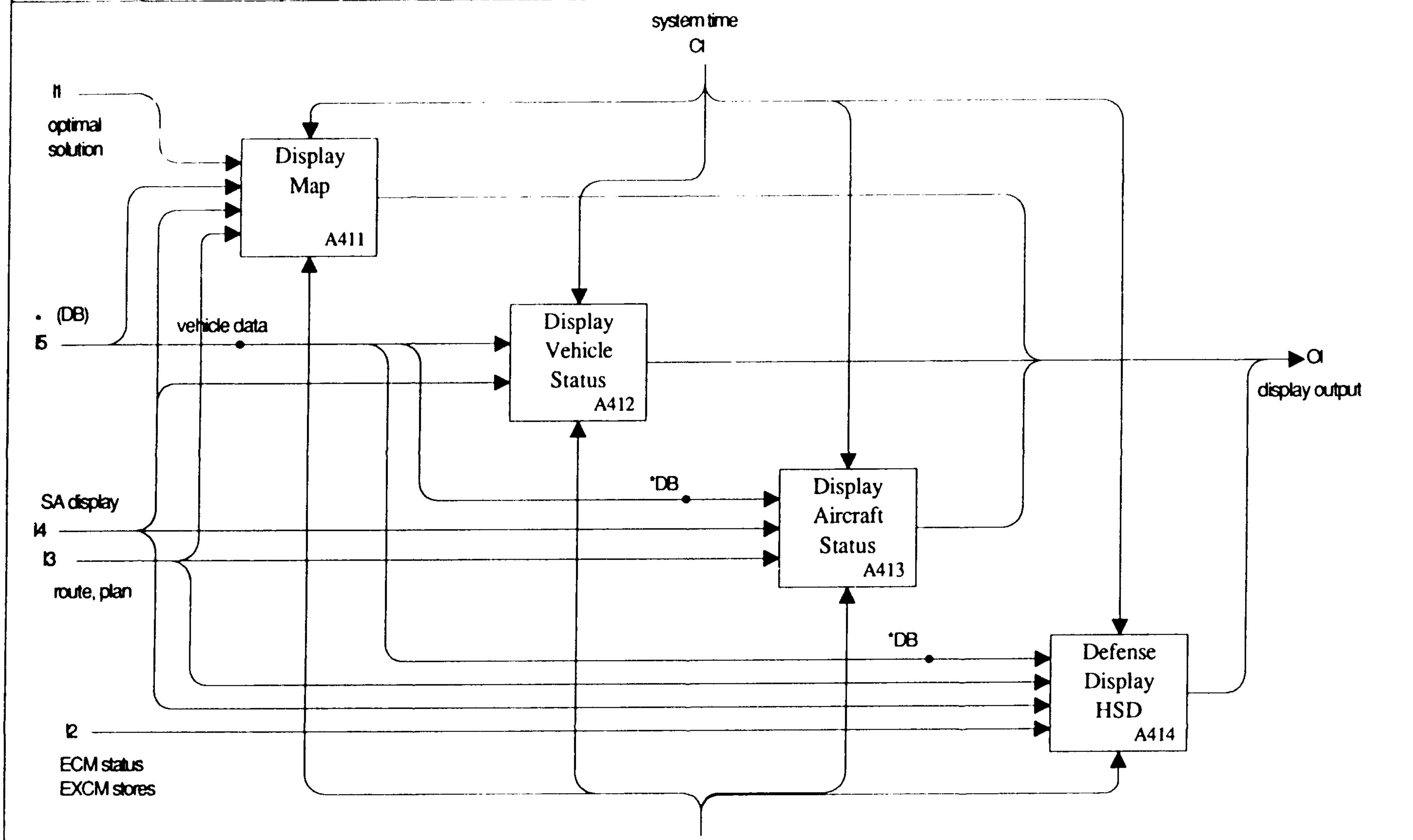


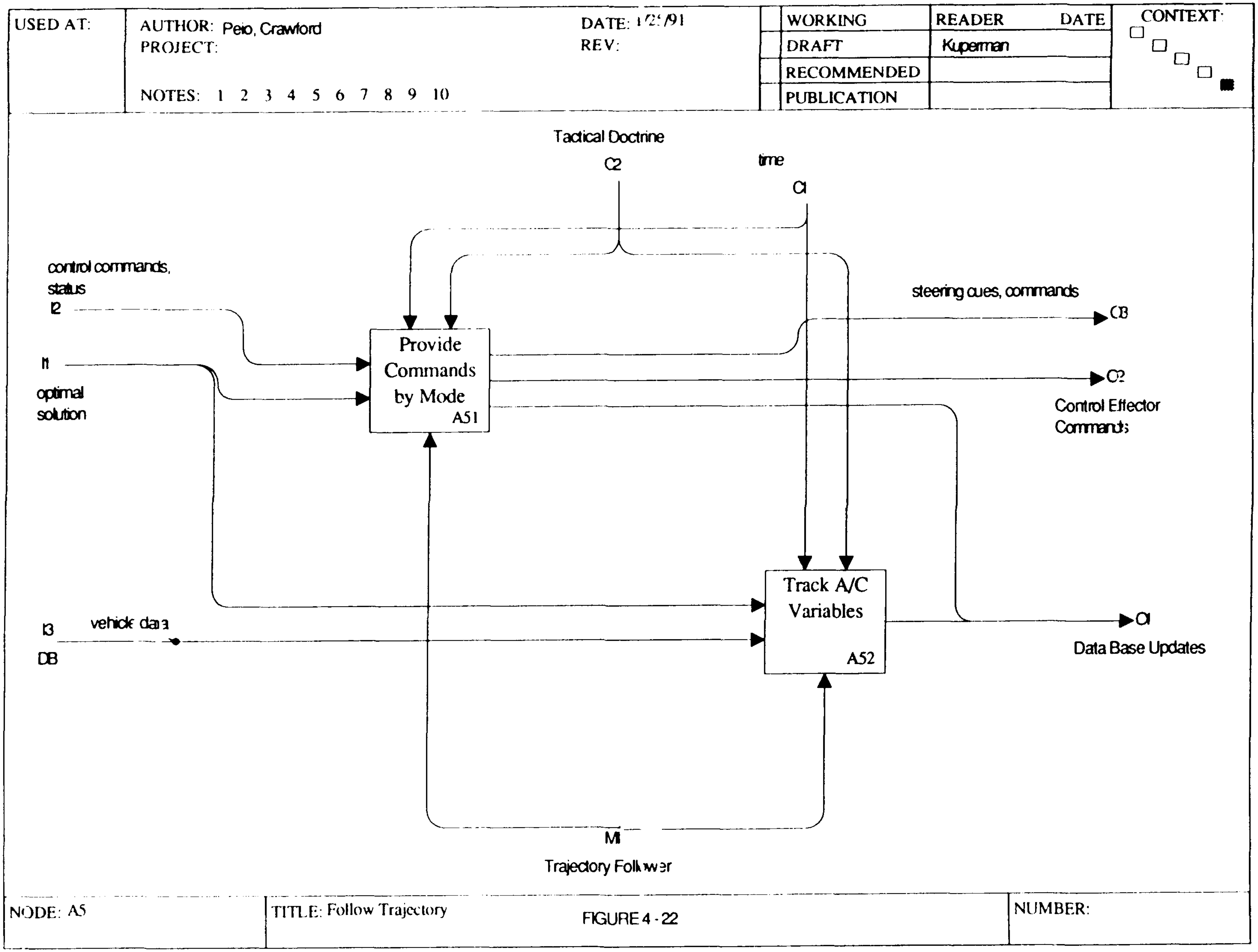
* current trajectory, mission data, vehicle data, targets, threats

NODE: A41	TITLE: Display Information	FIGURE 4 - 21	NUMBER:

A5 FOLLOW TRAJECTORY

The functional requirement for the Trajectory Follower (M1) is to provide flight director display commands, manual command, or coupled autopilot commands, depending on the mode of the FM, to fly the path defined by the Trajectory Manager (A51). Control commands and status (I1) are provided to the Trajectory Follower from the Trajectory Manager. Vehicle data from the FM data base are input (I2) to the flight control activity. The Trajectory Follower also tracks the aircraft variables (A52) and notes deviations from the planned trajectory. These variables are the heading, altitude, and speed of the aircraft. Output of the Trajectory Follower's actiivities that are represented on the A5 IDEF0 diagram are control effector commands (O2) and updates to the data base (O1). Control effector commands include: elevator commands, ailerons, rudder, and thrust.

Node A5, Follow Trajectory, was not decomposed to the next level of detail for this effort. However, a complete concept definition of Trajectory Follower functional requirements will include additional examination and definition of concepts of flight management mode of control and tracking of aircraft variables.



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DATE: 1/25/91
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READER
DATE
Kuperman
CONTEXT:
Tactical Doctrine
C2
time
C1
control commands, status
I2
I1
optimal solution
I3
vehicle data
DB
Provide Commands by Mode
A51
Track A/C Variables
A52
steering cues, commands
O3
O2
Control Effector Commands
O1
Data Base Updates
M1
Trajectory Follower
NODE: A5
TITLE: Follow Trajectory
NUMBER:

FIGURE 4 - 22

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Section 5

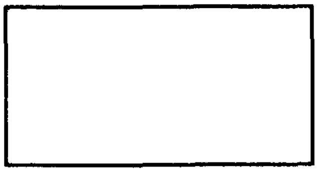
OPERATIONAL SEQUENCE DIAGRAMS

OSDs are used to represent the flow of information-decision sequences through a system. They can be used to: 1. establish sequence-of-operations requirements between subsystem interfaces, 2. depict the logical result of several decision-action sequences, and 3. evaluate panel layout and work-space designs (Kurke, 1961). OSDs graphically depict the flow of events and information in any type of system.

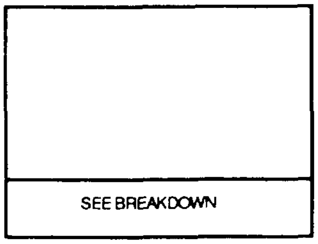
OSDs are used by the human factors community to determine possible system problems during the conceptual design phase. The diagrams represent the flow of events through a system, including the actions/processes, decision points, and information requirements. Examining the OSDs informs the system designer of processes or operator decisions to be performed with limited information available. Therefore, an OSD can be a useful tool in determining the requirements of the man-machine system.

OSDs have been developed to combine the FM system description with the four scenarios previously defined: pop-up threat, deconfliction (avoidance and delivery), and acquiring relocatable targets. Placing the mission scenario in context of the conceptual technology provides the environment for an Information Requirements Analysis, i.e., determine the needs of the PVI. The synthesis of the FM system description with each scenario was done by applying the scenario descriptions to the IDEF0 charts. The OSDs include actions, sensed information, received information, stored information, and operator decisions. When the detailed FM mechanization has been developed (controls and displays) the OSD process can be extended to the control activation level. This will assure functional completeness of the mechanization.

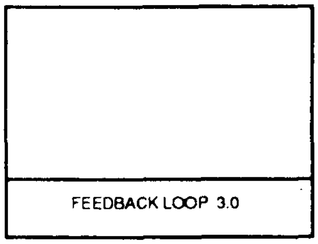
The symbology used for the OSDs is shown in Figure 5-1. Figures 5-2 - 5-3 present the OSDs for the scenarios. A description of each diagram was also prepared, including the specific type of data required for each process.



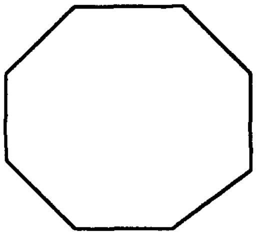
Process or action to be performed by the FM system.
Text in the box indicates the action that needs to be carried out.



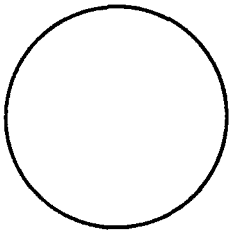
Breakdown Box indicates that a more detailed OSD has been developed and should be referred to.



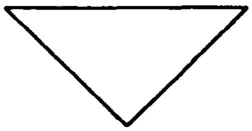
Feedback Loop is used to loop back to a previous box.
The number at the bottom of the box is the number of the box to be returned to so that the activity can be repeated.



Operator Decision.



Displayed Information to the crew.



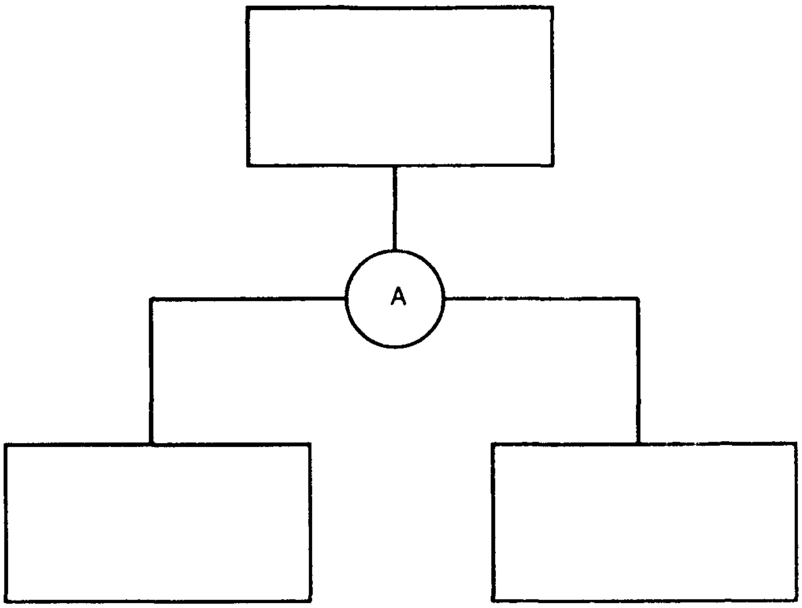
Information received by the FM system from a sensor.

——— MISSION DATA

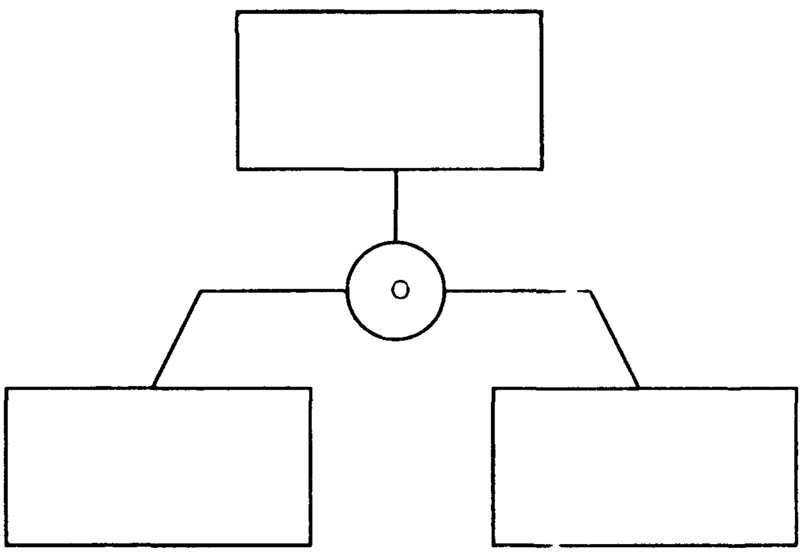
——— EVENTS

Current data and previously stored data used by the Force Management system are extended from the Process Box.

Figure 5-1 OSD Symbols



"AND" gate is drawn with vertical connection lines and is used to show events which are parrallel to each other.



"OR" gate is drawn with slanted connection lines and is used to show a condition where one path or another will be followed.

Figure 5-1 OSD Symbols (Continued)

POP-UP THREAT

1.0 Detect Threat -- A threat emission is sensed by the radar warning receiver (RWR) and received by the Threat Manager.

2.0 Correlate Threat Data -- The Threat Manager will have the capability to correlate threat data from multiple sensor sources (RWR, Elint).

3.0 Update Threat Data Base -- The Threat Manager will update the threat data base with any new information.

Display Threat Definition to Crew -- The new threat data will be added to the data base and the threat information will be displayed to the crew. This information will include the threat type, location, and kill radius.

4.0 Monitor Situation -- The Mission Strategist will continuously monitor updated information in all data bases as well as the current flight conditions.

5.0 Interpret Updated Mission Data -- The Mission Strategist will incorporate information from the crew, the mission, the current trajectory, the events, and tactics. The impact of this information on mission success will be interpreted.

6.0 Classify Threat -- The Threat Manager will assess the vulnerability of the aircraft based on the threat characteristics, the aircraft location, and countermeasure status. The threat will be classified as immediate, imminent, or non-threat.

7.0 Determine Method to Combat Threat -- The classification of the threat will determine the method used to combat the threat. The Threat Manager will select countermeasures and/or threat avoidance.

8.0 Perform Countermeasures -- If the aircraft is within the lethal zone of the threat, then the Threat Manager may activate expendable countermeasures (EXCM) or electronic countermeasures (ECM).

9.0 Issue Threat Avoidance Request -- If the bomber will enter the lethal envelope of the threat without changing its course then the Threat Manager will issue a threat avoidance request to the Mission Strategist. The data included in the threat avoidance request include: threat type, transmission characteristics, vertical and horizontal profiles, and threat state.

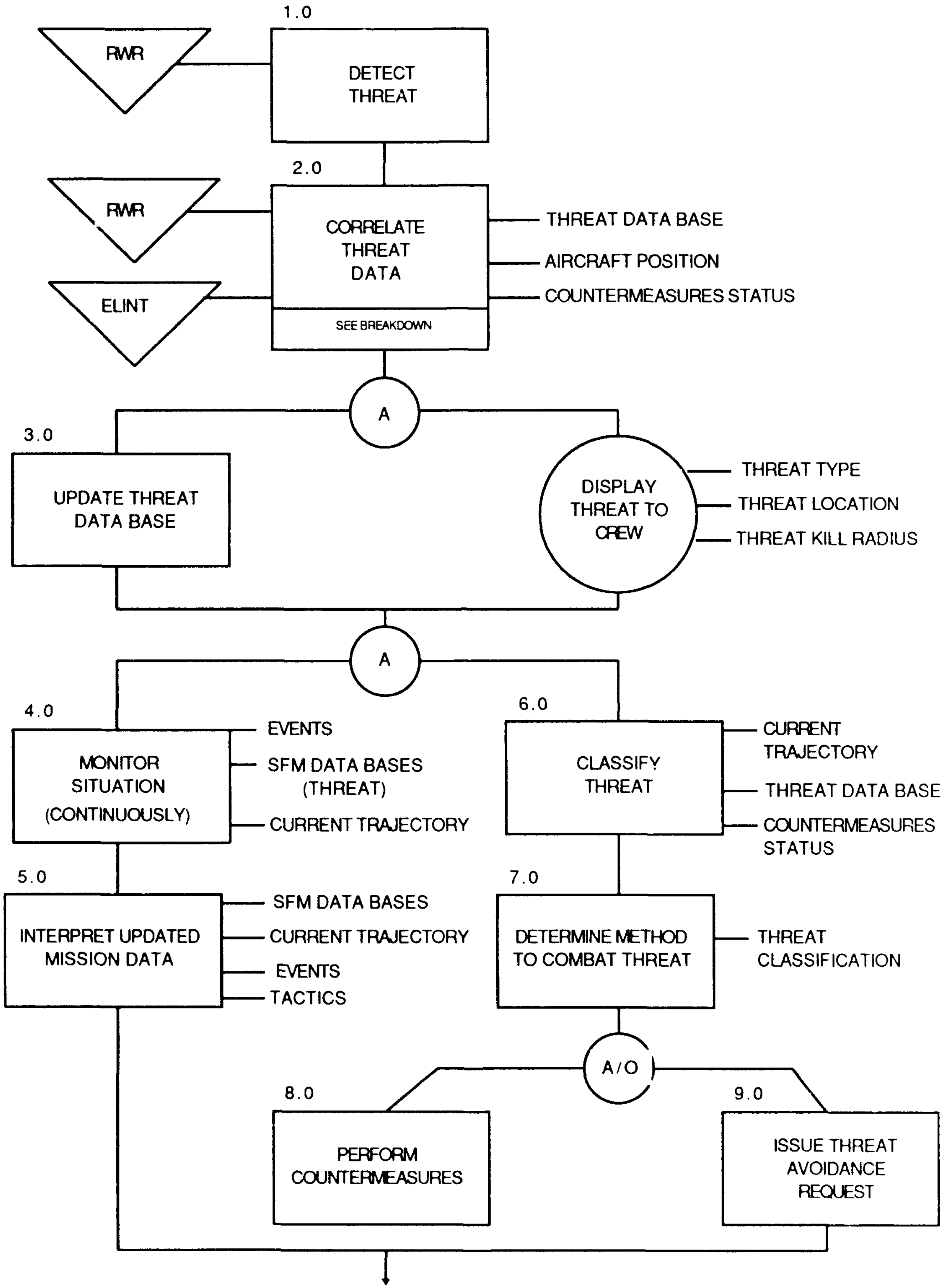


Figure 5-2 OSD: Pop-up Threat

10.0 Assess Situation -- After receiving the threat avoidance request, the Mission Strategist will combine information interpreted from the threat data base with knowledge rules to identify sources of the threat problem.

11.0 Generate Mission Objective Function -- The mission objective function supports fuel and range optimization, threat minimization, target prioritization, target and flight plan time constraints, aircraft malfunction compensation and adverse weather avoidance. The Mission Strategist will combine mission data, current global trajectory data, threat data, target data, and sources of the current threat problem with knowledge rules to generate a mission objective function. The mission data base will contain map data, terrain data and fleet target data (offensive order of battle). The current global trajectory data base includes waypoints, targets, and known threats. Knowledge rules will be derived from strategy, fuel and timing, and escape maneuver rule bases.

12.0 Formulate Strategies -- The Mission Strategist will coordinate the responses of the FM functions to generate a local candidate solution for dealing with the threat situation.

13.0 Issue Route Change Request -- The Mission Strategist will issue a route change request to the Trajectory Manager.

14.0 Establish Coarse Routes -- The Trajectory Manager will derive a coarse route based on heuristic and rule based approaches that minimize threats and maintain mission objectives.

15.0 Compute Optimal Trajectory -- The Trajectory Manager will fine tune the coarse route by addressing aircraft performance characteristics and the external environment for the optimal route generation.

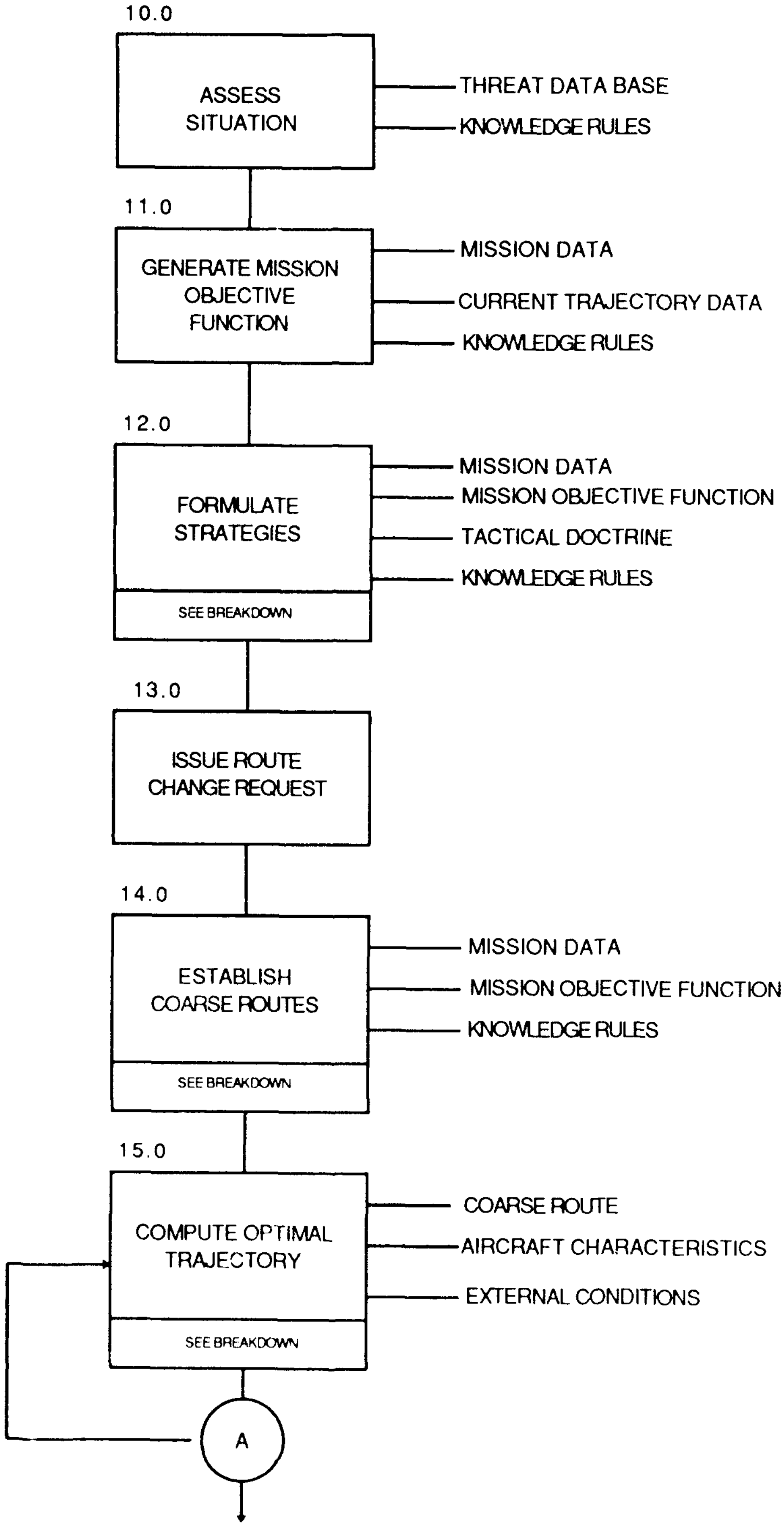


Figure 5-2 OSD: Pop-up Threat (Continued)

Display Optimized Route to Crew -- After computing the optimal trajectory, the Trajectory Manager will display the route to the crew, via the PVI. The "and" loop shows that the optimal trajectory is continuously updated while the crew makes a decision.

Crew Decision Regarding Route -- The crew will decide to accept or reject the proposed route. The response will be interpreted by the Mission Strategist.

16.0 Interpret Mission Data -- The Mission Strategist, which is continuously monitoring incoming data, will receive the crew's decision to accept or reject the recommended route change.

17.0 Assess Situation -- The Mission Strategist will then determine the impact of the crew decision and the processes which must follow.

18.0 Update Data Bases -- The Mission Strategist will update the appropriate data bases with the appropriate route information.

19.0 Generate Another Route -- If the crew rejects the optimized route displayed then another route will be generated starting the process with box 11.0.

20.0 Prioritize and Execute Processes -- If the route is accepted by the crew, then the Mission Strategist, acting as the system executive, will prioritize and oversee the functions to be carried out by the FM functions for the route to be updated.

Control Mode -- Some time throughout the mission the crew will select the command control mode (manual, auto-coupled, or flight director). This decision will be interpreted by the Trajectory Manager.

21.0 Generate Control Commands -- The Mission Strategist will evoke the Trajectory Manager to generate real-time control commands for the new route. The Trajectory Manager will generate real-time aircraft position, velocity, and acceleration state commands that will be used by the Trajectory Follower to control the aircraft along the computed course.

22.0 Provide Commands by Control Mode -- The Trajectory Follower will provide control commands depending on the mode of operation (manual, auto-coupled or flight director). The selected mode, system time, vehicle data, and control commands are data required by the Trajectory Follower. Control effecter commands (ailerons, rudder, thrust) and steering cues will be displayed to the crew.

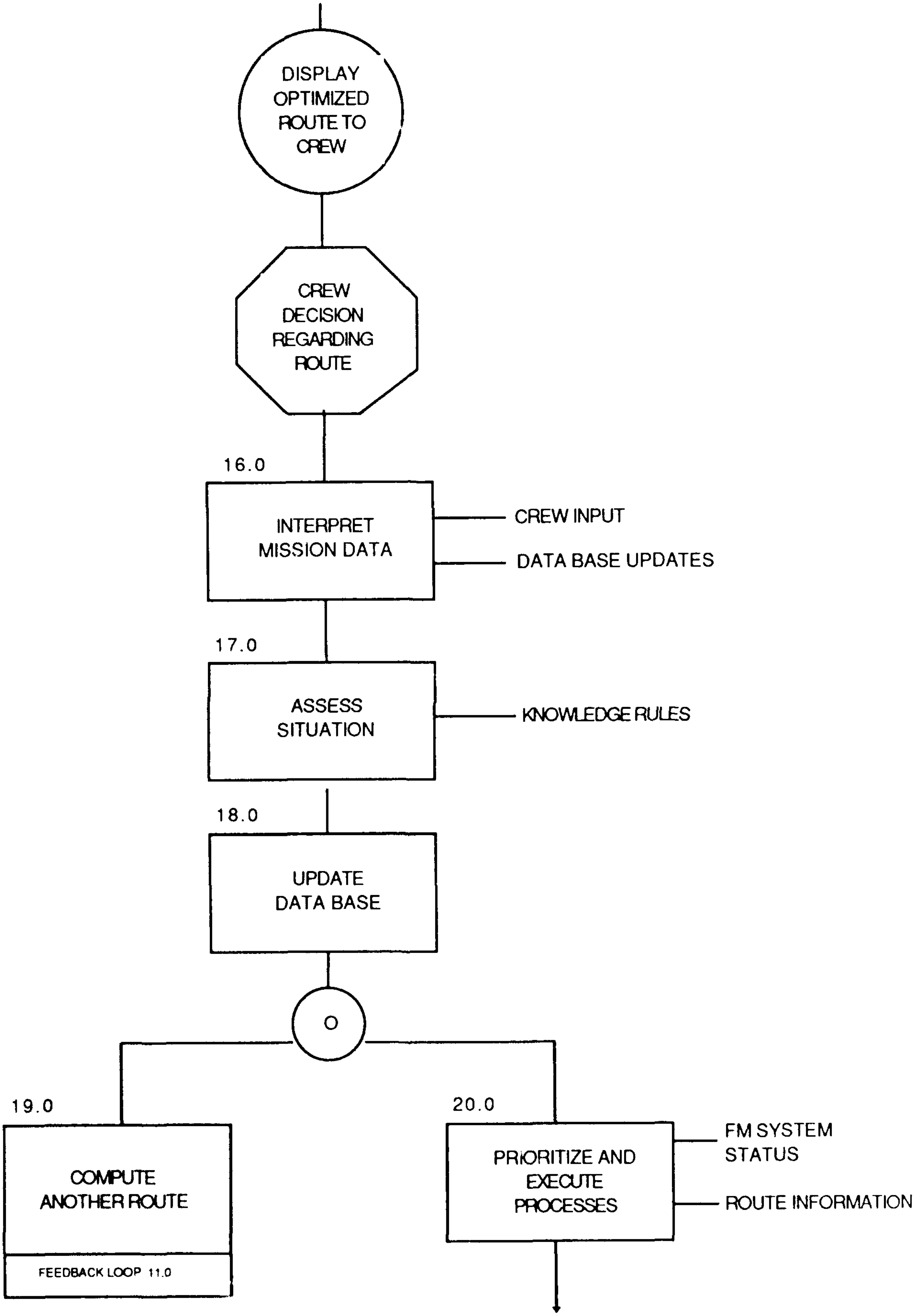


Figure 5-2 OSD: Pop-up Threat (Continued)

23.0 Track Aircraft Variables -- The Trajectory Follower will monitor vehicle data and track aircraft variables to meet objectives of the mission segments.

Display Control Commands -- The PVI will receive the appropriate control commands from the Trajectory Follower. The flight control commands displayed to the crew will be dependent on the control mode selected.

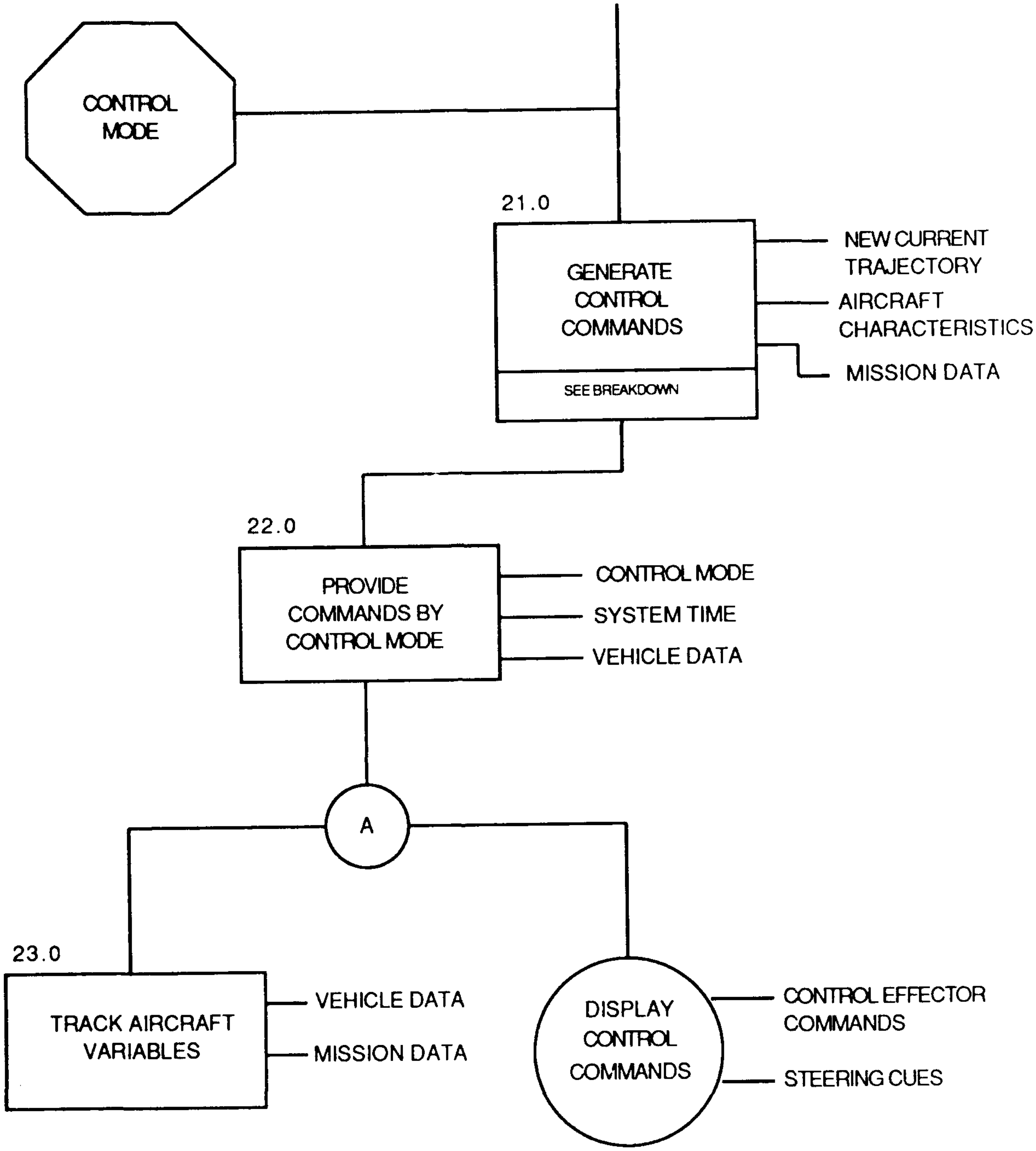


Figure 5-2 OSD: Pop-up Threat (Continued)

Correlate Threat Data Breakdown

2.1 Categorize Threat -- Threat transmission characteristics sensed by RWR and electronic intelligence (Elint) will be received and processed by the Threat Manager. The threat type, range, and transmission frequencies will be determined, with additional data from the threat database. Threat data from the FM Elint data base will include: Frequency of the source, power level, mode (search, track, or launch), and bearing.

2.2 Identify Threat -- Emission data collected by Elint will enable the Threat Manager to identify the type of threat that has been encountered by comparing the data with information from the threat data base. The threat data base offers threat characteristic data such as the threat/sensor type, range, transmission frequencies, and whether or not the threat is jammable.

2.3 Locate Threat -- Data provided by the passive RWR will allow the Threat Manager to locate the threat in relation to the location of the bomber. The threat manager will receive the current aircraft position via updates from the Trajectory Manager.

2.4 Determine the Kill Radius of the Threat -- The Threat Manager will determine the kill radius of the threat based on threat database information and the current countermeasure conditions.

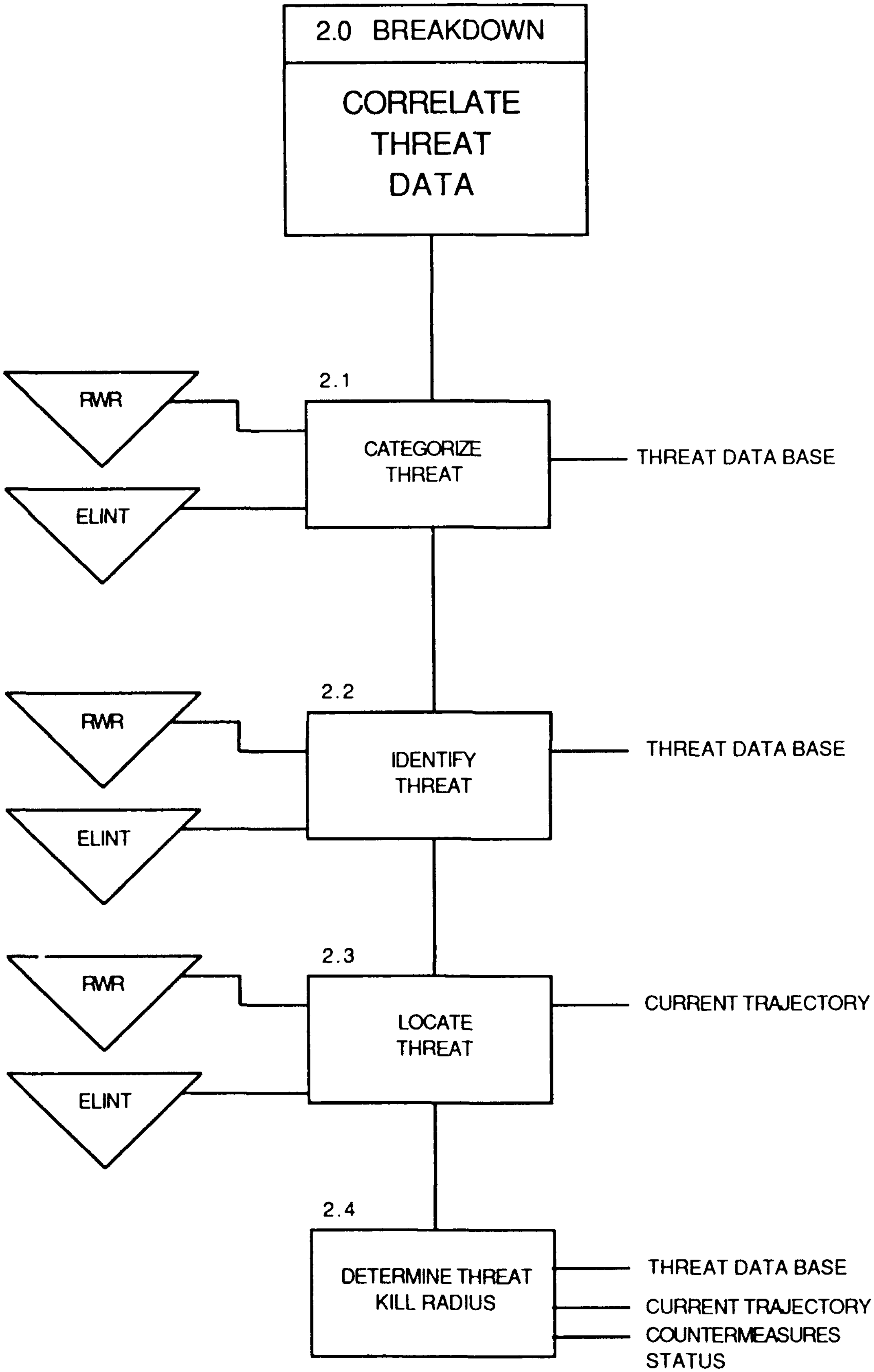


Figure 5-2 OSD: Pop-up Threat (Continued)

Formulate Strategies Breakdown

12.1 Coordinate Responses of FM Functions -- The Mission Strategist, acting as the mission executive, will interpret the current status of the FM functions and determine how they may affect the mission objective.

12.2 Evaluate Tradeoffs Between Mission Parameters -- The Mission Strategist will use knowledge rules, obtained from the strategy rule base, to evaluate the mission objective function with information from the current mission data. The mission parameters will be evaluated in terms of their cost functions to meeting mission objectives.

12.3 Compute Weighting Factors -- The weighting factors assigned to the mission parameters will be prioritized based on the trade-off evaluation.

12.4 Generate Scenarios -- Using the mission objective function, the weighting factors, tactical doctrine, and knowledge rules obtained from the strategy, and route selection rule bases, possible coarse route adjustments will be generated.

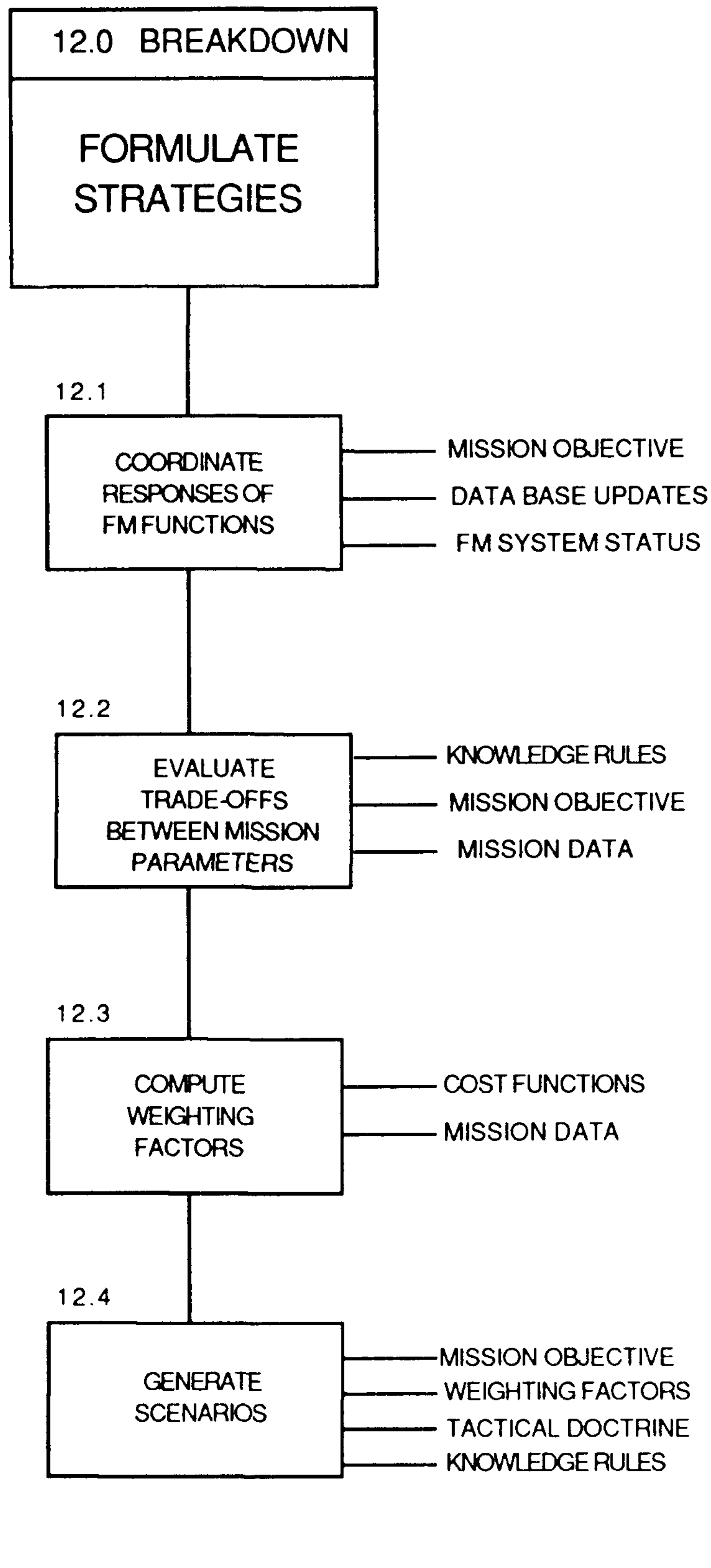


Figure 5-2 OSD: Pop-up Threat (Continued)

Establish Coarse* Routes Breakdown

14.1 Preplanned Route Selection -- Coarse trajectories may be computed in advance and stored in the mission data base. The Trajectory Manager will select an appropriate coarse route.

14.2 Generate Coarse Routes -- Coarse trajectories may be generated by the Trajectory Manager. Information from the global trajectory data bases will be combined with the mission objective function and solutions received from the Mission Strategist. The coarse route generation will output waypoints and targets to be added, deleted, or changed.

14.3 Construct Trajectory Objective Function -- This function combines mission goals and vehicle performance optimization objectives. The Trajectory Manager will call upon the coarse route, mission objective function, mission data, and current global trajectory.

14.4 Normalize Weighting Factors -- The Trajectory Manager will normalize the weighting factors generated by the Mission Strategist.

14.5 Plan New Trajectory -- The Trajectory Manager will determine the mission waypoints and targets for the reroute situation. The route will be based on tactical doctrine, mission objectives, and current global trajectory.

* Approximations of optimal trajectories

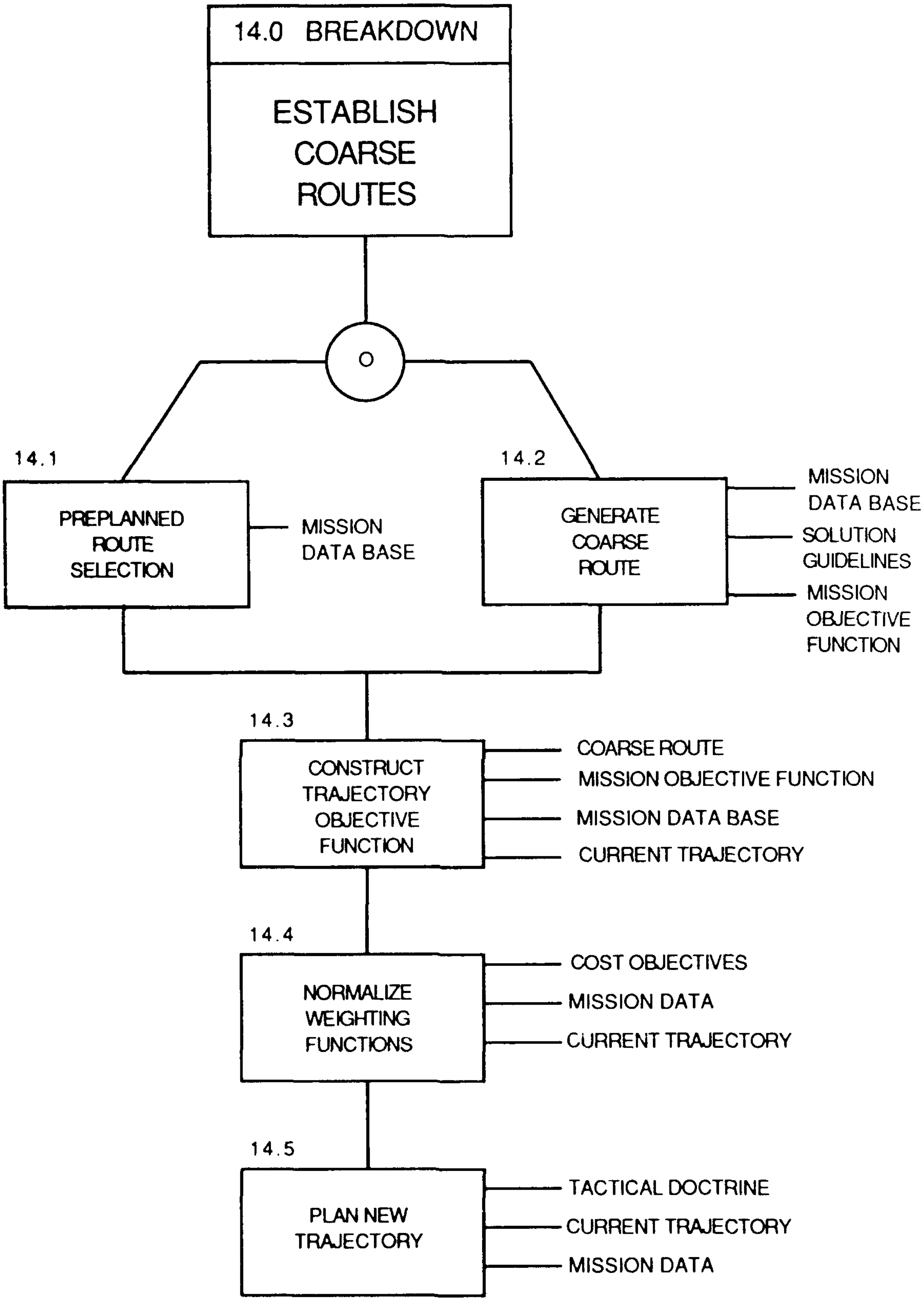


Figure 5-2 OSD: Pop-up Threat (Continued)

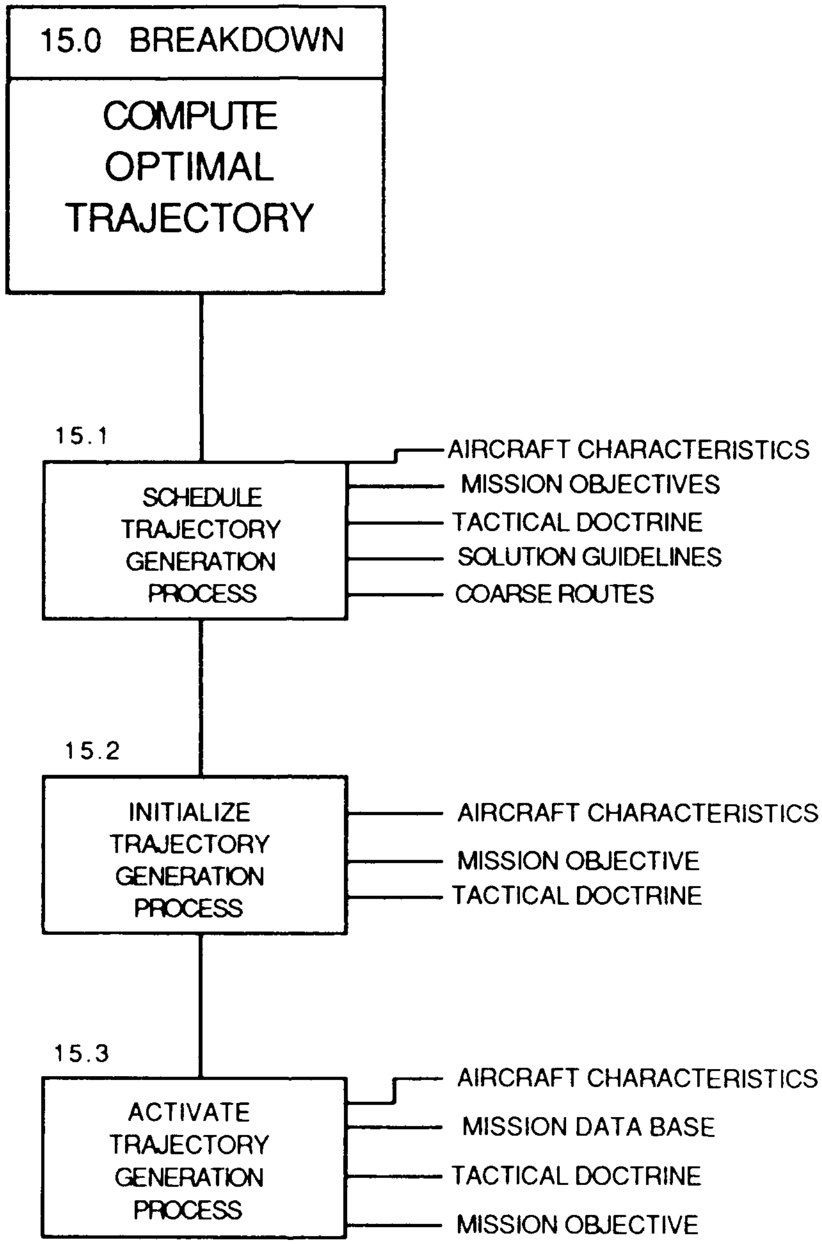
Compute Optimal Trajectory Breakdown

15.1 Schedule appropriate trajectory generation process -- A set of algorithmic processes have been established which generate a flyable, real-time trajectory. The Trajectory Manager will choose one or more of the processes depending on the situation. The data used will include the coarse route, mission objectives, tactical doctrine, aircraft characteristics and solution guidelines.

15.2 Initialize Trajectory Generation Process -- The Trajectory Manager will provide the selected process with the data needed to carry out that process.

15.3 Activate Trajectory Generation Process -- After the process has been initialized, it will be activated. The optimal solution will be generated and displayed to the crew via the PVI. The crew will make a decision to accept or reject the suggested solution.

The optimal trajectory generation process will repeat and display updated routes to the crew until it has been accepted or rejected. Updates are required as the aircraft continues enroute changing the current conditions, which may effect the optimized route, while the crew makes a decision.



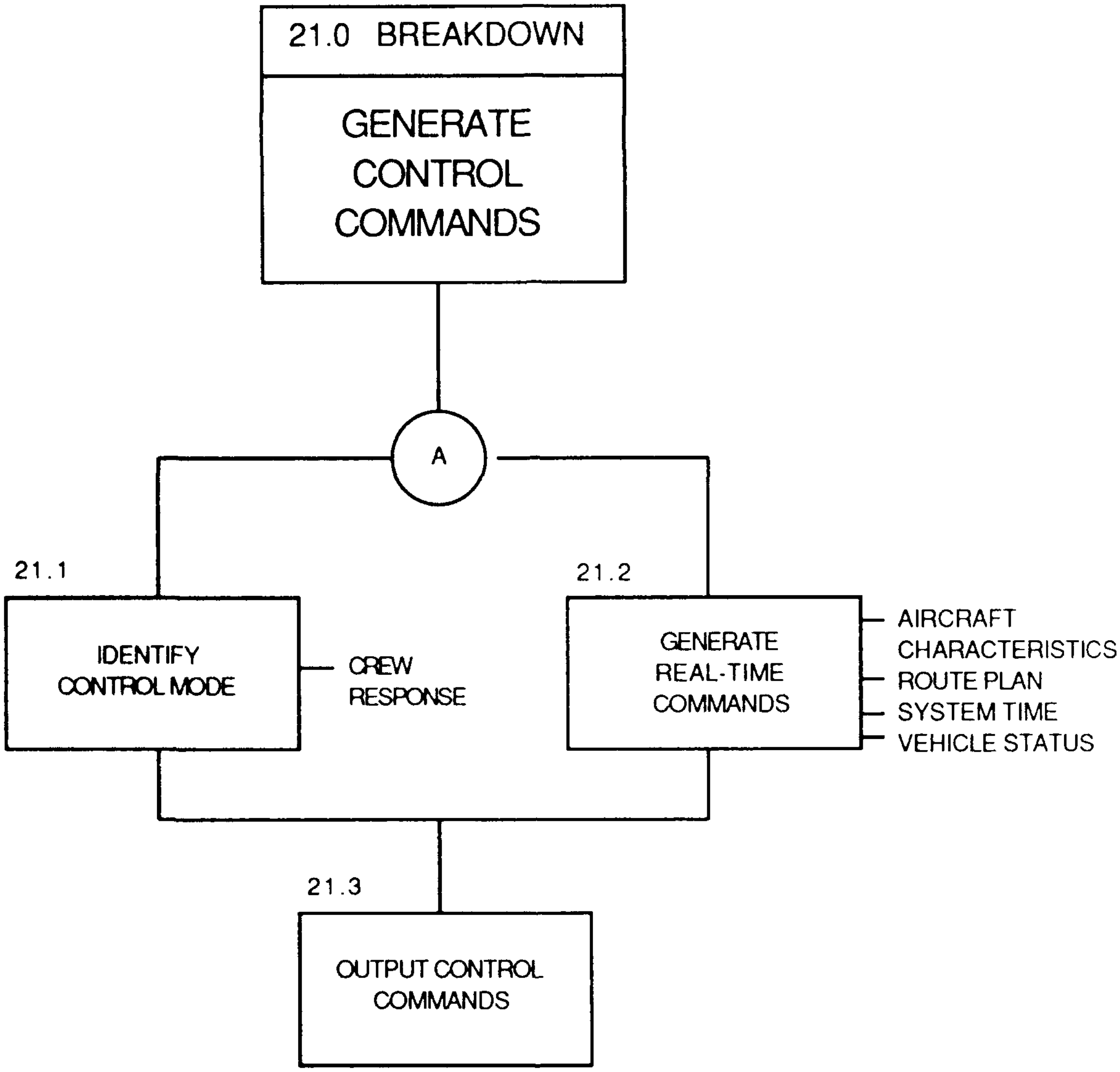
OSD: Pop-up Threat (Continued)

Generate Control Commands Breakdown

21.1 Identify Control Mode -- The crew will select the control mode to be either manual, coupled autopilot, or flight director. The Trajectory Manager will receive this information via the PVI.

21.2 Generate Real-time Commands -- The Trajectory Manager will need the following information: route plan and trajectory, vehicle status, and system time.

21.3 Output Control Commands and Status -- The following information will be forwarded to the Trajectory Follower and to the crew: heading and rate commands, altitude and rate commands, Mach/true airspeed, pitch angle and rate, bank angle and rate, throttle setting, and wing sweep.



OSD: Pop-up Threat (Continued)

DECONFLICTION: TIMELY WEAPON DELIVERY

1.0 Monitor Situation -- The Mission Strategist will continually monitor the ongoing activity of the FM functions and the updated data bases.

2.0 Discover Timing Deviation -- The Mission Strategist will determine the type of deviation and inform the crew of the problem.

Inform Crew of Deviation -- The PVI will display information regarding mission timing, received from the Mission Strategist.

3.0 Generate Mission Objective Function -- The time deviation, mission data, and the current trajectory are combined with knowledge rules derived from the strategy and fuel and timing rule bases by the Mission Strategist to generate a mission objective to restore weapon delivery timing.

4.0 Formulate Solutions -- The Mission Strategist will coordinate the responses of the FM functions to generate a local candidate solution that will permit timely weapon delivery.

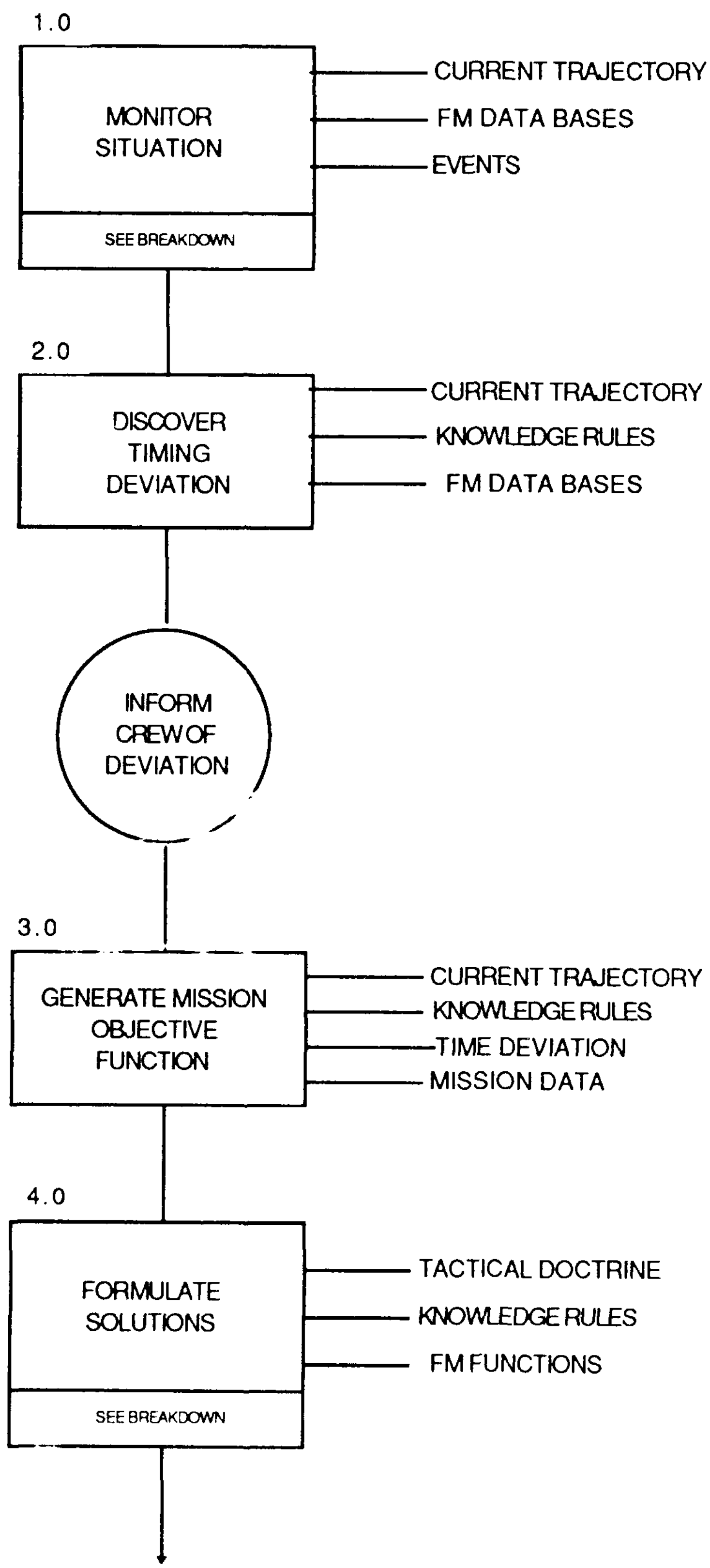


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery

5.0 Generate Airplane Configuration Change Request -- The Mission Strategist will issue an airplane configuration change request that will evoke the Trajectory Manager. The change request will send mission data, the mission objective function, and the solution guidelines to the Trajectory Manager.

6.0 Compute Optimal Solution -- The Trajectory Manager will use the information provided by the Mission Strategist to develop the best solution for permitting timely weapon delivery. The Trajectory Manager will address the aircraft performance characteristics and the external environment.

The computation of the optimal solution process will repeat and update the displayed solution continuously until the crew makes a decision. Updates are necessary because changes in aircraft position or the external environment will occur while the crew is making a decision, and they must be aware of these changes.

Display Solution to Crew -- The optimal solution for solving the deviation problem will be presented to the crew from the Mission Strategist, via the PVI.

Crew Decision Regarding Solution -- The crew will decide to accept or reject the proposed solution. The PVI will deliver the response to the Mission Strategist for interpretation.

7.0 Interpret Mission Data -- The Mission Strategist will receive and interpret the crew decision along with other mission data and status information.

8.0 Assess Situation -- The Mission Strategist will then determine the data bases to be updated, based on the crew decision.

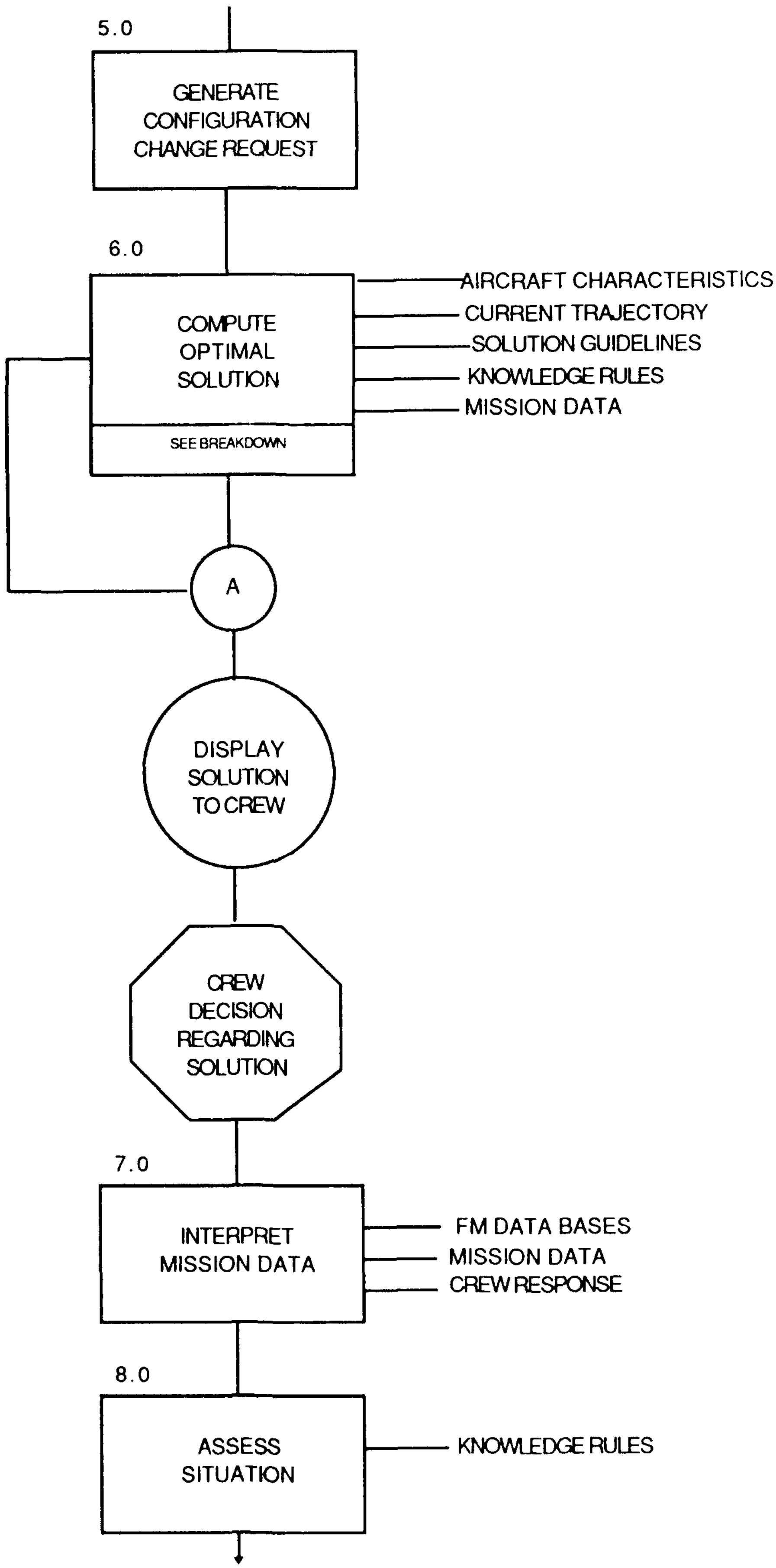


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery (Continued)

9.0 Update Data Bases -- Data bases will be update based on the Mission Strategist's assessment. These data bases include the aircraft characteristic and the mission data base.

10.0 Recompute Solution -- If the crew rejects the suggestion then another solution will be generated. This process will start with Process box 3.0 where the Mission Strategist generates the mission objective function.

11.0 Prioritize and Execute Processes -- If the crew accepts the suggestion then the Mission Strategist will prioritize and oversee the functions to be carried out by the FM functions to execute the solution.

Select Control Mode -- The crew, at sometime during the mission, will detect the desired control mode (manual, coupled autopilot, or flight director). This response will be sent to the Trajectory Manager, via the PVI.

12.0 Generate Control Commands -- The Mission Strategist will evoke the Trajectory Manager to generate real-time aircraft position, velocity, and acceleration state commands that will be used by the Trajectory Follower to control the aircraft along the computed course.

13.0 Provide Command by Control Mode -- The Trajectory Follower will provide control commands based on the mode of operation (manual, coupled autopilot, or flight director). The selected mode, system time, vehicle data, and control commands are the data required by the Trajectory Follower.
Control effecter commands (ailerons, rudder, and thrust) and steering cues will be displayed to the crew.

14.0 Track Aircraft Variables -- The Trajectory Follower will monitor vehicle data and track aircraft variables to meet objectives of the mission segments.

Display Control Commands -- The PVI will receive the flight control commands needed by the crew, as determined from the selected control mode. The PVI will then present the commands to the crew.

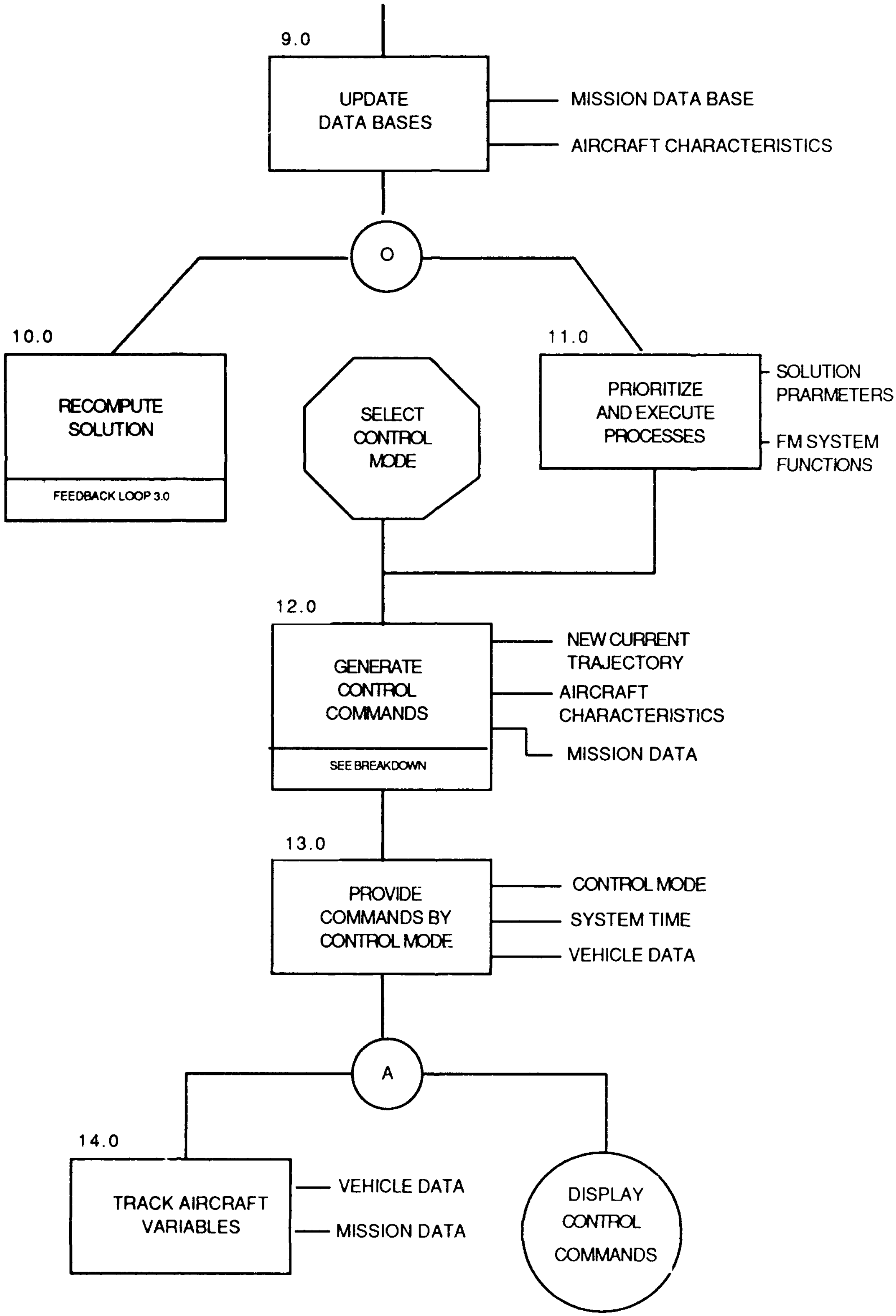


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery (Continued)

Monitor Situation Breakdown

1.1 Interpret Mission Data -- The Mission Strategist will incorporate information from the crew, the mission, the current trajectory, the events, and tactics. The impact of this information on mission success will be interpreted.

1.2 Assess Situation -- The Mission Strategist will apply knowledge rules to the mission data to identify any discrepancies to the planned route.

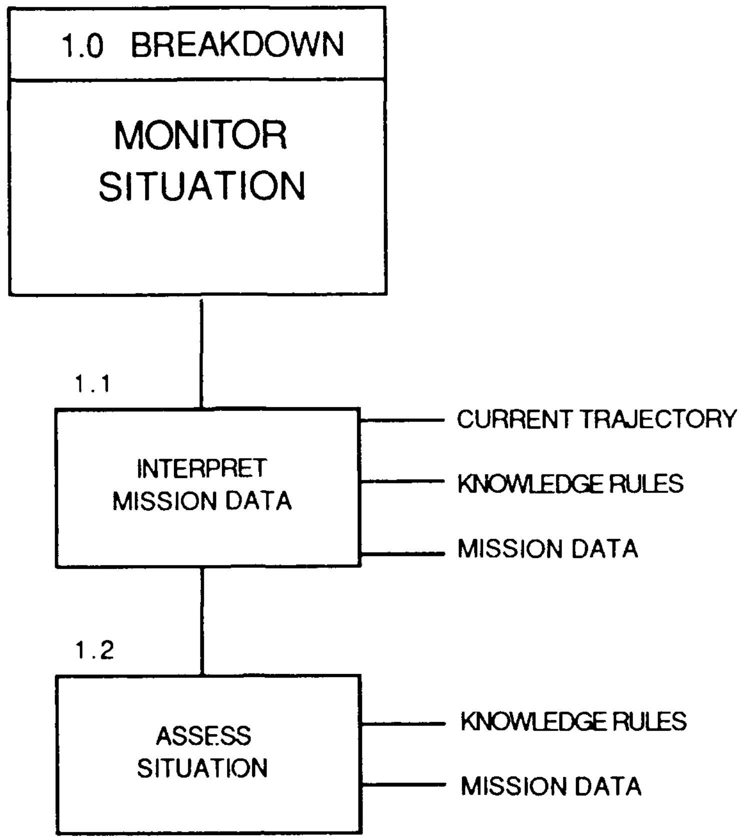


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery (Continued)

Formulate Solutions Breakdown

4.1 Coordinate Responses of FM Functions --The influence of the current status of FM systems and data base updates on the mission objective will be analyzed.

4.2 Evaluate Tradeoffs Between Mission Parameters --Knowledge rules, derived from the fuel and timing and strategy rule bases, will be used to compare the effects of aircraft/flight characteristics and mission parameters (targets, route, timing) on the mission objective. Cost functions for the parameters will be generated.

4.3 Compute Weighting Factors -- Using the cost functions from the trade-off evaluation, the mission parameters will be prioritized and assigned weighting factors.

4 .4 Generate Scenarios -- Using the mission objective function and the weighting factors, possible route adjustments will be generated. The fuel and timing rule base and tactical doctrine will direct the adjustments.

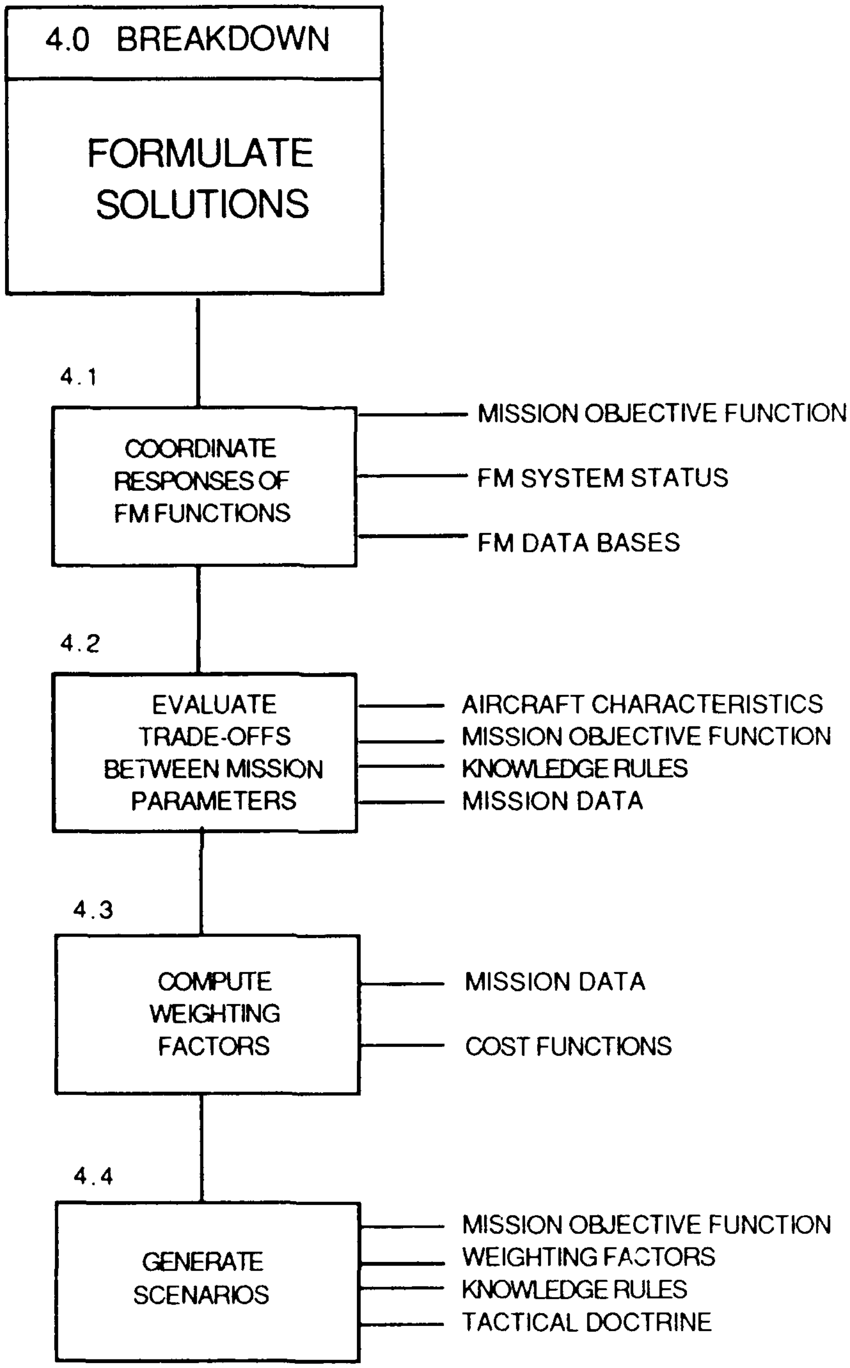


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery (Continued)

Compute Optimal Solution Breakdown

6.1 Schedule Appropriate Trajectory Generation Process -- One or more of the algorithmic approaches will be chosen to generate a flyable, real-time trajectory. The data required for this process include solution guidelines, mission objective function, and tactical doctrine.

6.2 Initialize Trajectory Generation Process -- The selected algorithmic processes will be provided with the needed data for them to be carried out. The aircraft/flight characteristics, current mission data, external environment conditions, mission objective function, and tactical doctrine will all be needed.

6.3 Activate Trajectory Generation Process -- Following initialization of the processes, they will be activated and generate the optimal solution.

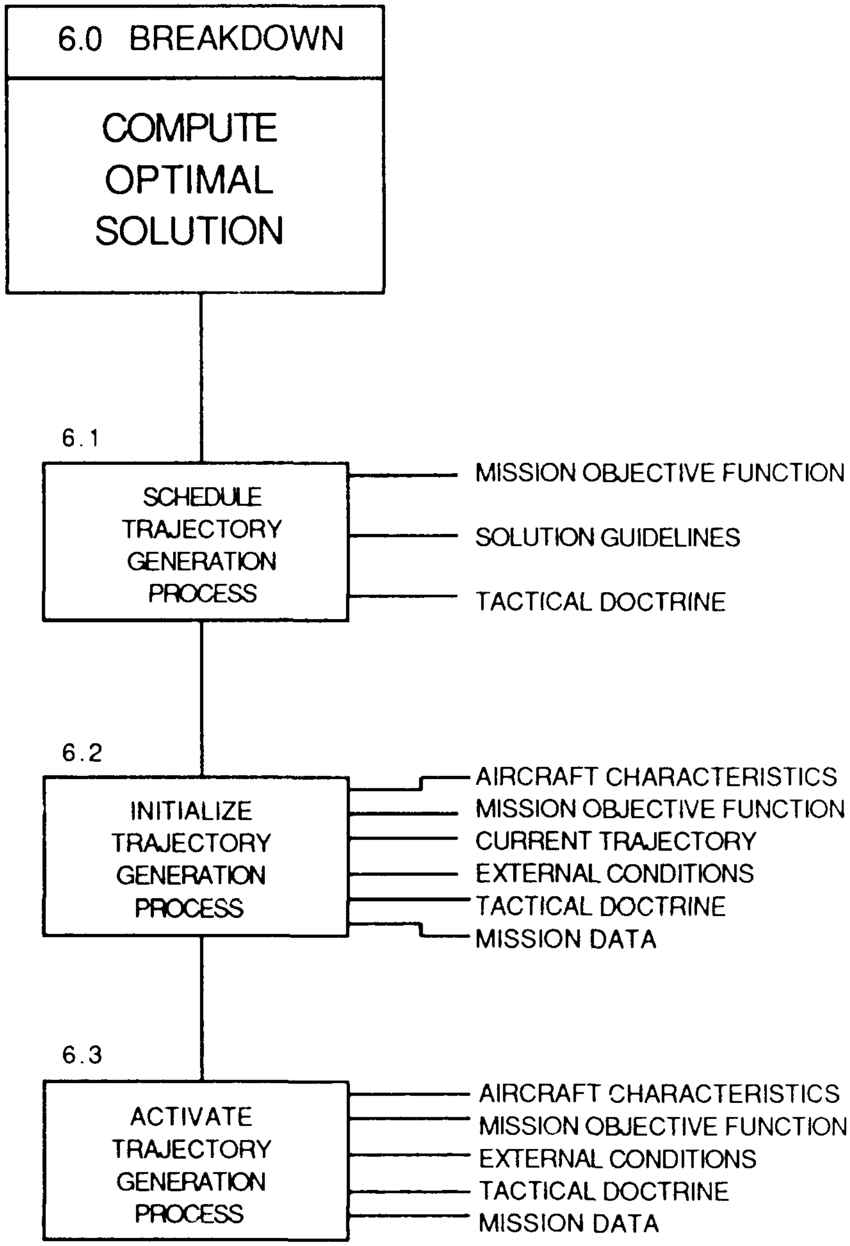


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery (Continued)

Generate Control Commands

12.1 Identify Control Mode -- The crew will select the control mode to be either manual, coupled autopilot, or flight director. The Trajectory Manager will receive this information via the PVI. The crew decision regarding the control mode could occur at any time throughout the scenario.

12.2 Generate Real-time Commands -- To perform this function the Trajectory Manager will need the route plan and trajectory, aircraft characteristics, vehicle status, and system time.

12.3 Output Control Commands and Status -- The following information will be forwarded to the Trajectory Follower and to the crew: heading and rate commands, altitude and rate commands, Mach/true airspeed, pitch angle and rate, back angle and rate, throttle percentage, and wing sweep.
The display presentation of this information to the crew will depend on the selected control mode.

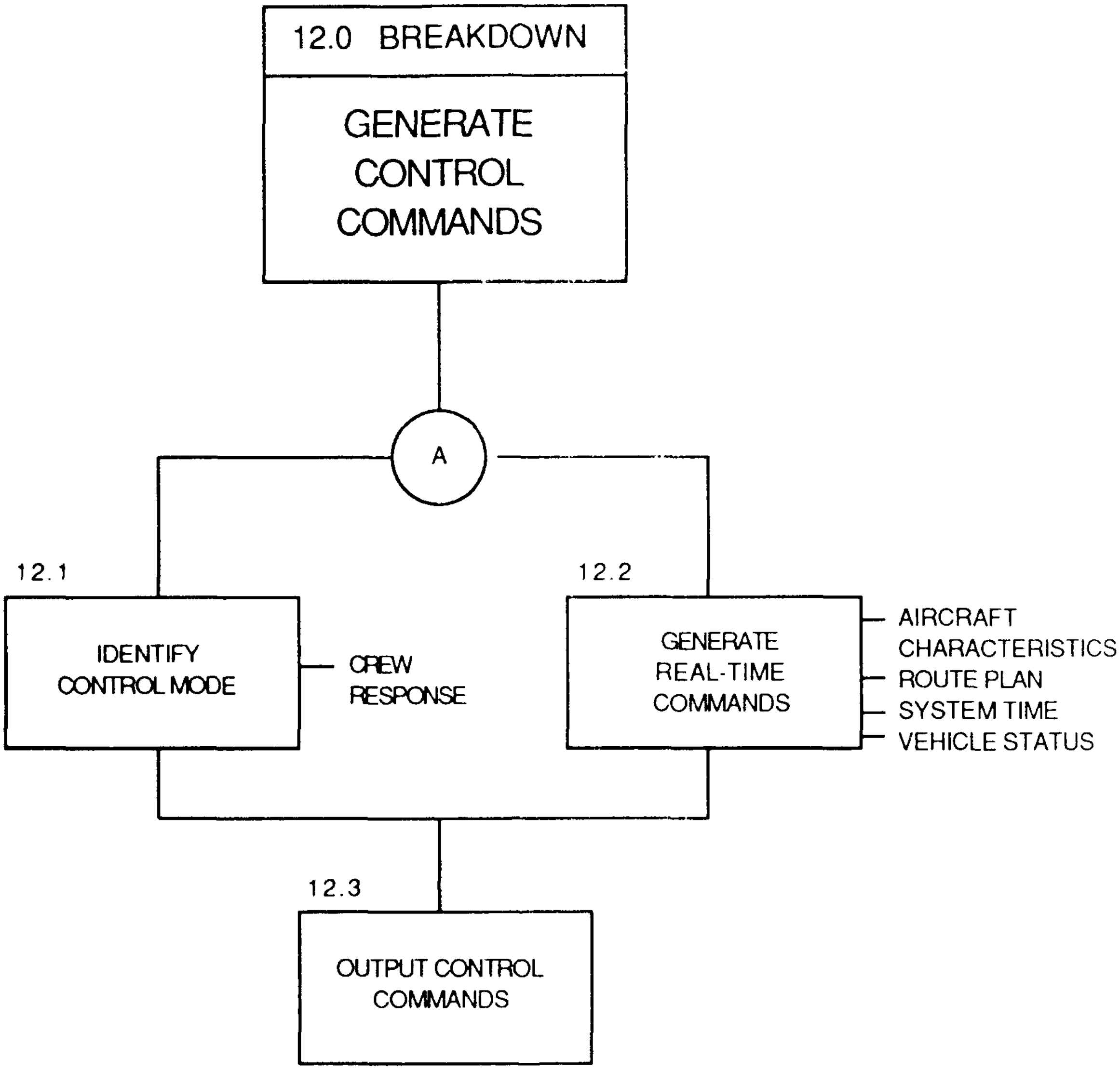


Figure 5-3 OSD: Deconfliction -- Timely Weapon Delivery (Continued)

DECONFLICTION: AVOIDANCE OF NUCLEAR EVENT

1.0 Monitor Situation -- The Mission Strategist will continuously monitor incoming mission data and events concerning deconfliction.

2.0 Determine Nuclear Threat Window -- The Mission Strategist will derive the area of coverage of the nuclear weapons effects with respect to the bomber's trajectory.

Display Threat to Crew -- The nuclear threat information will be presented to the crew.

3.0 Update Mission Data Base -- The Mission Strategist will also be responsible for updating the data bases with the nuclear threat information.

4.0 Generate Mission Objective Function -- The Mission Strategist will then take the mission data, threat window data, and current global trajectory data and apply knowledge rules to generate a mission objective function. The knowledge rules will be derived from the strategy rule base.

5.0 Formulate and Solutions -- The responses of the FM functions will be coordinated by the Mission Strategist to generate a local candidate solution for avoiding the nuclear threat.

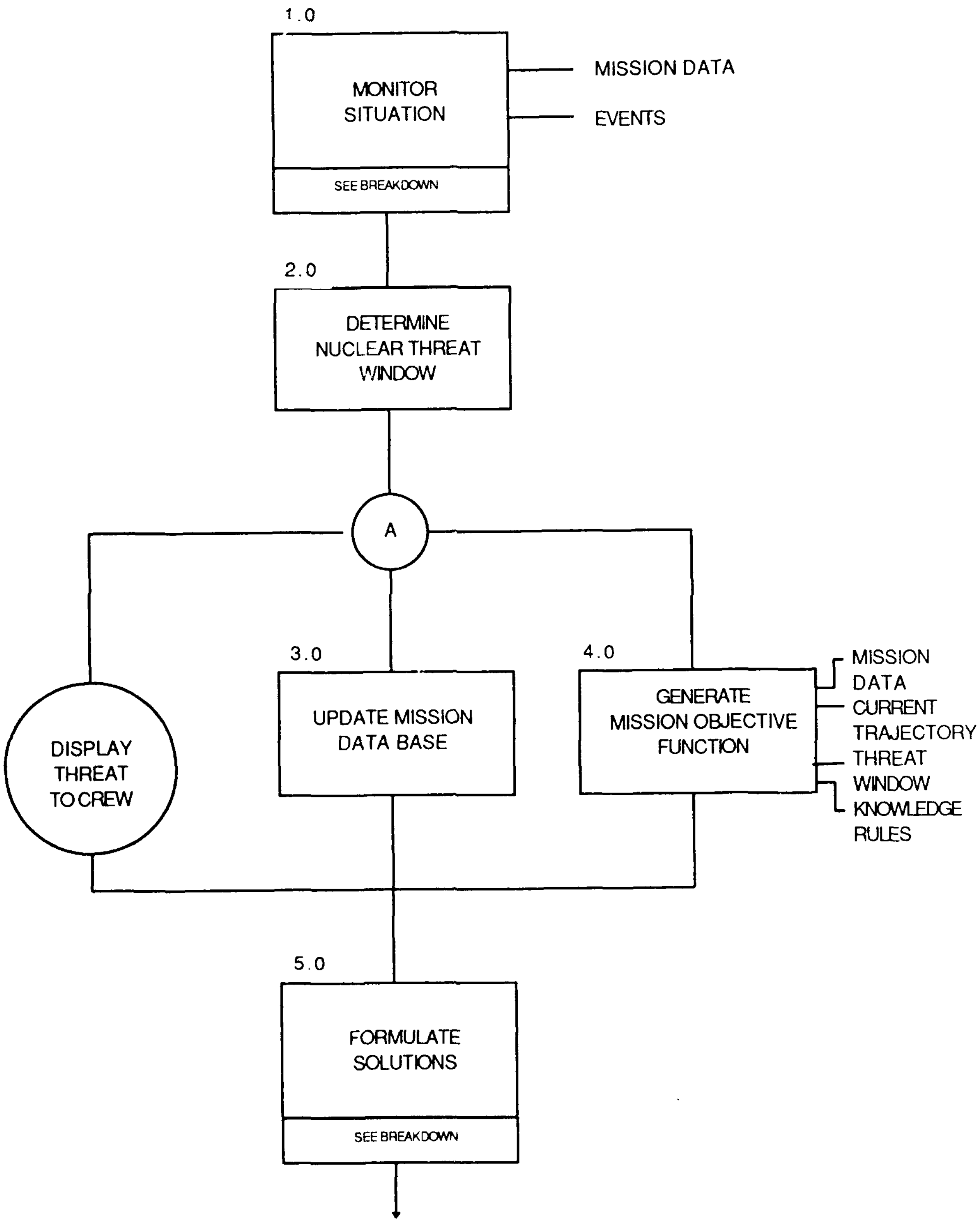


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat

6.0 Issue Route Change Request -- The Mission Strategist will issue a route change request to the Trajectory Manager which will avoid the nuclear threat area.

7.0 Establish Course Routes -- The Trajectory Manager will derive a coarse route based on heuristic and rule based approaches that minimize threats and maintain mission objectives.

8.0 Compute Optimal Trajectory -- The Trajectory Manager will fine tune the coarse route by addressing aircraft performance characteristics and the external environment for the optimal route generation. The optimal trajectory generation process will repeat and display updated routes to the crew until it has been accepted or rejected. Updates are required as the aircraft continues enroute changing the current conditions, which may effect the optimized route, while the crew makes a decision.

Display Optimized Route to Crew -- The optimal solution will be generated and displayed to the crew via the PVI.

Crew Decision Regarding Route -- The crew will make a decision to accept or reject the suggested solution.

9.0 Interpret Mission Data -- The Mission Strategist, which is continuously monitoring incoming data, will receive the crews decision to accept or reject the recommended route change.

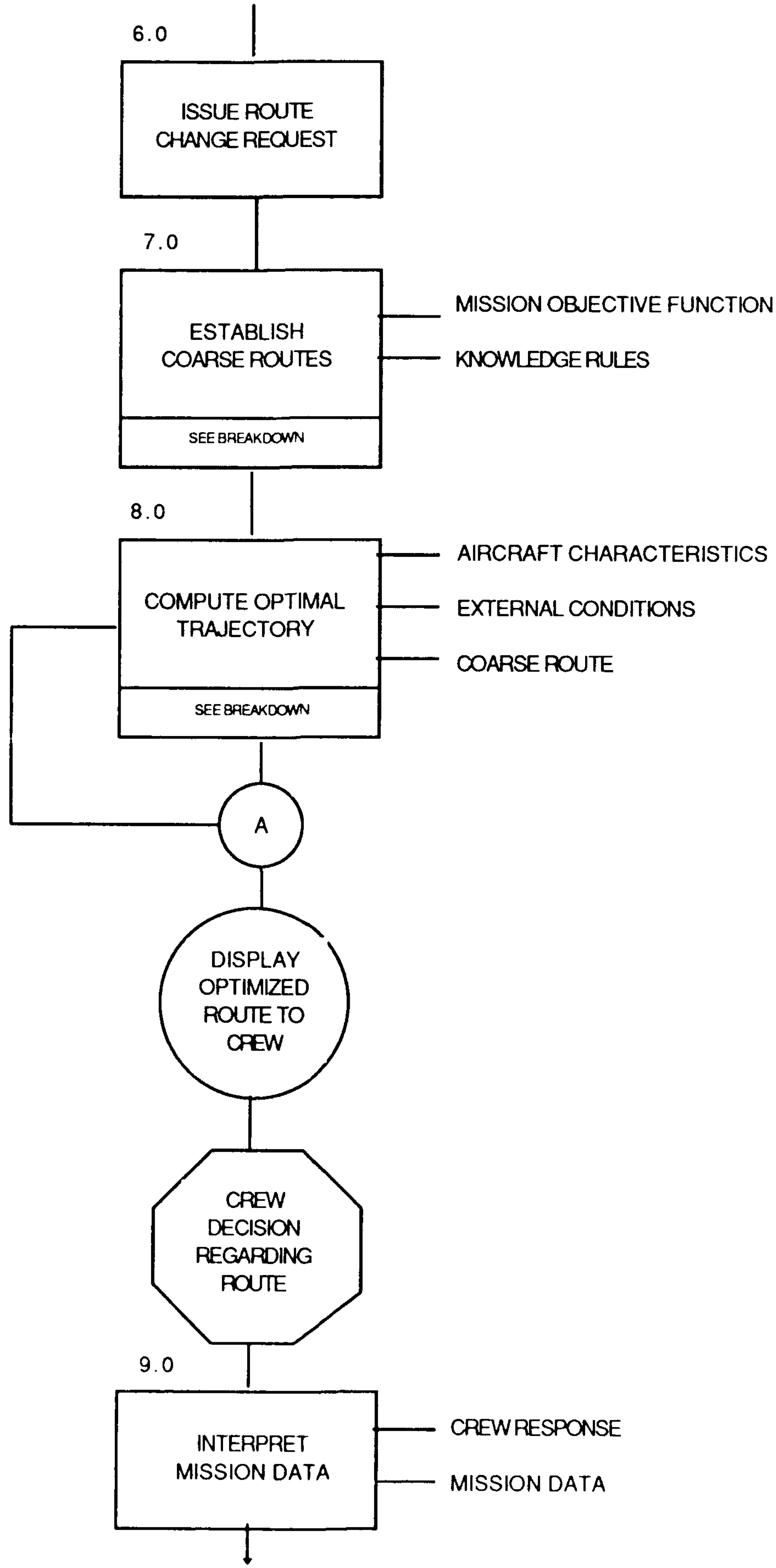


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

10.0 Assess Situation -- The Mission Strategist will then determine the impact of the crew decision and the processes which must follow.

11.0 Update Data Bases -- The Mission Strategist will update the appropriate data bases with the appropriate route information.

12.0 Generate Another Route -- If the crew rejects the optimized route displayed then another route will be generated starting the process with box 4.0.

13.0 Prioritize and Execute Processes -- If the route is accepted by the crew, then the Mission Strategist, acting as the system executive, will prioritize and oversee the functions to be carried out by the FM functions for the route to be updated.

Control Mode -- The mode of operation (manual, coupled autopilot, or flight director) will be selected by the crew at some point in the mission.

14.0 Generate Control Commands -- The Mission Strategist will evoke the Trajectory Manager to generate real-time control commands for the new route. The Trajectory Manager will generate real-time aircraft position, velocity, and acceleration state commands that will be used by the Trajectory Follower to control the aircraft along the computed course.

15.0 Provide Commands by Control Mode -- The Trajectory Follower will provide control commands depending on the mode of operation (manual, coupled autopilot, or flight director). The selected mode, system time, vehicle data, and control commands are the data required by the Trajectory Follower.

Display Control Commands -- Control effecter commands (ailerons, rudder, thrust) and steering cues will be sent to the PVI from the Trajectory Follower. The form of the information displayed to the crew will depend on the control mode selected.

16.0 Track Aircraft Variables -- The Trajectory Follower will monitor vehicle data and track aircraft variables to meet objectives of the mission segments.

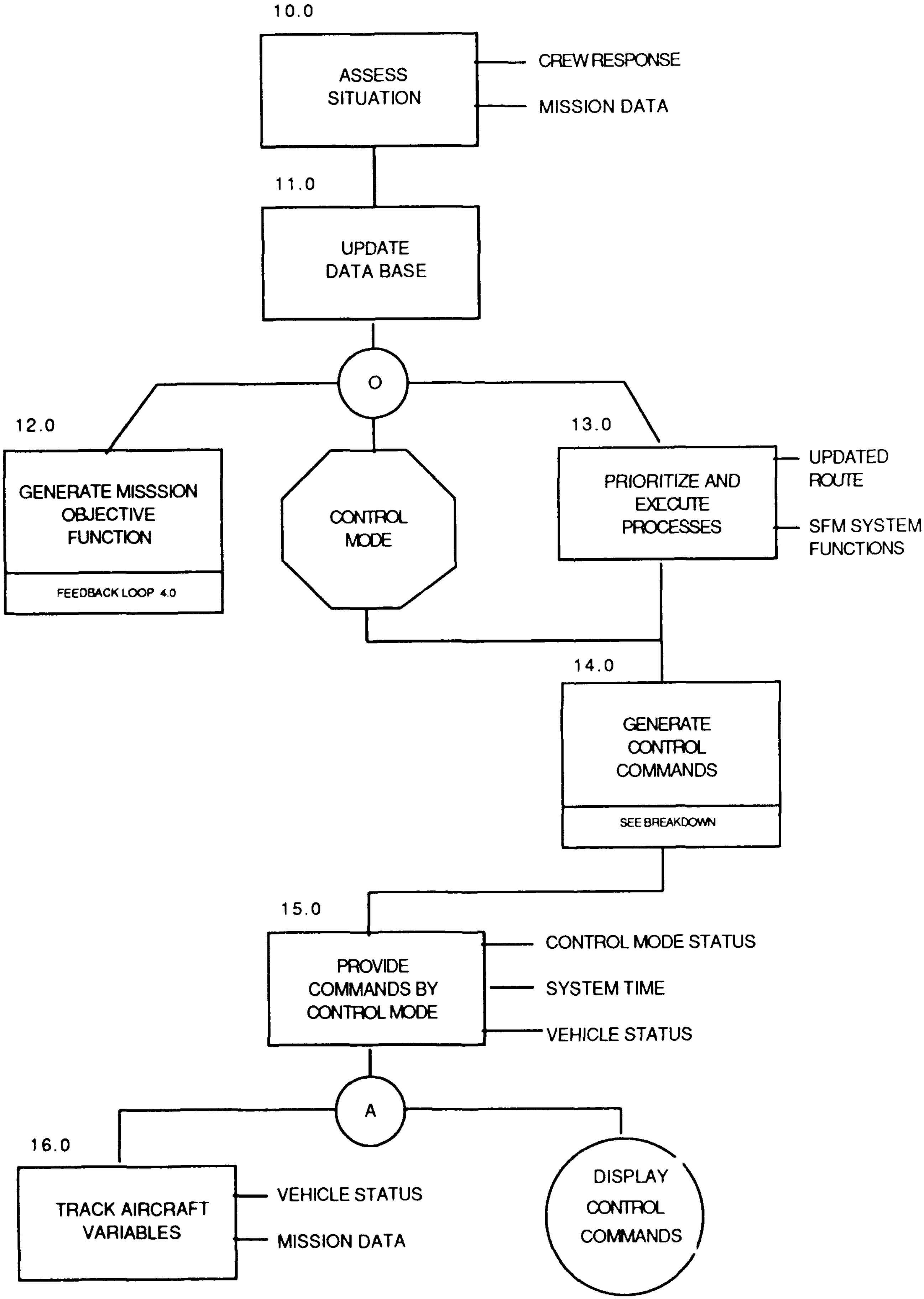


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

Monitor Situation Breakdown

1.1 Interpret Mission Data -- Events, current trajectory, and mission data information, particularly the offensive order of battle (OOB), will be of interest for this scenario.

1.2 Detect A Nuclear Threat Nearby -- The Mission Strategist will compare the OOB data with the current trajectory and determine that a nuclear threat is within the bomber route.

1.3 Assess Situation -- The mission parameters essential to deconfliction will be assessed. This will include mission data (fleet data regarding the threat type and location), and the current trajectory.

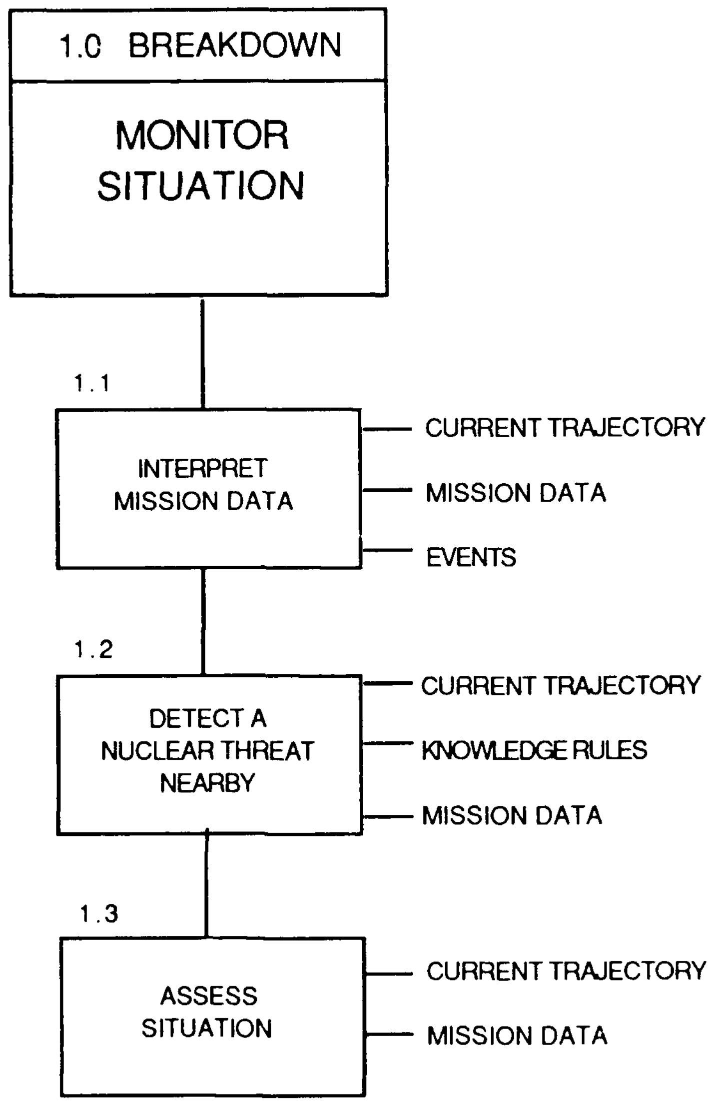


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

Formulate Solutions Breakdown Chart

5.1 Coordinate Responses of FM Functions -- The effects of the current status of the FM functions on the mission objective will be determined.

5.2 Evaluate Tradeoffs Between Mission Parameters -- Knowledge rules, derived from the strategy rule base, will be used to evaluate the mission objective function with information from the current mission data. The mission parameters will be evaluated in terms of their cost functions to meeting mission objectives.

5.3 Compute Weighting Factors -- Using the cost functions from the trade-off evaluation, the mission parameters will be prioritized and assigned weighting factors.

5.4 Generate Scenarios -- Using the mission objective function and the weighting factors, possible route adjustments which avoid the nuclear threat will be generated. The fuel and timing rule base and tactical doctrine will direct the adjustments.

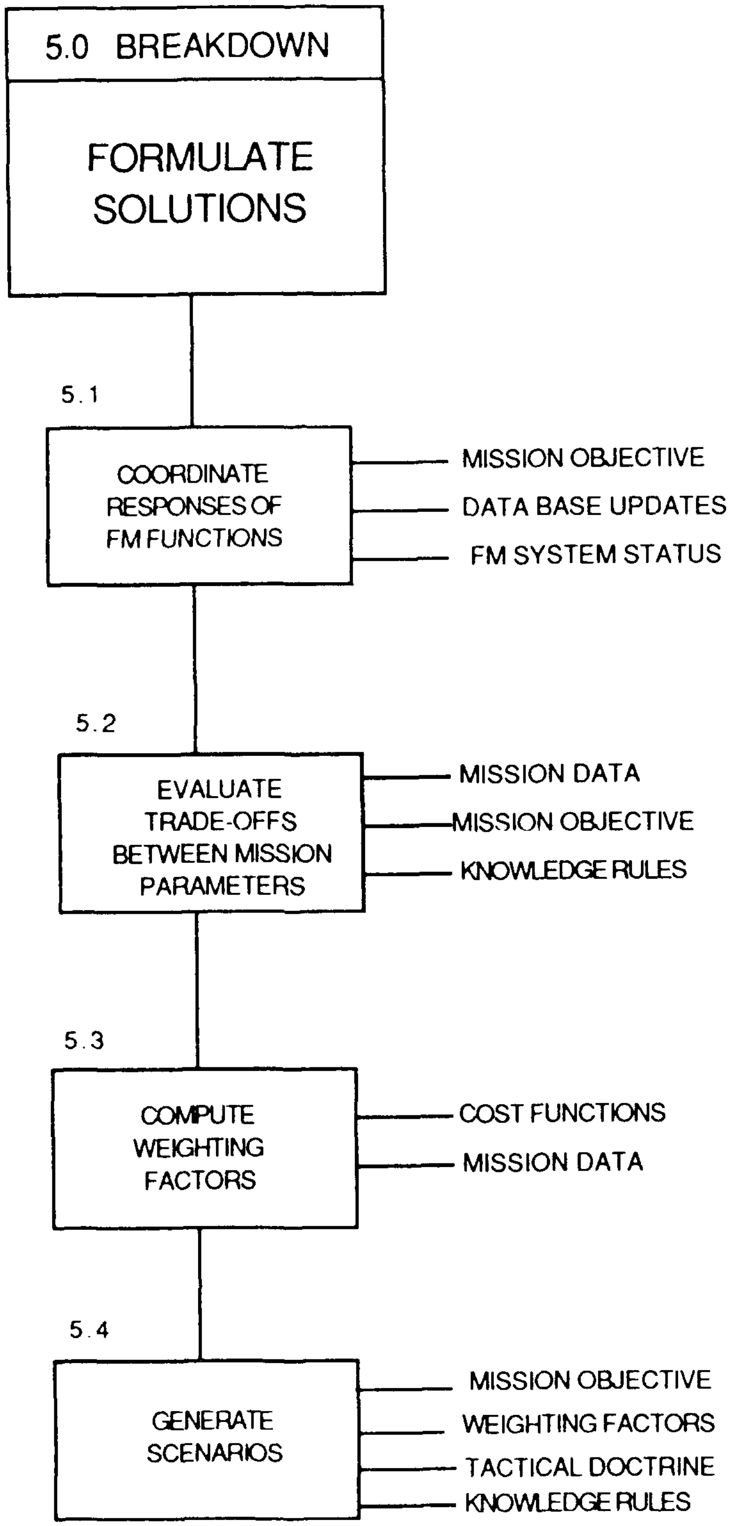


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

Establish Coarse Routes Breakdown

7.1 Preplanned Route Selection -- Coarse trajectories may be computed in advance and stored in the mission data base. The Trajectory Manager will select an appropriate course route.

7.2 Generate Coarse Routes -- Coarse trajectories may be generated by the Trajectory Manager. Information from the threat, target, mission, and current global trajectory data bases will be combined with the mission objective function and solutions received from the Mission Strategist. The coarse route generation will output waypoints and targets to be added, deleted, or changed.

7.3 Construct Trajectory Objective Function -- This function combines mission goals and vehicle performance optimization objectives. The Trajectory Manager will call upon the coarse route, mission objective function, mission data, and current global trajectory.

7.4 Normalize Weighting Factors -- The Trajectory Manager will normalize the weighting factors generated by the Mission Strategist.

7.5 Plan New Trajectory -- The Trajectory Manager will determine the mission waypoints and targets for the reroute situation. The route will be based on tactical doctrine, mission objectives, and current global trajectory.

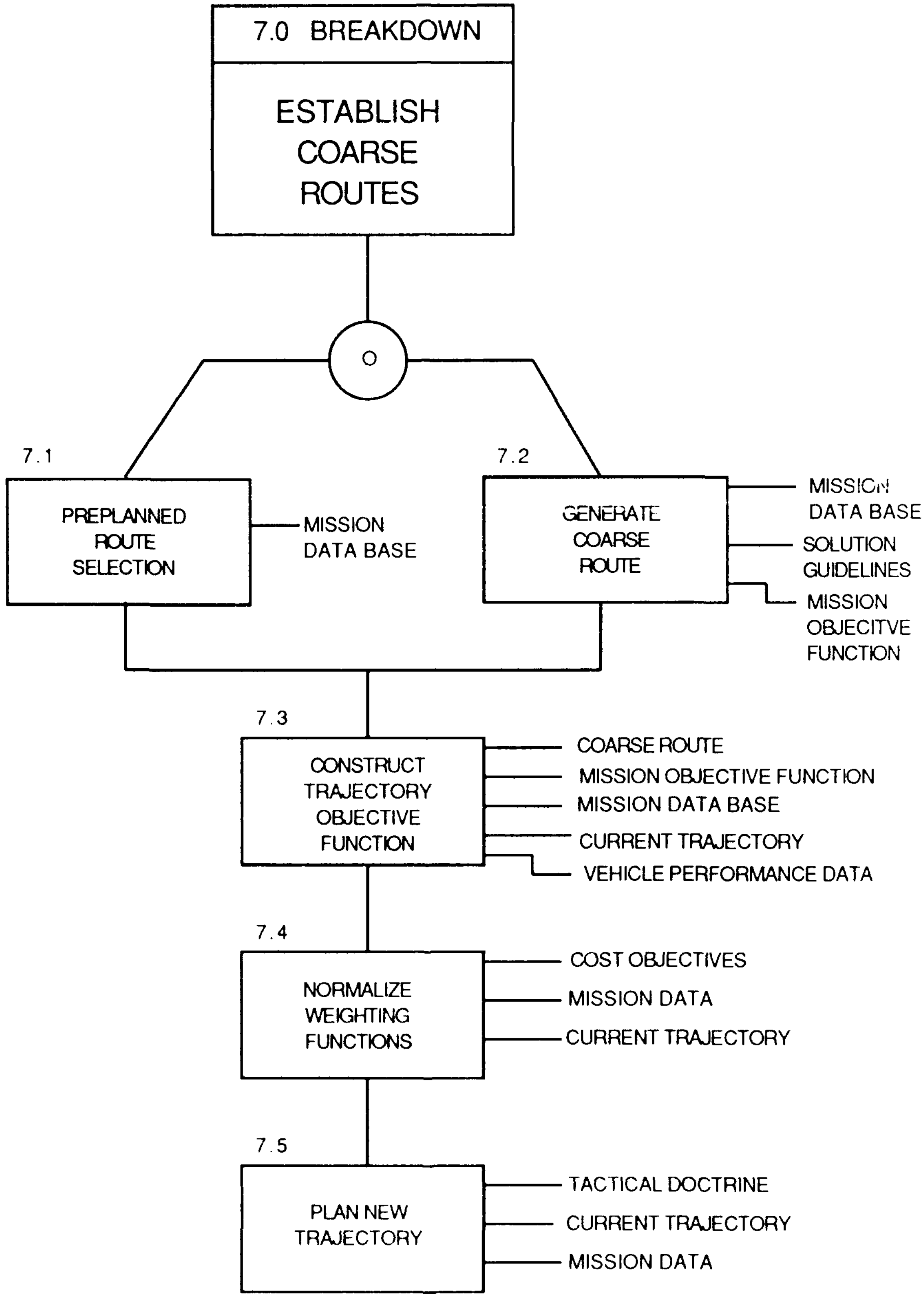


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

Compute Optimal Trajectory Breakdown

8.1 Schedule appropriate trajectory generation process -- A set of algorithmic processes have been established which generate a flyable, real-time trajectory. The Trajectory Manager will choose one or more of the processes depending on the situation. The data used will include the coarse route, mission objectives, tactical doctrine, aircraft characteristics and solution guidelines.

8.2 Initialize Trajectory Generation Process -- The Trajectory Manager will provide the selected process with the data needed to carry out that process.

8.3 Activate Trajectory Generation Process -- After the process has been initialized, it will be activated. The optimal solution will be generated and displayed to the crew via the PVI.

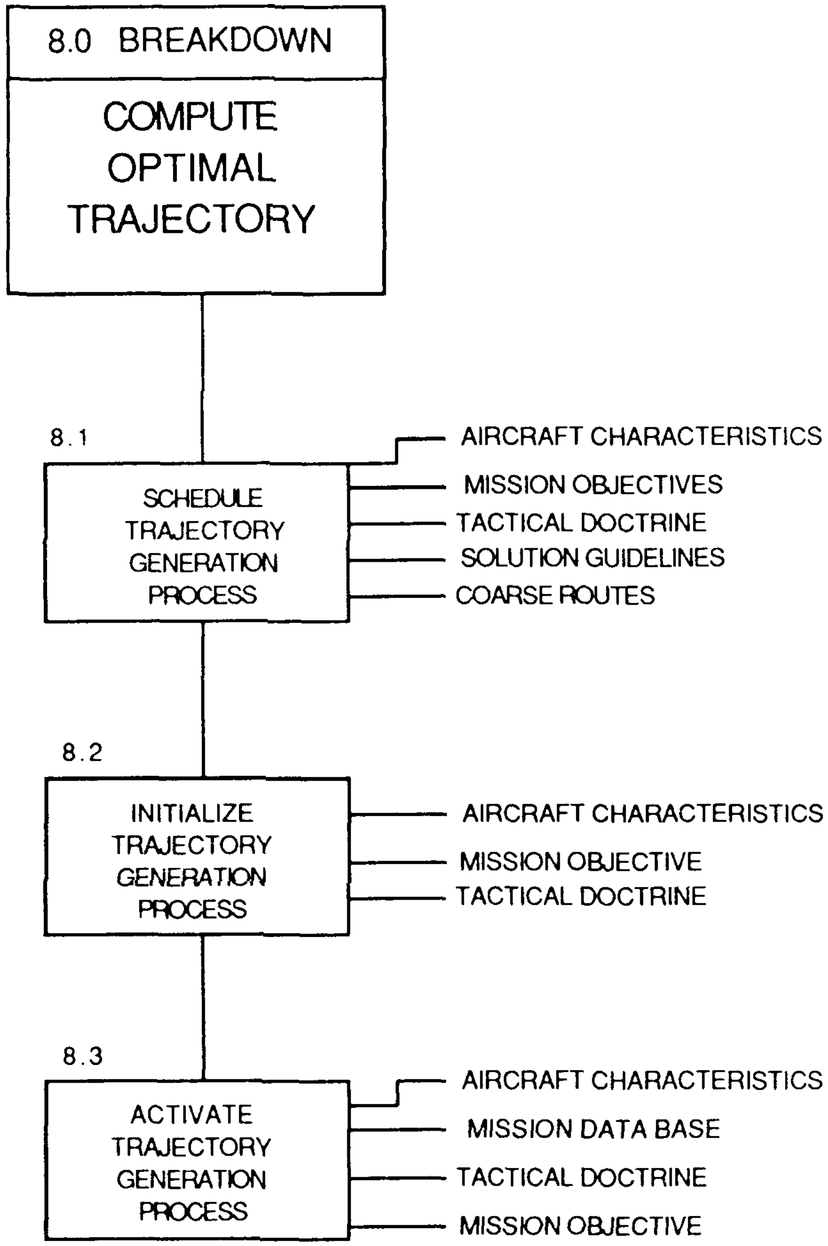


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

Generate Control Commands Breakdown

14.1 Identify Control Mode -- The crew will select the control mode to be either manual, coupled autopilot, or flight director. The Trajectory Manager will receive this information via the PVI.

14.2 Generate Real-time Commands -- The Trajectory Manager will need the following information: route plan and trajectory, vehicle status, and system time.

14.3 Output Control Commands and Status -- The following information will be forwarded to the Trajectory Follower and to the crew: heading and rate commands, altitude and rate commands, Mach/true airspeed, pitch angle and rate, bank angle and rate, throttle percentage, and wing sweep.

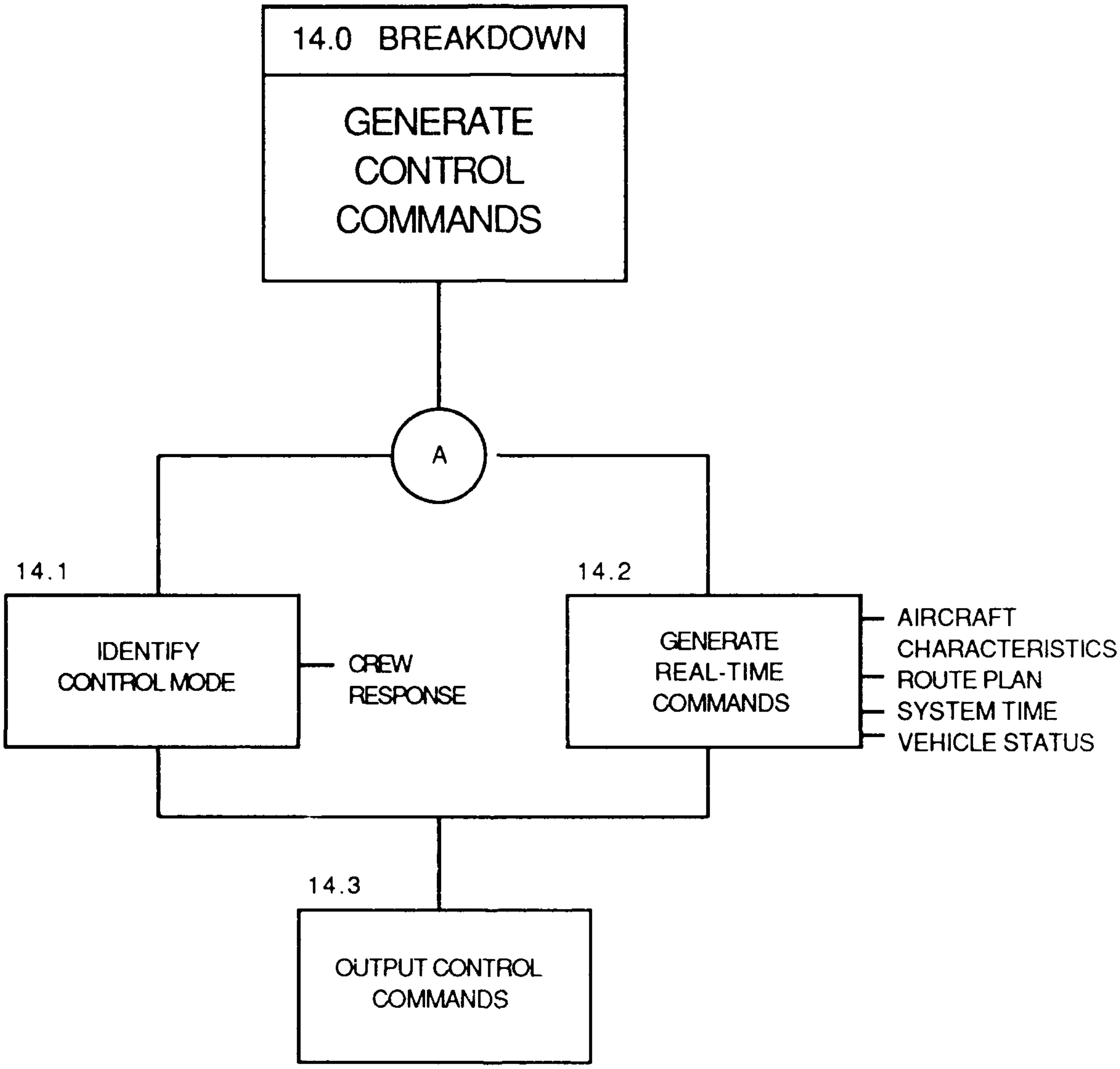


Figure 5-4 OSD: Deconfliction -- Avoidance of Nuclear Threat (Continued)

RELOCATABLE TARGET DEMONSTRATION

1.0 Monitor Situation -- The Mission Strategist will continuously receive mission data, global trajectory data, and event information.

Display Discrepancy to Crew -- The crew will be informed of any discrepancies between the planned and the actual route. The Mission Strategist will update the PVI to display the information to the crew.

2.0 Update Data Bases -- The Mission Strategist is responsible for constantly updating the data bases based on the incoming information received.

3.0 Generate Mission Objective Function -- The Mission Strategist will use knowledge rules, derived from the strategy rule base, to interpret the mission data, aircraft characteristics, and tactical doctrine. The mission objective will support target prioritization and aircraft flight conditions.

4.0 Formulate Solutions -- The Mission Strategist will construct solution guidelines which will support the mission objective function.

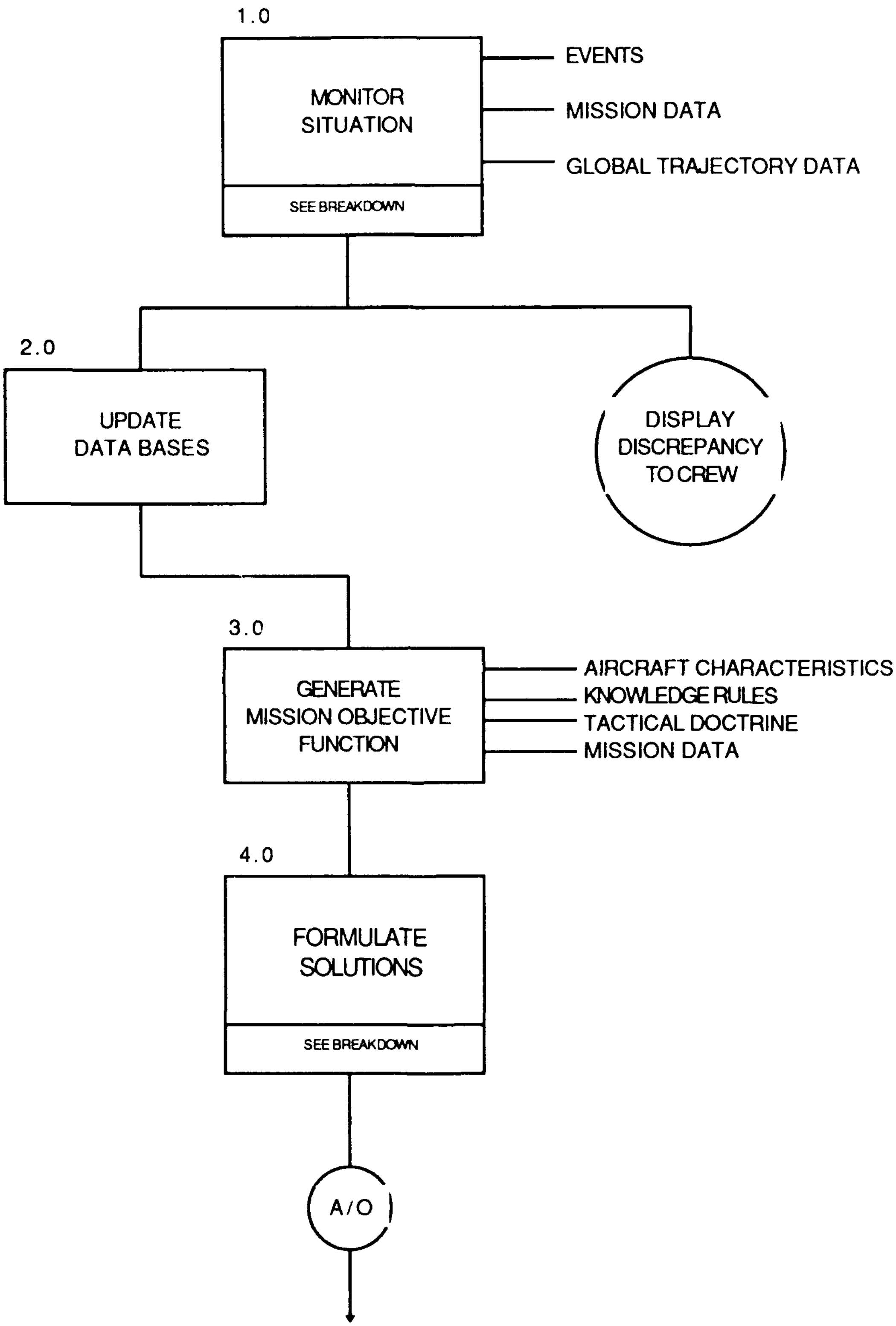


Figure 5-5 OSD: Relocatable Target Demonstration

5.0 Issue Route Change Request -- The Mission Strategist will send a route change request with the solution guidelines to the Trajectory Manager. The guidelines will optimize the trajectory for the actual point of entry into the target search area.

6.0 Target Reprioritization -- The Mission Strategist will adjust the priority of targets based on the evaluation done when formulating solutions. Because of the location of the bomber, the targets capable of being hit while still remaining within an envelope of the preplanned route may be altered.

7.0 Update Data Base -- The target data base will be updated with the new priority assignments.

8.0 Establish Coarse Routes -- The Trajectory Manager will derive a coarse route based on heuristic and rule based approaches that minimize threats and maintain mission objectives.

9.0 Compute Optimal Trajectory -- The Trajectory Manager will fine tune the coarse route by addressing aircraft performance characteristics and the external environment for the optimal route generation. The optimal trajectory generation process will repeat and display updated routes to the crew until a route has been accepted or rejected. Updates are required while the aircraft continues enroute changing the current conditions, which may effect the optimized route, while the crew makes a decision.

Display Optimized Route to Crew -- The proposed trajectory through the target search area will be displayed to the crew for acceptance or rejection.

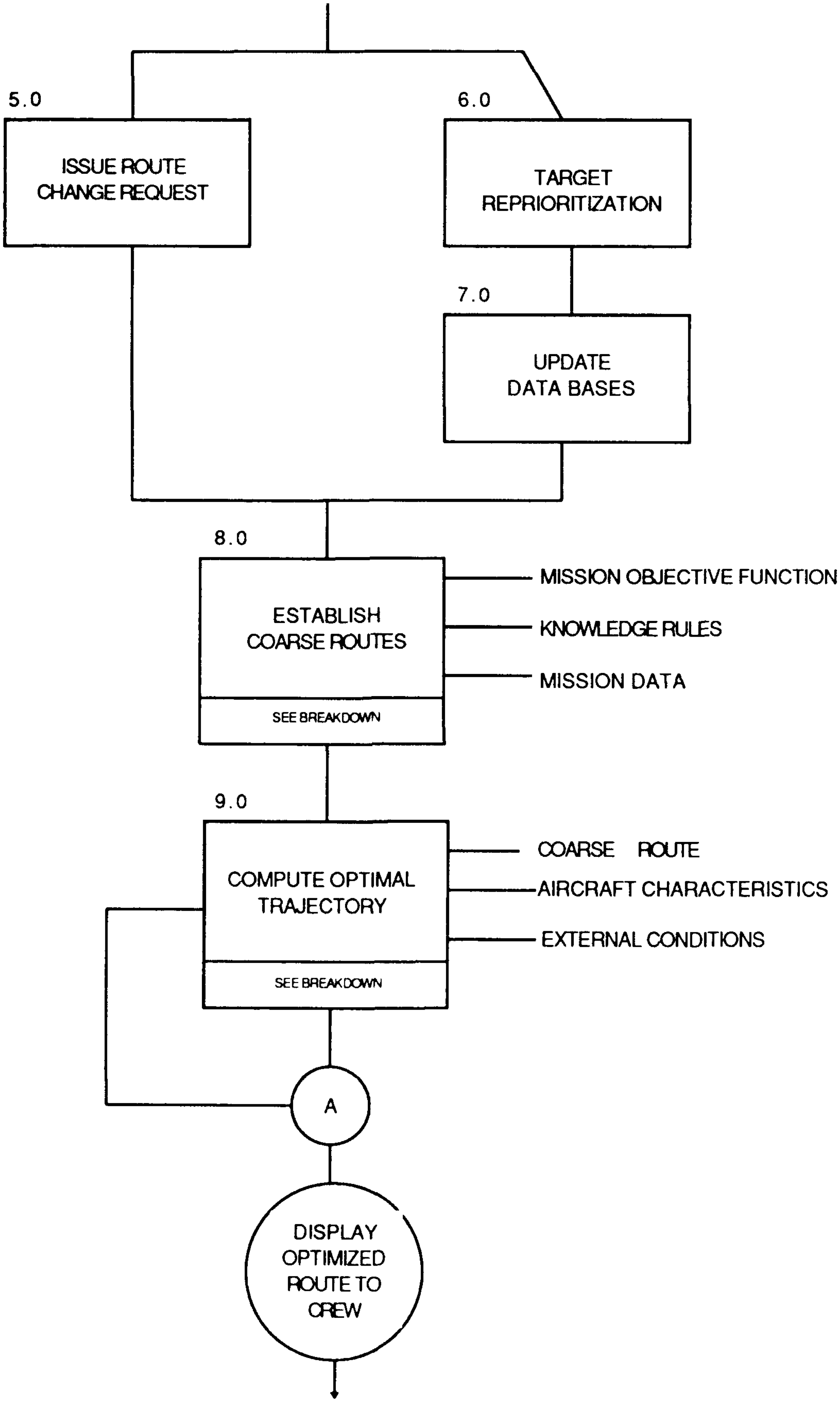


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Crew Decision Regarding Route -- The crew will make a decision to accept or reject the suggested solution.

10.0 Interpret Mission Data -- The Mission Strategist, which is continuously monitoring incoming data, will receive the crews decision to accept or reject the recommended trajectory.

11.0 Assess Situation -- The Mission Strategist will then determine the impact of the crew decision and the processes which must follow.

12.0 Update Data Bases -- The Mission Strategist will update the appropriate data bases with the appropriate route information.

13.0 Generate Another Route -- If the crew rejects the optimized route displayed then another route will be generated starting the process with box 3.0.

14.0 Prioritize and Execute Processes -- If the route is accepted by the crew, then the Mission Strategist, acting as the system executive, will prioritize and oversee the functions to be carried out by the FM functions for the route to be updated.

Control Mode -- At some point in the mission, the crew will decide which mode of control to use (manual, coupled autopilot, or flight director). This information will be interpreted by the Trajectory Manager.

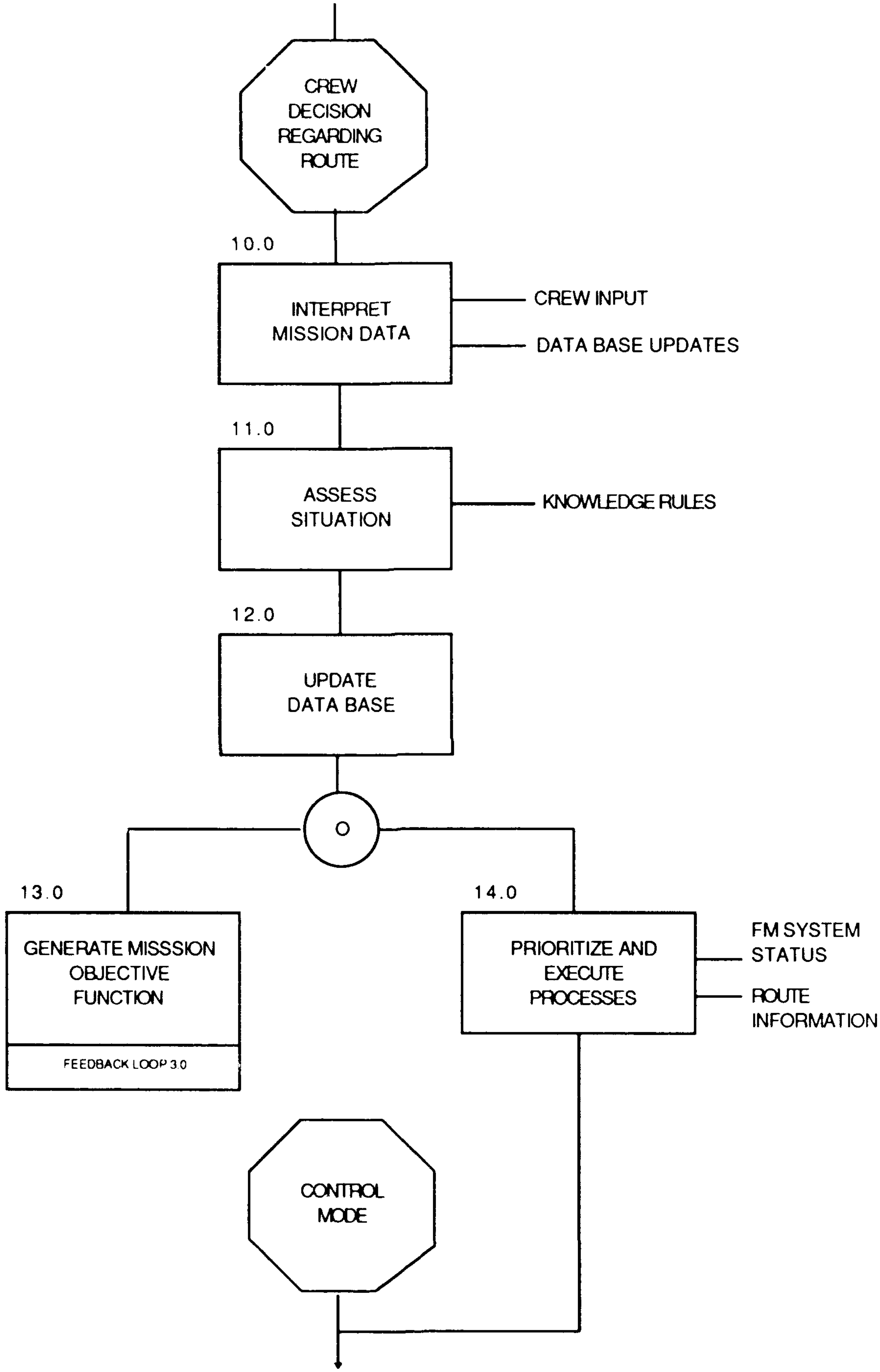


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

15.0 Generate Control Commands -- The Mission Strategist will evoke the Trajectory Manager to generate real-time control commands for the new route. The Trajectory Manager will generate real-time aircraft position, velocity, and acceleration state commands that will be used by the Trajectory Follower to control the aircraft along the computed course.

16.0 Provide Commands by Control Mode -- The Trajectory Follower will provide control commands depending on the mode of operation (manual, coupled autopilot, or flight director). The selected mode, system time, vehicle data, and control commands are the data required by the Trajectory Follower.

17.0 Track Aircraft Variables -- The Trajectory Follower will monitor vehicle data and track aircraft variables to meet objectives of the mission segments.

Display Control Commands -- Control effecter commands (ailerons, rudder, thrust) and steering cues will be displayed to the crew, via the PVI.

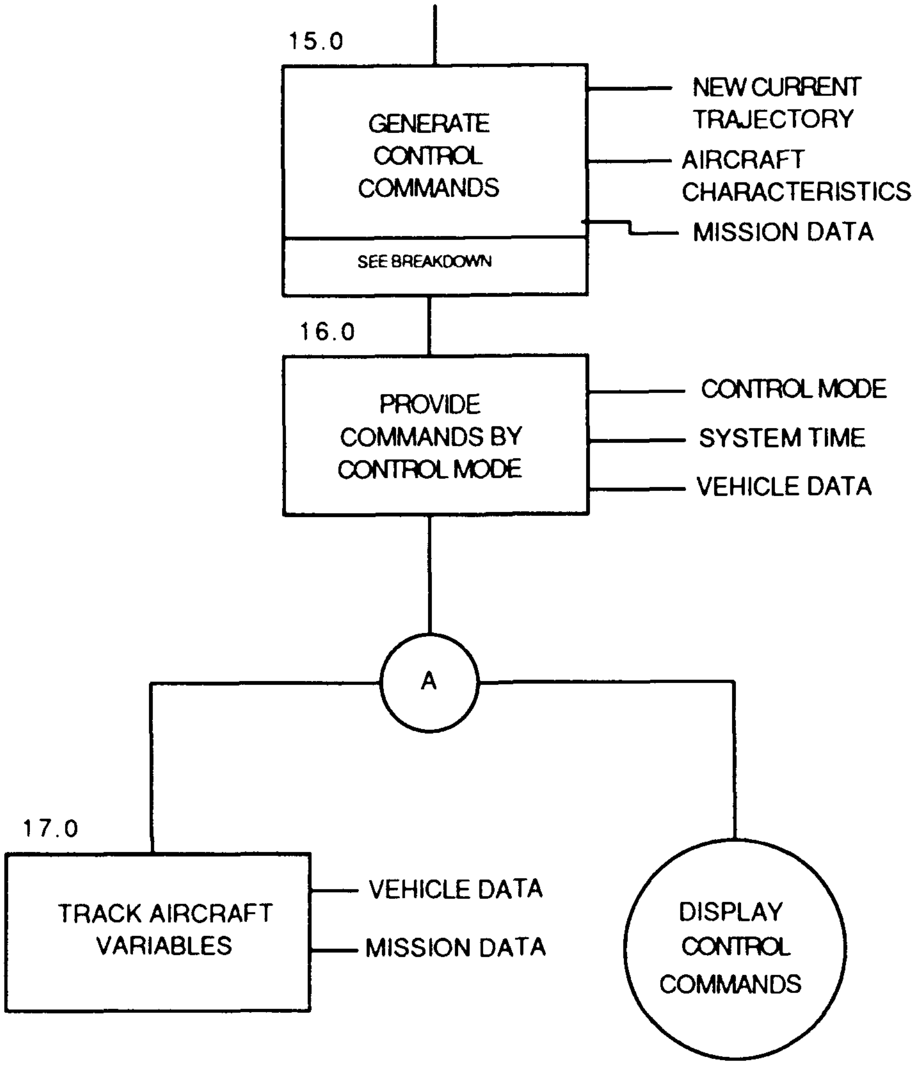


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Monitor Situation Breakdown

1.1 Interpret Mission Data -- The mission data and global trajectory data will be received by the Mission Strategist continuously throughout the mission.

1.2 Assess Situation -- Knowledge rules from the strategy rule base will be applied to the incoming mission and trajectory data to determine the status of approaching target area. The current location of the bomber will be compared with the preplanned arrival point to the target area.

1.3 Discover Discrepancy -- The Mission Strategist will detect a difference between the preplanned arrival point into the target area and the actual arrival point.

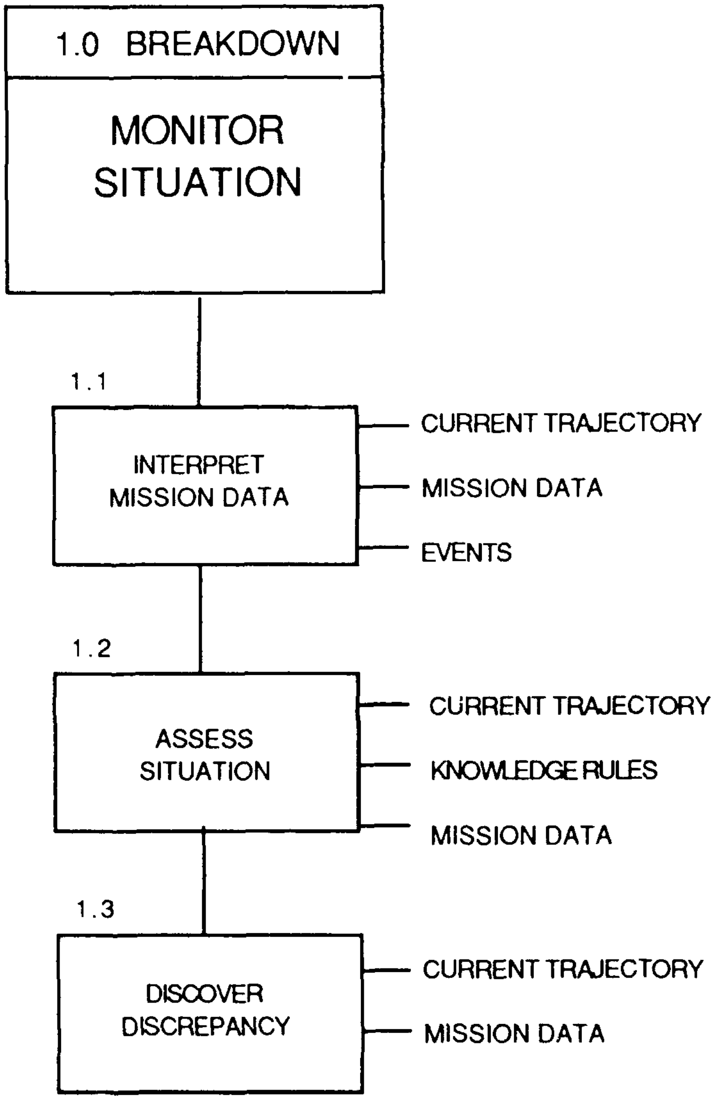


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Formulate Solutions Breakdown

4.1 Coordinate Responses of FM Functions -- The FM function status and data base updates will be interpreted based on their effects on the mission objective.

4.2 Evaluate Tradeoffs Between Mission Parameters -- Knowledge rules will be used to generate cost functions for the mission parameters. Knowledge rules will be obtained from the strategy, route selection, and fuel and timing rule bases. Mission parameters include targets, waypoints, threats, and launch times.

4.3 Compute Weighting Factors -- The weighting factors assigned to the mission parameters will be prioritized based on the trade-off evaluation.

4.4 Generate Scenarios -- Solution guidelines will be constructed based on the weighting factors of the mission data, the mission objective, and tactical doctrine. The solution guidelines will include possible route adjustments and the reprioritization of targets.

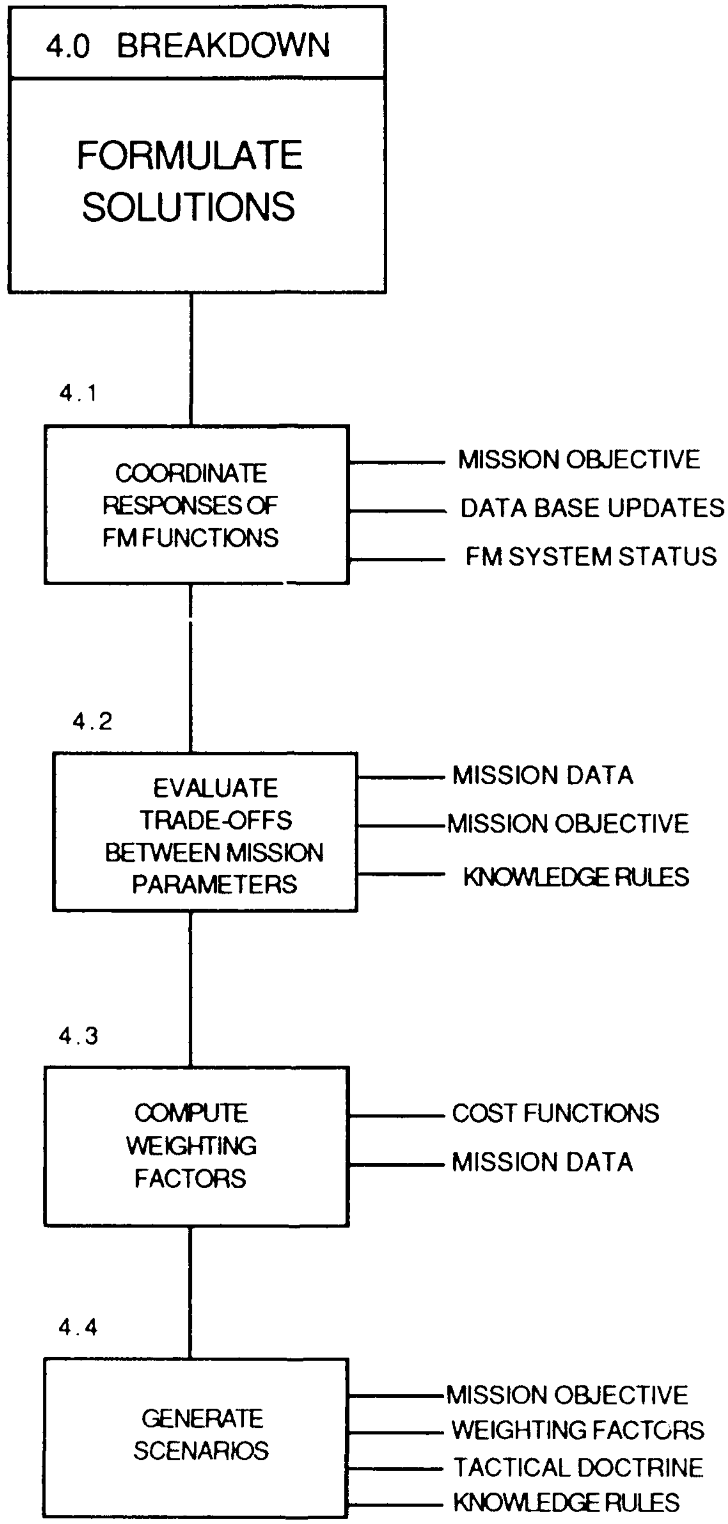


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Establish Coarse Routes Breakdown

8.1 Preplanned Route Selection -- Coarse trajectories may be computed in advance and stored in the mission data base. The Trajectory Manager will select an appropriate coarse route.

8.2 Generate Coarse Routes -- Coarse trajectories may also be generated by the Trajectory Manager. Information from the threat, target, and mission data bases will be combined with the mission objective function and solutions received from the Mission Strategist.

8.3 Construct Trajectory Objective Function -- This function combines mission goals and vehicle performance optimization objectives. The Trajectory Manager will call upon the coarse route, mission objective function, mission data, and current global trajectory.

8.4 Normalize Weighting Factors -- The Trajectory Manager will normalize the weighting factors generated by the Mission Strategist.

8.5 Plan New Trajectory -- The Trajectory Manager will determine the mission waypoints and targets for the reroute situation. The route will based on tactical doctrine, mission objectives, and current global trajectory.

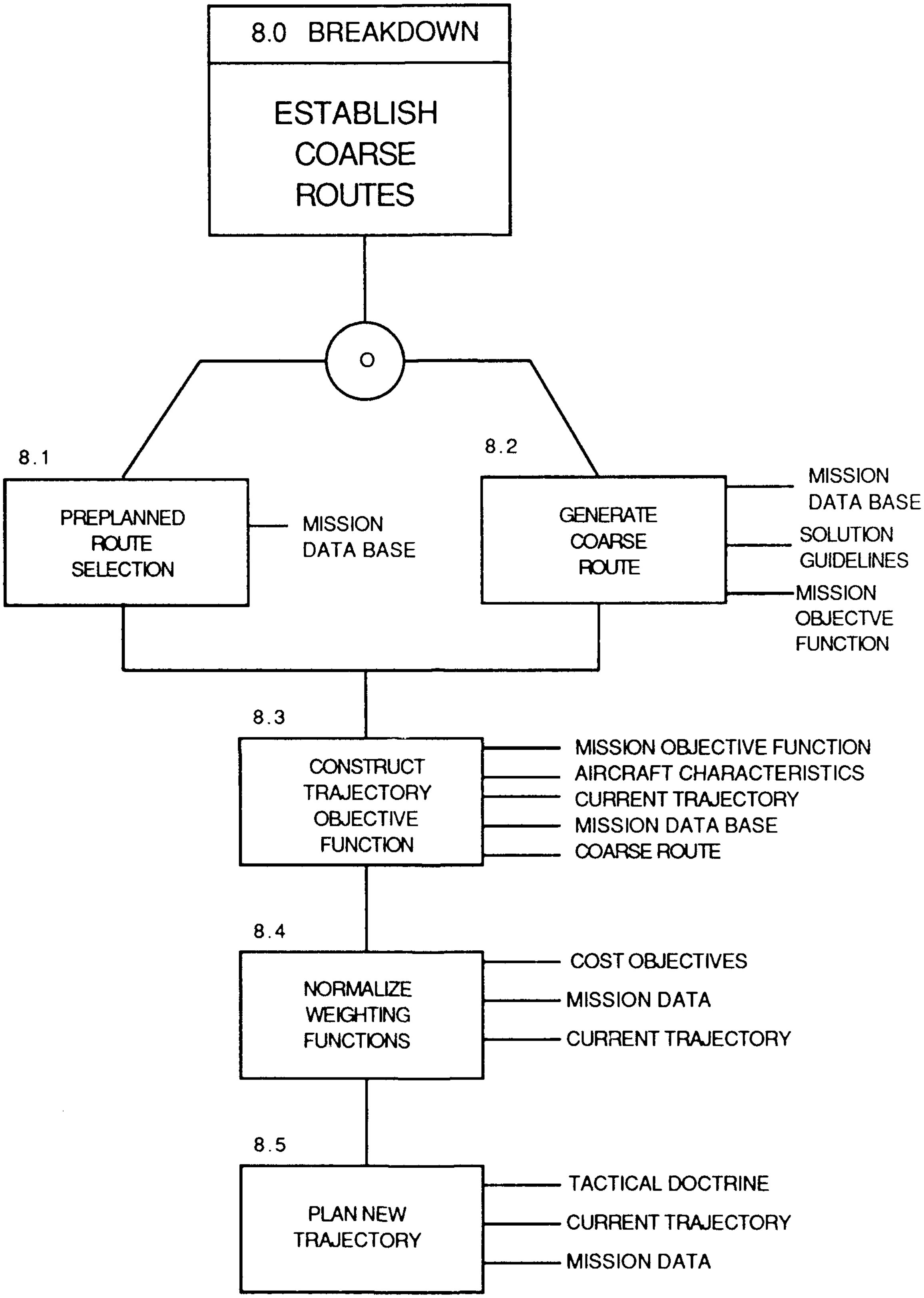


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Compute Optimal Trajectory Breakdown

9.1 Schedule appropriate trajectory generation process -- A set of algorithmic processes have been established which generate a flyable, real-time trajectory. The Trajectory Manager will choose one or more of the processes depending on the situation. The data used will include the coarse route, mission objectives, tactical doctrine, aircraft characteristics and solution guidelines.

9.2 Initialize Trajectory Generation Process -- The Trajectory Manager will provide the selected process with the data needed to carry out that process.

9.3 Activate Trajectory Generation Process -- After the process has been initialized, it will be activated. The optimal trajectory through the target area will be generated and displayed to the crew via the PVI. The crew will make a decision to accept or reject the suggested solution.

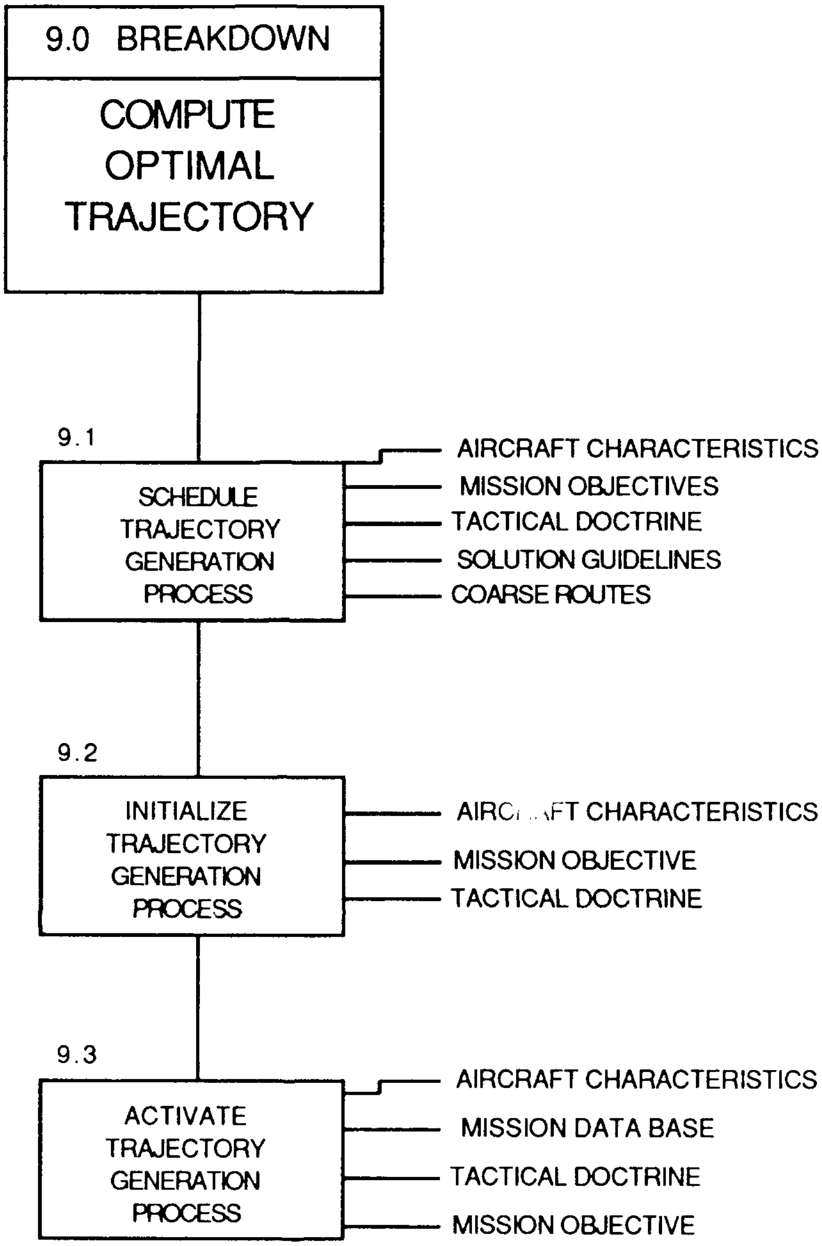


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Generate Control Commands Breakdown

15.1 Identify Control Mode -- The crew will select the control mode to be either manual, coupled autopilot, or flight director. The Trajectory Manager will receive this information via the PVI.

15.2 Generate Real-time Commands -- The Trajectory Manager will need the following information: route plan and trajectory, vehicle status, and system time.

15.3 Output Control Commands and Status -- The following information will be forwarded to the Trajectory Follower and to the crew: heading and rate commands, altitude and rate commands, Mach/true airspeed, pitch angle and rate, bank angle and rate, throttle percentage, and wing sweep.

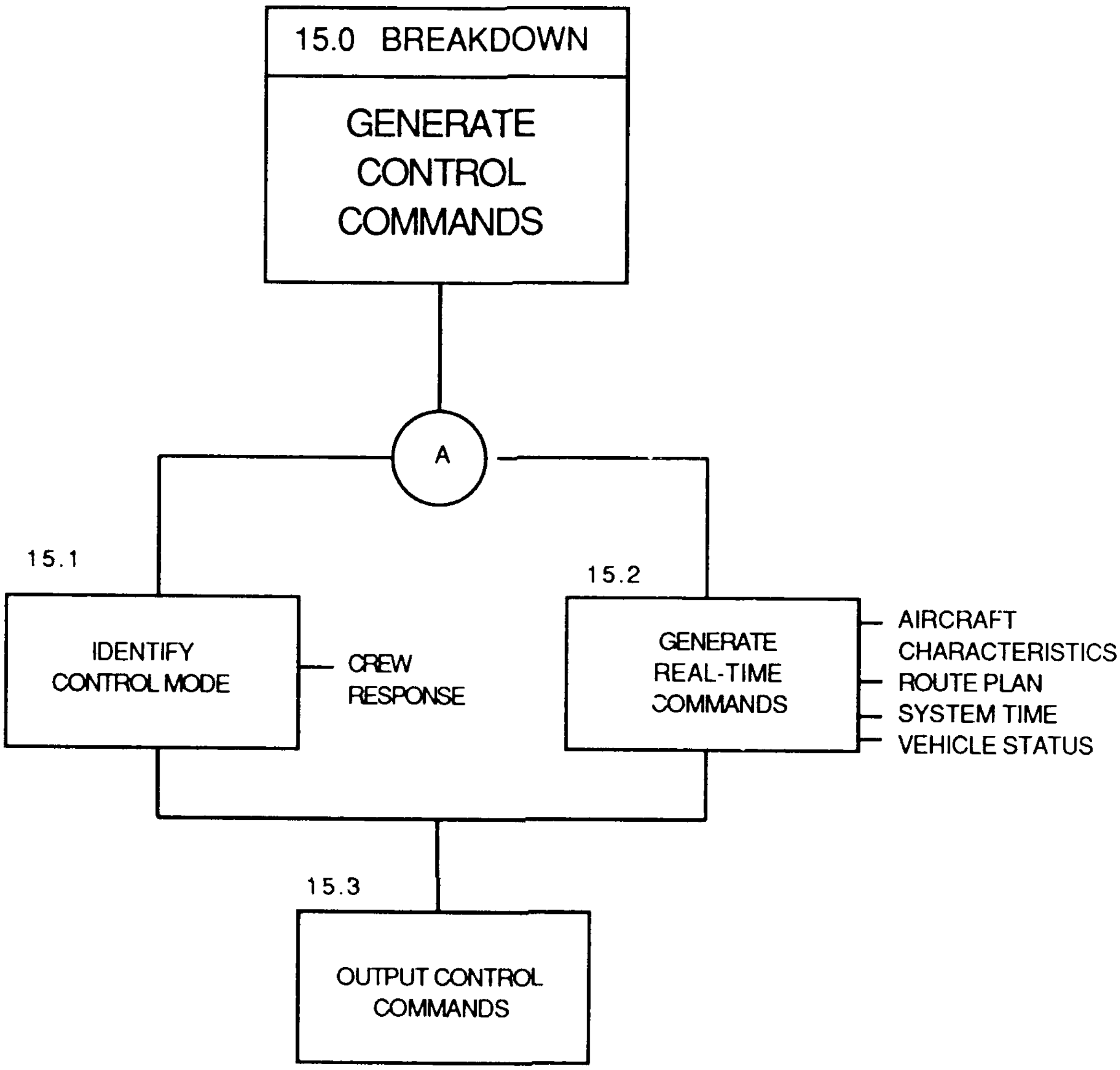


Figure 5-5 OSD: Relocatable Target Demonstration (Continued)

Section 6

CONCLUSIONS

This Concept Definition of FM represents the initial phase of a study that is directed to exploring the MMI issues inherent in the development and integration of an FM avionic subsystem into a manned, penetrating bomber weapon system. It is a graphic description of the logical flow of events and an examination of the relationships between the subsystems, including the crew. The current effort represents one of the first steps, a Function Analysis, in the design and demonstration of "optimum" display formats. The resultant functional description of a FM system included subsystem interactions, interdependencies, and a hypothetical flow of data and information through the system. The objective of this effort was to lay the groundwork to support continued FM MMI conceptual design and analysis.

There were four FM MMI overall requirements addressed in the introduction to this report. The first requirement, the development and documentation of "optimum" conceptual display formats, was the overriding concern in developing a "human-centered" technology. Crew system information requirements should impact design of these formats. In defining system requirements, attention must not only be paid to what information is required by the operator, but also to how and when that information will be presented. There are four products of the graphic concept definition that provide the foundation for that information requirements analysis. The mission scenarios and OSD diagrams provide an insight, in terms of the sequence of operational responses to unplanned events. In addition, the semantic maps, in current form and with continued development, provide an enhancement to the knowledge base in regard to the complexity and type of information required. The fourth product, IDEF0 diagrams, defined the flow of information through the system.

Semantic maps afforded an examination of the objects of the system and provided a glimpse at the relationships between those system objects. Continued modeling of the system concepts, with IDEF0 diagrams, not only represented the flow of information through the system, it also examined FM functionality in terms of system activities. The model also illustrated the interdependencies of FM ancillary subsystems.

The second requirement was to integrate a software development/ demonstration FM processor into the DET 1, AL/HED SABER advanced conceptual bomber crew system simulator. A thorough understanding of the system functionality and interdependencies, achieved with the IDEF0 model, provides the foundation with which to define hardware linkages and will also support development of the software specifications.

The third requirement was to conduct a laboratory, part-mission demonstration of the FM avionics concept in the SABER facility. The part-mission scenarios, described in this report are prototypical scenarios to be utilized for a concept demonstration of FM. Utilization of these particular scenarios provides the mission context specific to three FM problems. The OSDs, event timelines and scenario narratives provide the foundation for concept demonstration. Measures of merit, derived from user requirements that test FM effectivity, survivability and flexibility will be applied.

A fourth requirement for FM MMI support addresses the assessment of FM MMI display formats. A "strawman" road map for FM MMI conceptual display development was provided (Figure 1-1) in this report. Development of display guidelines and "optimal" display formats occurs during the Function Allocation phase of the Concept Definition. At this time, the assessment criteria developed as a product of Information Analysis are addressed. These criteria will be applied to provide review and critique of display formats as consultative support to FMI subsystem development organizations in both government and industry.

The preliminary Function Analysis accomplished during the current effort supports the "first steps" in addressing the above issues of FM MMI requirements. The resulting products: technology-free part-mission mini-scenario narratives, based on Boeing scenarios; concept/semantic map representation of system objects, attributes, and relationships; an IDEF0 FM system activity model, that includes data and information flow and system interdependencies, provide a multi-faceted concept definition of FM.

RECOMMENDATIONS

Complete understanding of user requirements is critical in design and development of MMI in FM systems. The analysis completed for this report addresses user requirements in terms of system functional capabilities. The intent of this initial Concept Definition was to lay the groundwork for continued investigation of user requirements at the level of the system MMI. Ongoing user involvement in continued Concept Definition is recommended to ensure validity of system concept.

There are two reasons for including the operator-in-loop at the Concept Definition level of system development. Not only is veridicality of user requirements confirmed, but a level of acceptance in the user community is achieved. This acceptance of design concepts is typically expected only of fielded system demonstrations that exhibit the ability to satisfy user requirements and have built a "track record" of successful responses to unplanned events. However, the goal is to show, in the FM Concept Definition and Demonstration phase of development, an increase in mission effectivity, system flexibility, and survivability in response to unplanned events.

REFERENCES

Anderson, A.F.; Ever, K.; Green, C.D.; and Wallace, M.R. (1990). Cockpit Automation Technology, Interim Report, HSD-TR-90-011

Aretz, A.J. (1984). Cockpit Automation Technology, Proceedings of the Human Factors Society 28th Annual Meeting, 487-491, Santa Monica.

Cheney, R. (1990) Soviet Military Power. Office of the Secy. of Defense. United States Government Printing Office, Washington, D.C., Ninth Edition.

Churchman, D.A. (1990). Strategic Flight Management Program. Boeing Defense and Space Group Briefing to WRDC/WL.

Fisher, K.M.; Faletti, J.; and C.N. Quinn (1990). Exploring cognitive structure with semantic networks, Unpublished manuscript, available from K.M.Fisher San Diego State Univ., San Diego, CA

Eberts Ray E. and Brock, John F. (1987). Computer-Assisted and Computer-Managed Instruction, in Salvendy, G. (Ed.), Handbook of Human Factors., 991, New York: John Wiley and Sons.

Hutchins, Jr., C.W.; Douglas, E. N.; and Lind, J. H. (1991). Intelligent Air Attack System (IAAS) Evaluation Results, NWC TP 7052.

Lambiotte, Judith G.; Bansereau, Donald F.; Cross, David R.; and Reynolds, Sharon B. (1989). Multirelational Semantic Maps, Educational Psychology Review, 1 (4).

Kuperman, G.C. and Wilson, D.L. (1986). A Human-Centered Technology for Advanced Bomber Crew Stations. AAMRL-TR-86-052.

Kuperman, G.C. and Wilson, D.L. (1988). An Advanced Conceptual Aircraft Simulator. Proceedings of the IEEE Engineering Management Conference, Dayton, Ohio, October 24-26.

McFarren, M.R. (1987). Using Concept Mapping to Define Problems and Identify Key Kernels During the Development of a Decision Support System. Masters Thesis, Air Force Institute of Technology, Air University.

McNeese, M.D.; Zaff, B.S.; Peio, K.J.; Snyder, D.E.; and Duncan, J.C. and McFarren, M.(1990) An Advanced Knowledge and Design Acquisition Methodology: Application for the Pilot's Associate. AAMRL-TR-90-060.

Probert, J. (1990). Strategic Flight Management (SFM) Program Elements 62201F, 63367, Program Planning Material.

Ruess, J.C. and Kobarg, R.J. (October 1982). White Paper: The 1990s Defensive Battle Manager (U), HQ SAC/XOBD/XOKF, Offutt Air Force Base, Nebraska (SECRET)

Storer, M. (May 15, 1991). Real-Time Targeting Concept Development, General Dynamics, Convair Division, Initial Progress Report 1.

Strategic Flight Management Concepts for Large Aircraft Industry Review. (1989).

Strategic Relocatable Target Capability Program Office Briefing to Industry. (1990).

Quillian, M.R. (1969). The teachable language comprehender: A simulation program and theory of language. Communications of the ACM, 12, 459-476.

Welch, R.J., (March 1982), White Paper: The 1990a Bomber Offensive Crew Station, HQ SAC/XOKF, Offutt Air Force Base, Nebraska. (SECRET)

Wilber, G.F. (1988). Strategic route planning using informed best-first search. Proceedings of the 40th IEEE National Aerospace Conference (NAECON), Dayton: 1137-1144.

Wilber, G.F. and Dryer, E.J. (1988). Strategic real-time airborne electronic warfare using knowledge base techniques. Proceedings of the 40th IEEE National Aerospace Conference (NAECON), Dayton: 1208-1213.

Wilber, G.F. (1989). Automated strategic relocatable target mission planning. Proceedings of the 41st IEEE National Aerospace Conference (NAECON), 976-980.

Wilber, R. (1989). Expert systems aid on-board mission management. Defense Computing, 2, 27-30.

Wilber, G.F. and Plaisted, S.J. (1989). Intelligent real-time electronic warfare. Proceedings of the 41st IEEE National Aerospace Conference (NAECON) Dayton.

Wilson, D.L. and Kuperman, G.G. (1988). Strategic Avionics Battle-Management Evaluation and Research. Proceedings of the 40th IEEE National Aerospace Conference, (NAECON) Dayton: 844-849.

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