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Identification of Artificial Intelligence (AI) Applications for Maintenance, Monitoring, and Control of Airway Facilities

Lori Adkisson

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16. Abstract

This document provides information acquired from a study conducted on Artificial Intelligence (AI). The study had four goals, as follows:

a. To identify Airway Facilities (AF) maintenance, monitoring, and control of activities suitable for AI application development.

b. To determine the AI technologies, tools, architectures, and algorithms that would be most suitable for the identified applications.

c. To develop a set of criteria for AI applications development, and evaluate each of the identified applications in terms of this criteria.

d. To make short- and long-term recommendations for AI applications development within AF.

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EXECUTIVE SUMMARY

The Airway Facilities (AF) organization of the Federal Aviation Administration (FAA) is responsible for the maintenance of all facilities, systems, and services involved in the control of aircraft using the National Airspace System (NAS). New technologies and approaches for the enhancement of AF maintenance are of interest to FAA management. Artificial Intelligence (AI) technologies provide alternatives for enhancing the reliability and integrity of the maintenance, monitoring, and control services provided by the FAA.

The purpose of this study was to:

a. Determine the applicability of AI technologies for maintenance, monitoring, and control.

b Recommend the means by which AI can augment required personnel skills.

Identify the AI technologies suitable to these tasks

This report is the final product of a study to identify AI applications for AF. The scope of the study was restricted to the maintenance, monitoring, and control operations of the FAA.

There were 10 AI technologies identified and studied for application to AF maintenance. Five types of equipment were investigated and 24 potential expert system (ES) applications were identified. All 24 ESs were judged to be possible, appropriate, and justified. Included among the applications is the potential use of AI for PC-based training for FAA technicians. Another use for AI is for the documentation of maintenance information retrieval in electronic media to be used by technicians.

Implementation of an ES should be evolutionary. It is recommended that an ES development environment such as KEE, ART, Nexpert Object, Level5 Object, or CLIPS be installed on a workstation or PC. This environment would provide excellent development tools and capabilities at a reasonable cost.

The implementation plan for an ES consists of three major phases and four milestones. The three phases are requirements engineering, knowledge engineering, and knowledge management. Important milestones for each project include the requirements analysis, a proof-of-concept rapid prototype, a production system, and knowledge management and delivery. An ES can be built, tested, and integrated in approximately 12 to 15 months by a 3 or 4 person team.

Artificial Neural Networks (ANN) are identified as the appropriate AI technology for the alarm processing system and monitoring. The problem resolution file (PRF) system is based on the results of the analysis phase. An implementation plan for the ANN is provided, including milestones and estimates of needed resources.

1. INTRODUCTION.

1.1 BACKGROUND.

The Federal Aviation Administration (FAA) Airway Facilities (AF) organization is responsible for the maintenance of all facilities, systems, and services used for air traffic control (ATC). The methods used to maintain these facilities, systems, and services are changing.

In the past, maintenance has been performed on-site. Each technician has been responsible for a single facility or, at most, a few facilities of a given type. Remote Maintenance Monitoring (RMM) is decreasing the need for on-site maintenance, and is changing the entire maintenance concept and philosophy within the AF organization. The AF organization is becoming more centralized. Individual technicians are responsible for many facilities, rather than a single facility, and site visits are decreasing as more maintenance, monitoring, and control activities are carried out remotely, through the Remote Maintenance Monitoring System (RMMS).

In addition, changes in the AF work force are demanding changes in the maintenance concept and philosophy. The present AF work force was hired primarily during the late 1950's and early 1960's, and many AF personnel are currently, or will soon be, eligible for retirement. The FAA, thus, is experiencing an influx of new, less experienced technicians.

A knowledge vacuum for many existing systems may be created by the anticipated loss of older, more experienced technicians, within the next few years. The FAA's Maintenance Automation Program is responsible for research and development efforts to support the Maintenance Automation System. This program is continually searching for improved methods of data acquisition, data processing, and information display to assist AF personnel in maintaining the service of the entire ATC system.

There is a strong belief that Artificial Intelligence (AI) applications would be of significant benefit in solving current problems and enhancing the performance of AF maintenance, monitoring, and control of activities for newer systems. Therefore, the Advanced Systems Technology Branch (ACD-350) initiated an in-depth study to determine the applicability of AI technologies to the maintenance, monitoring, and control of the National Airspace System (NAS).

1.2 PURPOSE.

The purpose of this document is to report the data analysis, conclusions, and recommendations of AI technologies for application to the AF problems and issues. The objectives can be summarized as follows:

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The study provides both short- and long-term recommendations. The short-term recommendations are for applications where mature AI technologies are available. Important short-term recommendations are the PRF system and the corrective maintenance advisor. Both systems will use a combination of the ES and the neural network technologies. The long-term recommendations are for areas in which appropriate infrastructures are not available in the FAA, or the AI technology has not matured enough to handle the application. These long-term recommendations include areas such as alarm processing, certification, information retrieval, and training.

a. Identify AF maintenance, monitoring, and control of activities suited to AI applications development.

b. Determine the AI technologies, tools, architectures, and algorithms that are most suitable for the identified applications.

c. Develop a set of criteria for AI applications development, and evaluate each of the identified applications in terms of those criteria.

d. Prepare a report summarizing: (1) the potential applications, (2) the AI technologies, tools, and architectures needed to develop those applications, (3) the evaluation of the applications, and (4) the short and long term recommendations for AI applications development within AF.

1.3 SCOPE

The scope of this study was limited to identifying AI applications for maintenance, monitoring, and control of facilities. For this study, maintenance, monitoring, and control of activities were defined as follows:

a. Maintenance is the process of keeping the system in peak working condition. There are two types of maintenance - periodic (i.e., preventative or routine) and corrective (i.e., scheduled or unscheduled).

b. Monitoring is the observation of system performance, and the planning of any necessary corrective actions based on the information obtained through observation.

c. Control is the process by which actions are taken to achieve a desired level of operation from a system. It involves the analysis of available data, the control actions taken (e.g., reconfiguration and/or rerouting of communications), and recommendations for repair or replacement of system components.

This study identifies two additional activities, AF administrative tasks, and training of AF personnel.

1.4 ORGANIZATION

This report is organized into seven main sections. Section 1, "Introduction contains an introduction to the report, and defines the purpose and scope of the study.

Section 2, "Study Approach," contains a review of the methodology, and documents the information sources used in the study.

Section 3, "Current FAA AF Maintenance Operations, presents an overview of the current AF maintenance, monitoring, and control operations.

Section 4, "Identification of AI Applications," presents an overview of AI, expert systems (ES), Artificial Neural Network (ANN), fuzzy logic (FL), and other technologies. It also explains the applications identified and presents an analysis of each application.

Section 5, "Development Issues for Knowledge-Based Expert Systems (KBES)," describes a strategy for developing the KBES. General implementation issues are addressed, technology issues are examined, and an implementation plan is presented.

Section 6, "Developmental Issues for ANN systems," describes a strategy for developing the ANN. General implementation issues are addressed, technology issues are examined, and an implementation plan is presented.

Section 7 Recommendations. presents the short- and long-term conclusions of the study.

The final section, "Appendixes," contains: (1) a list of the documents reviewed, (2) a summary of each document, (3) site visit questionnaires, (4) interview summaries, and (5) an acronym list.

2. STUDY APPROACH

This section outlines the formal approach taken by the study team, and is divided into two subsections. The first subsection describes the methodology. The second describes the information sources used during the information elicitation phase of the study.

2.1 METHODOLOGY.

The methodology is the general approach that was taken by the study team. The methodology applied to the AF study consisted of five fundamental phases, as follows

a. Information Elicitation. The most common methods of information elicitation were observation and sampling from existing records, interviews, or group discussions, and questionnaires or forms.

b. Analysis. This phase examined the data gathered during the information elicitation phase. The results of the analysis were an understanding of AF operations, the development of criteria for ranking alternate applications, and the identification of potential applications.

c. Technology Assessment. This phase identified the various advanced technologies such as ES, Neural Network (NN), FL, and genetic algorithms (GA) that can be used in the improvement of AF operations. Tools were selected to cover a range of hardware and costs Strengths and weaknesses of each tool were evaluated and documented.

d. Advanced Analysis. This phase included a detailed analysis of the identified potential maintenance applications to determine which applications were feasible and justified. The results of this phase were the ranking of applications, and an implementation plan for the applications that were determined to be the best alternatives.

e. Recommendations. This phase was the final determination of the appropriate technologies to be applied to AF operations.

2.2 INFORMATION SOURCES.

Information elicitation allows for the gathering and understanding of information from many sources. Three types of information sources were used during the study, as follows:

a. Documents. The written sources of information ranged from introductory documents to more detailed manuals. All the documents that were reviewed are listed in appendix A, while appendix B contains detailed summaries of these documents.

b. Interviews. Interviews were an integral part of the study. The study team interviewed both supervisors and maintenance staff at the Memphis General National Airspace System (GNAS) Sector Office and Air Route Traffic Control Center (ARTCC), and the Memphis and Nashville GNAS Sector Field Offices. Each interview was one to two hours in length. Participants were asked a similar set of general questions tailored to accommodate his or her specific knowledge area and expertise. The basis of these questions was a checklist similar to the one illustrated in figure 2.2-1. Appendixes C and D contain a list of questions used in the interviews and interview summaries.

c. On-site Observations. During each interview, the study team observed the day-to-day operations of the supervisors and technicians. These observations allowed the team to gain insight into the environment in which the interviewees worked to decide where best to implement any AI technologies.

3. CURRENT FAA AF MAINTENANCE OPERATIONS.

This section presents an overview of current AF maintenance operations. The material presented in this section is based on the results of the information elicitation and analysis phases. FAA AF maintenance operations have been divided into nine separate areas:

a. Corrective Maintenance (CM)

Checklist, Selecting Problems

Overall Objective of Project

R&D/Proof of Concept
Specific benefit to organization

Problem/Opportunity

- How is the problem currently being solved?
- What opportunity is being missed?
- What is the problem or missed opportunity costing the organization?
- Which of the following will the system do?

  - O Capture and distribute knowledge
  - O Preserve knowledge
  - O Integrate the knowledge of several people
  - O Facilitate faster decisions
  - O Facilitate better decisions
  - O Facilitate consistent decisions
  - O Make bookkeeping more efficient
  - O Provide better approach to software development
  - O Provide better approach to updating and maintaining
  - O Reduce training costs
  - O Reduce labor costs

Is the Problem/Opportunity Well Defined?

- Is there expertise? Would an expert be available for 3-6 months?
- Is there documentation?
- How long does the task currently take?
- What does a good solution look like?
- How consistent are the current solutions?

Developing a System

- How would the system be developed? On what hardware? On what software?
- Who would manage the project?
- What kinds of budget constraints do you have?
- Do you have schedule constraints? A completion deadline?
- Who is sponsoring the effort?
- Do you have the support of senior management?

Fielding a System

- Who are the users? Do they currently use computers?
- How would the system be fielded? On what hardware? On what software?
- Would the system be integrated with existing software? How?

FIGURE 2.2-1. A CHECKLIST USED AS A BASIS FOR DEVELOPING INTERVIEW QUESTIONS

b. Alarm Processing
c. Monitoring
d. Administrative Functions
e. Information Retrieval
f. Problem Resolution
g. Certification
h. Training
Periodic Maintenance (PM)

These nine areas of maintenance operations form a set of components that together describe all aspects of AF maintenance operations. These nine areas are further discussed in section 4.3.

3.1 THE AF SYSTEMS AND MAINTENANCE OPERATIONS FIELD WORK FORCE.

This section describes the organization of the AF Systems and Maintenance Operations field work force. The organization is described in terms of the locations in which personnel conduct their activities, and the types of work they perform.

3.1.1 AF Systems and Maintenance Operations in the ARTCC.

There are 21 ARTCCs in the United States (23, including combined CEnter Radar APproach control (CERAP) at Honolulu, Hawaii and San Juan, Puerto Rico). Each has its own airspace, and is responsible for the en route control of aircraft. Control is achieved through data from long range radars and air-to-ground communications facilities.

The AF Systems and Maintenance Operations personnel in the ARTCC are responsible for the monitoring and control of facilities that provide service to the center. They are also responsible for the maintenance of facilities within the center grounds.

The AF Systems Operations organization in the ARTCC consists of seven NAS Operations Managers (NOMs), each of whom are supported by two NAS Area Specialists. At any given time, one or two NOMs will be on duty, along with their associated NAS Area Specialists. (These individuals maintain rotating shifts.) They have the primary responsibility for the monitoring and control of the center's facilities.

The Maintenance Operations organization within the center consists of four to six work units whose personnel report to a unit supervisor. The Maintenance Operations organization is responsible for the maintenance of all facilities on the center grounds. Six possible technical specializations exist, as follows:

a. Radar Data Processing
b. Flight Data Processing

c. Flight Service Data
d Environmental
e. Interfacility Data
Communications/Telecommunications Maintenance and Operations

3.1.2 AF Systems and Maintenance Operations in the GNAS Sectors.

Each ARTCC is supported by two or three GNAS Sectors; approximately 56 exist, nationwide. Each sector is responsible for the maintenance, monitoring, and control of NAS facilities located within its designated geographic area. Administrative functions within each sector are carried out at the Sector Office.

It should be noted that the AF Systems and Maintenance Operations organizations in the GNAS Sectors are changing. The material that follows represents the structures that will exist following the current transition.

The Systems Operations organization is located at the Sector Office. This includes a NOM and several GNAS Maintenance Control Center (GMCC) NAS Area Specialists. In addition to their responsibilities of monitoring and control of facilities within the GNAS Sector, they may perform remote maintenance activities. They also have a major responsibility for the coordination of maintenance activities with the Sector Field Offices (SFO) and the relevant ARTCCs.

GMCC NAS Area Specialists have one of the three technical specialties, as follows

a. Navigational Aids/Communications.
b Radar/Communications/Automation
Environmental.

However, they also have a broad-based general knowledge of the areas outside their specialty.

The Maintenance Operations organization within a GNAS Sector consists of 4 to 5 SFOs, each of which consists of a manager and 6 to 40 technicians. The technicians are normally organized into three or more work units, by specialty. Each work unit is headed by a unit supervisor.

SFOs are responsible for the maintenance of facilities within their designated geographic areas.

3.2 AF SYSTEMS AND EQUIPMENT

AF is composed of many systems and equipment that have evolved over the years There are five major systems maintained by AF personnel:

a. Radar Systems
b. Computer Systems
c. Navigational Aids Systems
d. Environmental Systems
e. Communication Systems

Systems within each area vary widely in complexity, age, and technology. Because there are several systems, the following subsections discuss only a few representative systems of each area. The AI applications discussed later in this report may be developed for all systems.

3.2.1 Radars.

Radar systems are used to determine the distance and bearing of aircraft in order to track and maintain proper separation. There are two basic radar systems used by the FAA:

a. Air Surveillance Radar Systems (ASRS) provide the controller with a map-like radar display that consists of all aircraft radar echoes within detection range of the radar facility. There are two types of ASRS:

1. Airport surveillance radar (ASR) provides terminal controllers with radar coverage of the airspace up to a 60-mile radius of a given airport.

2. Air Route Surveillance Radar (ARSR) is similar to the ASR, but provides the controllers at the Center with long-range radar coverage of about 200 miles.

b. Airport surface detection equipment (ASDE) is a surveillance system that scans the airport surface for radar targets. It is designed for short-range operation and provides the terminal controller with positive airport ground control of aircraft.

3.2.2 Computers.

AF personnel maintain a variety of computer equipment in both the ARTCC and GNAS environments. Some representative examples of computer equipment include:

a. Central Computer Complex Host (CCCH) is an IBM 3083, located in an ARTCC which uses existing software from another computer system. Current systems are 10 times faster than its predecessors and have 5 times more data storage capacity. The system processes and routes data such as flight plans, flight plan amendments, weather data, and radar data to other subsystems.

b. Automated Radar Terminal System (ARTS) IIA and IIIA carry out the computer processing of short range radar data.

c. Computer Display Channel (CDC) accepts and stores display data messages received from the CCCH, and routes the display data to the appropriate air traffic controller displays. The CDC also accepts, stores, and inputs all controller-entered data.

d. Maintenance Processor Subsystem (MPS) is a Tandem computer used for transaction processing of remote maintenance, monitoring, and control information. It is the host for the Maintenance Management System (MMS) used for logging maintenance and control activities, and the Interim Monitor and Control Software (IMCS). Technicians use the MPS in carrying out remote maintenance, monitoring, and control functions.

3.2.3 Navigational Aids.

Navigational aids serve to guide pilots during the en route phase of flight, and during their approaches to airports. Some representative navigational aids are as follows:

a. Instrument Landing System (ILS) is a precision all-weather system for landing aircraft via the use of radio instruments. The ILS provides a path for exact alignment and descent of an aircraft on its final approach. The ILS consists of:

1. A series of marker beacons which provides accurate radio fixes along the approach path to the runway. Markers are either inner-, middle-, or outer-marker beacons

2. Glideslopes which provide vertical guidance along the correct descent angle to the proper touchdown point on the runway.

3 Localizers which provide horizontal guidance to the airport runway

b. Lighted systems which provide visual ground contact, runway identification, guidance, and hazard information to pilots. Some types of lighted navigational aid systems are:

Approach lighting system (ALS)
Omnidirectional ALS.

3. Medium Intensity ALS with Runway Alignment Indicator Lights.

c. Precision Approach Path Indicator which provides accurate visual approach path information to pilots of landing aircraft.

d. VHF Omnidirectional Range (VOR) and Tactical Air Navigation (TACAN) systems which are often co-located (in which case the designation VORTAC is used). The VOR provides VHF-bearing reference signals that define distinct airways distributed radially around the VOR. When avionics are tuned to the VOR, they will show the position of an aircraft relative to the selected radial. TACAN systems are used primarily to provide the capability for an aircraft to determine the distance between itself and the TACAN system ground station. Analogous to the VOR, the TACAN system also transmits bearing reference signals that are used primarily by the military.

3.2.4 Environmental Systems.

Environmental systems play an important role in maintaining reliable facility performance. Environmental systems are separated into four categories:

a. Power Conditioning Systems (PCSs) process unregulated input power into uninterruptible output power. PCSs can be either AC to DC or DC to DC.

b. Heating, Ventilating, and Air Conditioning (HVAC) equipment maintains the atmosphere of an enclosure at the desired temperature, humidity, and air purity.

c. Engine generators are standby power sources that are either gasoline, propane, or diesel fueled, and are used to furnish power to a facility during a commercial power failure.

d. Electrical distribution systems include primary power distribution systems, underground power systems on airports, building electrical distribution systems, and interconnecting communication cables.

3.2.5 Communications.

Communications are an integral part of ATC. Some communications systems of concern to AF personnel are as follows:

a. Remote Center Air/Ground (RCAG) is an unattended, remote-controlled facility that provides direct voice communications between the en route controller and the aircraft pilot.

b. Modems handle all flight data, data information between Centers, and radar information from remote radar sites.

c. Remote Transmitter/Receivers (RTR) and Remote Communications Outlets (RCO) provide a means for communication between a pilot and a terminal controller, and a pilot and a Flight Service Station, respectively.

d. BackUp Emergency Communications (BUEC) is the Center's backup system for air-to-ground radio communications.

3.3 TECHNICIAN TASKS.

The technician plays an integral role in maintaining a safe and operational facility. His or her day-to-day tasks can be separated into four categories:

a. PM consists of tasks such as daily, weekly, monthly, quarterly, semiannual, and annual maintenance checks of various equipment. To the extent that RMM has been implemented, PM may also involve monitoring and control of equipment.

b. CM consists of the repair of failed equipment.

c. Administrative Functions consist of logging maintenance activities and completing other reports that must be filed.

d. Certification is the process of formally determining that a given system is fully operational, and is within its design parameters. There is a certification schedule, similar to the PM schedule, but certification of a system may also be required at other times (e.g., following a CM procedure).

The FAA technician is supplied with a set of written procedures to perform these tasks. As a technician becomes more experienced, the written procedures are used less.

3.4 TECHNICIAN TRAINING.

The FAA provides the technician with entry-level and advanced training through several channels:

a. The FAA Academy in Oklahoma City conducts training in four major specialized areas:

1. Airports.
2. Flight Standards.

3 Air Traffic (AT).
4 Systems Maintenance

FAA Academy training is provided in two ways:

(a) Resident Training. This is a formal classroom instruction that consists of entry-level, refresher, and advanced training courses in many specialized fields.

(b) Non-Resident Training. This consists of correspondence study programs that are designed to either prepare the technician for resident courses, be used as refresher training, or provide further development for the employee.

b. On-The-Job-Training (OJT). OJT is an informal type of training that relies on the more experienced technician to teach the less experienced technician correct procedures to use in a variety of situations.

c. Computer-Based Instruction (CBI). CBI is administered by the FAA Academy and may be conducted at the academy, Sector, or SFO. All CBI courses are self-paced, but the technician has a maximum allotted time for completing the course.

3.5 PROBLEM DETECTION AND SOLUTION

Problem detection and solution are integral parts of current FAA AF maintenance operations. The process of problem detection and solution is separated into three parts: problem recognition, problem source, and problem resolution. This process will be discussed further in section 4.

3.6 AF OPERATIONS EVOLUTION AND SUMMARY

The FAA is currently implementing the RMMS to allow maintenance, which would otherwise require a technician on-site, to be conducted from a central location. With RMMS, equipment downtime and operating costs will be significantly reduced. RMMS will provide an interface between specialists at Maintenance Control Centers (MCCs), work centers, and unmanned remote facilities. This requires the automation of various tasks associated with maintenance.

After analyzing AF maintenance operations, several areas were identified as potential domains for ES applications. The following sections discuss, in detail, applications suited to AI technology for maintenance, monitoring, and control. These sections also detail which AI technologies, tools, architectures, and algorithms are most suitable for each application, and which architectures and tools are appropriate for augmenting personnel skills.

4. IDENTIFICATION OF AI APPLICATIONS

This section identifies and analyzes the AI applications for the FAA AF maintenance operations. An introduction to AI is provided to familiarize the reader with the terms associated with the various AI technologies. The remainder of the section identifies 24 possible AI applications within 10 principal activity areas, and analyzes the benefits of the application areas.

Figure 4-1 provides an overview of the process used to select AI applications. During this process, the requirements and knowledge of the managers, supervisors, technicians, and documents are systematically synthesized, and filtered into a final set of ES applications. This section describes each step of this process.

4.1 INTRODUCTION TO AI.

The reader may be unfamiliar with many terms associated with AI technology. This section presents a brief introduction to AI and its related fields. There is a short definition of AI and an examination of ES and the techniques used to build them. This section concludes with a list of the general activities that AI applications perform.

4.1.1 Definition of AI.

AI is a field offering solutions to problems that resist solution by procedural methods. For this study, AI is defined as a growing set of computer problem solving techniques. AI is being developed to imitate human thought or decision-making processes to produce the same results as these human processes.

AI has many fields including:

a. KBES
b. ANN
c. Expert Neural Network (ENN)
d. Natural Language Processing (NLP)
e. FL
   GA
g. Machine Learning (ML)
h. Distributed Artificial Intelligence (DAI)

Our emphasis in this study is placed on KBES, ANN, ENN, and NLP and their applications to AF. Therefore, the remainder of this section will concentrate on the fundamentals of these technologies as they relate to the applications.

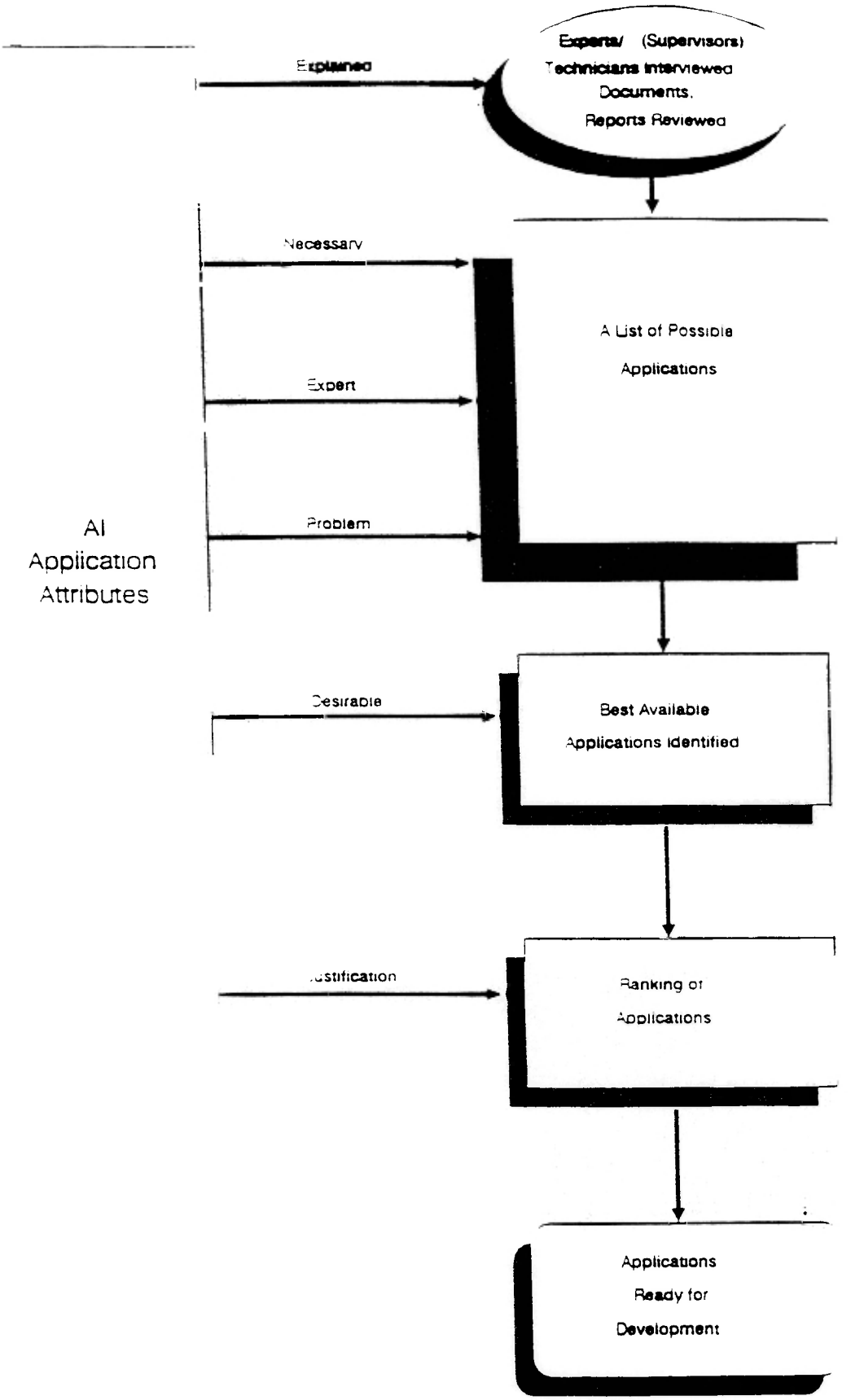

FIGURE 4-1 PROCESS USED TO SELECT AI APPLICATIONS

Conference proceedings, technical journals, vendor reports, and some unpublished applications encompassing 1984 to 1992 were surveyed. KBES, or simply ES, has been used extensively (see table 4.1.1-1). ANN is being used to reduce the costs of knowledge acquisition. ENN is being employed in diagnostics where explanations and lines of reasoning are wanted. Elemental applications of FL, ML, DAI, and GA were also discovered in the literature. While still exploratory in nature, apparently, they are the technologies of the future.

4.1.2 KBES or ES.

ES is one of the most successful areas of AI today. An ES is a computer-based system that uses knowledge, facts, and reasoning techniques to solve problems that normally require the abilities of human experts. The power of an ES comes from both knowledge contained in the system, and the inferencing methods used to manipulate this knowledge.

As figure 4.1.2-1 shows, all ESs contain three basic components: a knowledge base, an inference engine, and a user interface.

a. Knowledge Base. A knowledge base contains expert-level knowledge on a particular subject. Knowledge is obtained from documents and one or more human experts, and is stored using a knowledge representation technique that is inherent to the knowledge. Two knowledge representation techniques are of interest at the FAA: rules and frames.

1. Rules are the most common knowledge representation method. Rules provide a formal way of representing recommendations, directives, or strategies, and are expressed in terms of condition(s)-action, or if-then pairs:

IF (condition(s))
THEN (action)

Example:

IF a flammable liquid was spilled
THEN call the fire department.

In a rule-based ES, the domain knowledge is represented as sets of rules that are checked against a collection of facts about the current situation. When the condition of a rule is satisfied, the action portion of the rule is performed.

2. A Frame is a data-structure for the collection of attributes (name, color, size) that describes a given object. Each attribute is stored in a slot (name), which may contain values (Smith, red, small), rules, or procedures. As figure 4.1.2-2 shows, a frame is a

TABLE 4.1 -1 EXAMPLES OF EXPERT SYSTEMS FOR DIAGNOSTICS AND MONITORING

System	Task Performance	AI Method	Type Status	Environment
Advanced Maintenance Facility (AMF)	Finds faults in TXE4A telephone exchanges	Basically a production system	Diagnostic, field tested	16-bit Micro: UNIX, SAGE and LISP
Central Office Maintenance Printout Analysis and Suggestion System (COMPASS)	Finds faults in GTE's No. 2 EAX telephone exchanges	Mix of Frames, rules, LISP and active values	Diagnostic, field tested	Xerox 11xx, KEE and INTERLISP-D
Network Maintenance Expert Systems	Finds network faults in GTD's No. 5 EAX telephone exchanges	Forward-chaining rules	Diagnostic, research prototype	Xerox 11xx, KEE and INTERLISP-D
Switching Maintenance Analysis and Repair Tool (SMART)	Finds faults in 1 AESS telephone exchange on demand from SCC personnel	Production system with certainty factors	Diagnostic, field tested	Xerox 1109-PC, AT, S.1 and LISP-S.1 and C
Automated Cable Expertise (ACE)	Trouble-shoots telephone company local loop plant	Forward-chaining rules	Diagnostic, commercial prototype	AT&T3B2: UNIX OPS4-LISP-C
Real-Time Systems (RTS)	Filters 1 AESS alarms in a network and passes important ones on to SMART for analysis	Forward-chaining rules	Interpret, research prototype	Symbolics; KEE and LISP
Network Management Expert System (NEMESYS)	Reviews traffic completion data and suggests traffic control changes	Mix of rules, procedures, and active values	Monitor, research prototype	Symbolics; KEE
Network Troubleshooting Consultant (NTC)	Finds problems in DECnet and Ethernet LANS	Forward-chaining rules with confidence factors	Diagnostic, field tested	VAX, EXPERT
Trouble-shooter	Finds problems in Datakit Centrex-style LANs	Rules with conditional probability adjustment learning	Diagnostic, research prototype	AT&T3B2-PC7300: Franz LIPS
Net/Advisor	Monitors real-time network status and suggests actions to take when problems are diagnosed	Back-chaining rules (PROLOG with LISP interface code)	Diagnostic, commercial product	Symbolics; PROLOG and LISP
COM-NET	Performs fault "sectionalization" of digital data service and analog circuits (fault isolation)	Object-oriented programming	Diagnostic, research prototype	LASER
Communication Network Trouble-shooting Expert Systems	Diagnoses failures on private switching packet networks	Rules	Diagnostic, research prototype	LISP and MORSE
Integrated Communications Officer (INCO)	Performs Space Shuttle telemetry monitoring by expert systems in mission control	Rule based	Monitoring and control field tested	LISP
Fault Isolation System (FIS)	Does electronic troubleshooting project	Model based	Diagnostic, research prototype	LISP
System Operations Computer Control System (SOCCS)	Is a real-time alarm analysis advisor	Rule based	Monitoring and control field tested	T1 Explorer

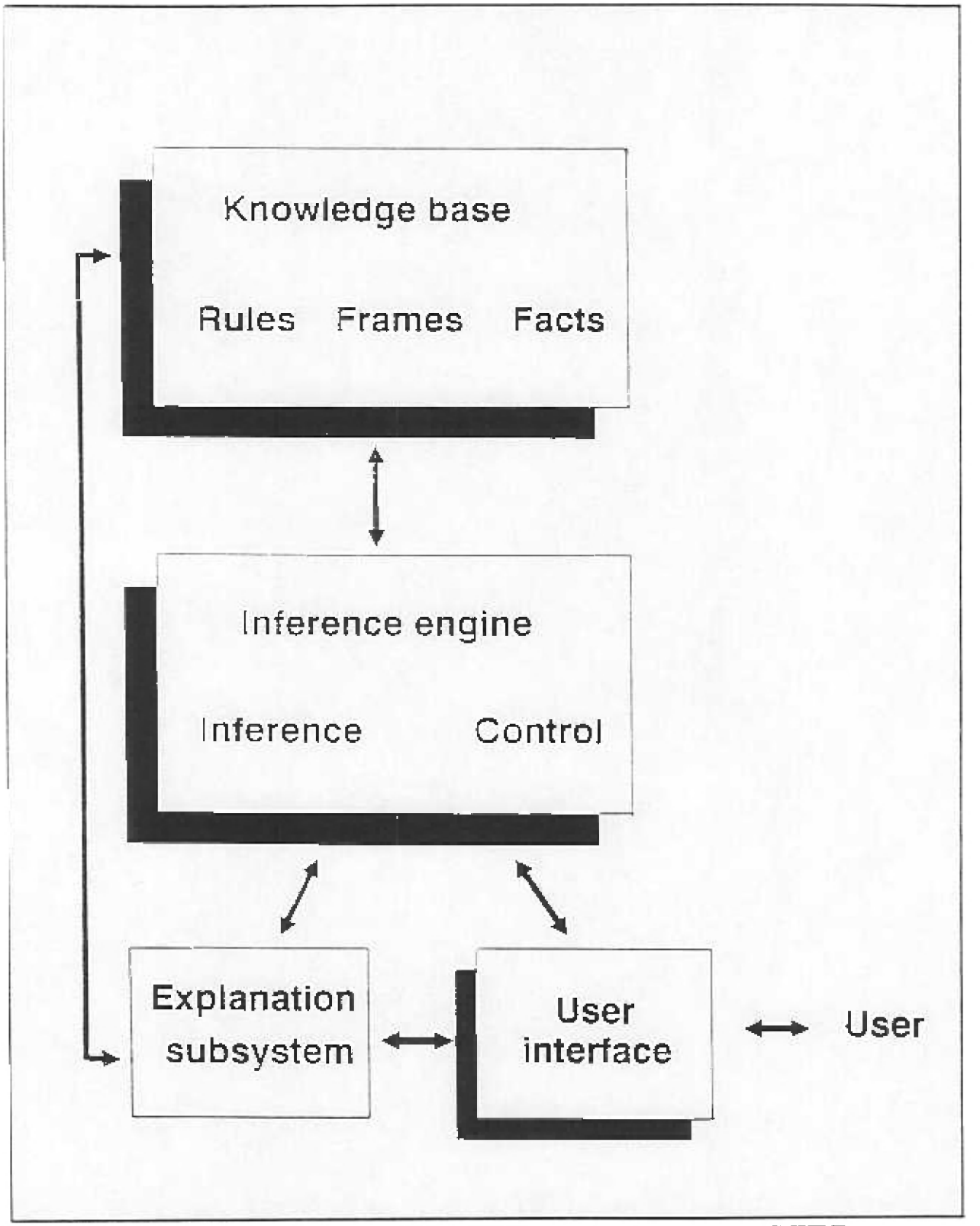

FIGURE 4.1.2-1 KNOWLEDGE-BASED EXPERT SYSTEM ARCHITECTURE

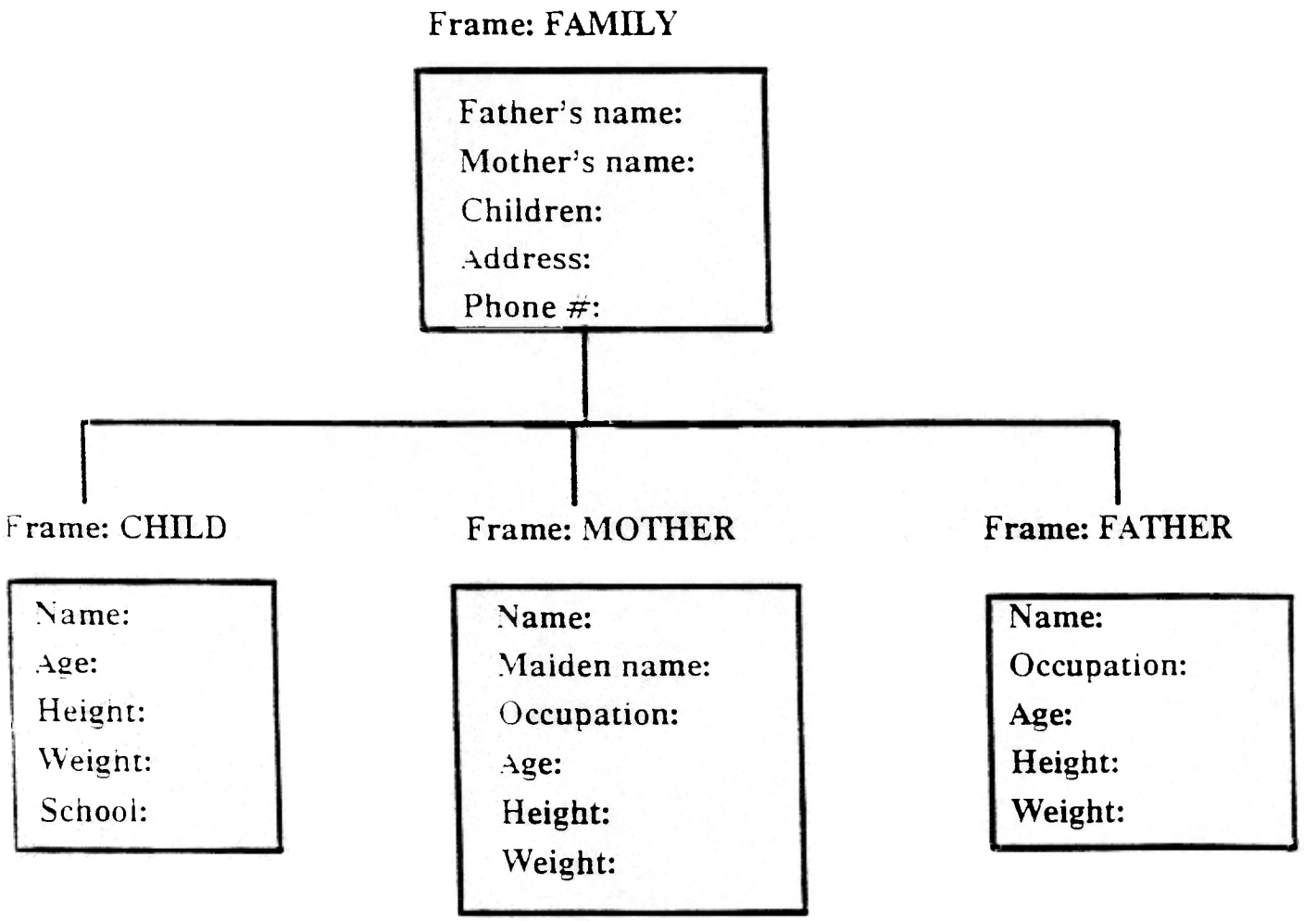

FIGURE 4.1.2-2 FRAME REPRESENTATION

network of nodes and relations organized in a hierarchy. The topmost nodes represent general categories and the lower nodes, more specific subcategories. Frames are used when the knowledge can be represented in chunks, or blocks of data.

Each slot may have any number of procedures attached to it. Three fundamental types of procedures are:

(a) If-Added Procedure: executes when a value is added to a slot.
(b) If-Removed Procedure: executes when a value is removed from a slot.
(c) If-Needed Procedure: executes when a slot needs a value, but one is not present.

Thus, a frame-based system uses knowledge through the execution of a variety of procedures and rules.

b. Inference Engine. An inference engine is the portion of an ES that contains the strategies for controlling the selection and application of knowledge and facts in the knowledge base. In short, it is the part of the ES where the reasoning takes place.

This mechanism uses the information provided to it by the knowledge base and the user, to infer new facts. In so doing, it is simulating the deductive thought processes of a human. The new facts that are generated by the system might be the advice the system user is seeking.

The inference engine also supports the explanation or justification of recommendations formulated by the ES. This means that a user can ask the ES "how" a conclusion was reached, or "why" a question was asked.

c. User Interface (UI). A UI allows communication between the system user and the system. It allows the user to enter facts and questions about a particular situation. It also permits the ES to respond to these requests and query the user for more information.

To simplify communication, the UI may employ menus, dialogues, graphics, or other appropriate vehicles. ESs for natural language processing are often used as part of the user interface for another ES.

4.1.3 ES Application Activities.

As ESs have been developed over the years, their activities have been grouped into the categories described next. These activities are not used to categorize applications because almost all ESs perform two or more of these activities.

For instance, a diagnostic ES usually contains both diagnosis and debugging activities. The following are 10 activities performed by ESs:

a. Interpretation refers to hypothesis selection performed on measurement data and corollary information. These systems typically use sensor data to infer situation descriptions.

b. Prediction involves the examination of situation information and the forecast of future situations. It can be looked at as inferring future consequences of current decisions. This includes the activities of observing situations and correlating common aspects of a situation with other situations that have been previously experienced.

c. Diagnosis encompasses identifying, investigating, and analyzing the cause or nature of a problem or condition. During diagnosis, the system not only interprets data to determine the difficulty, but also seeks additional data when such data are required to aid its line of reasoning.

d. Design constitutes configuring a system from a set of alternate possibilities, under constraints. In short, it is the mental task of creating, fashioning, or constructing according to a developed plan.

e. Planning is the activity of establishing goals, policies, and procedures to determine what actions should be performed to achieve a desired end.

f. Monitoring involves observing an ongoing situation for its predicted or intended progress, and alerting the user if there is a departure from normal activity.

g. Debugging is the activity of recommending or prescribing remedies for a problem such as time constraints, resource availability, and consequences.

h. Repair is the execution of a plan to correct a malfunction.

i. Instruction entails the imparting of knowledge or skill by systematic means or methods. This activity teaches the student to diagnose, debug, and make repairs.

j. Control activities govern complete system behavior. They are a combination of monitoring a system, and taking appropriate actions to achieve the desired results.

4.1.4 ANNs.

ANNs are computational systems, either hardware or software, that mimic the computational abilities of biological systems by using large numbers of simple, interconnected artificial neurons (see figure 4.1.4-1). Artificial neurons are simple emulations of biological neurons; they receive information from sensors or other artificial neurons, perform very simple

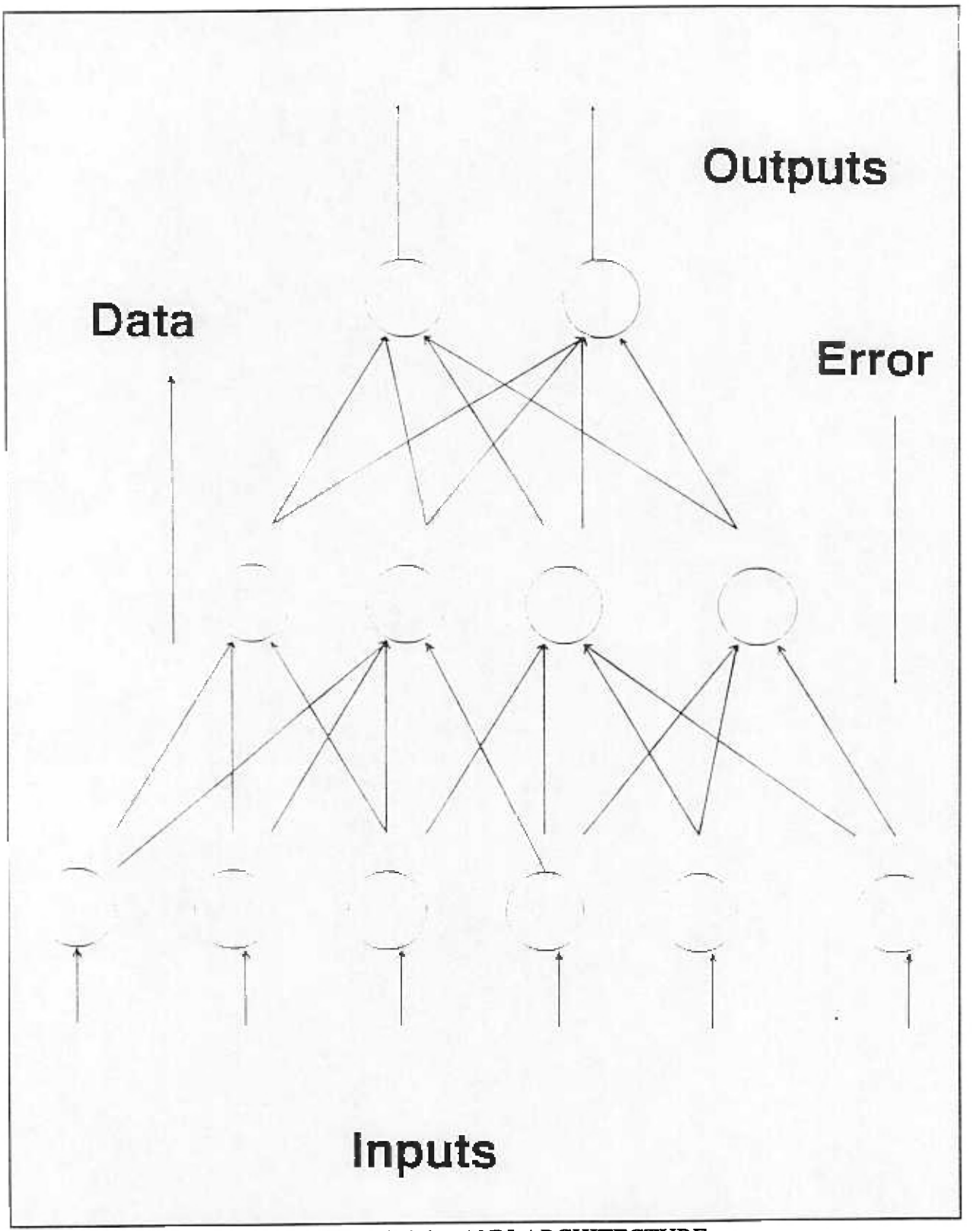

FIGURE 4.1.4-1. ANN ARCHITECTURE

operations using these data, and pass the results on to other artificial neurons. ANNs operate by having many neurons process data in this manner. The networks use logical parallelism combined with serial operations. The three main characteristics that describe an ANN and contribute to its functional abilities are structure, dynamics, and learning.

ANN is an emerging technology that can significantly enhance many applications. They are being adopted for use in a variety of commercial and military applications that range from pattern recognition to optimization and scheduling.

ANNs can be developed within a reasonable period and can often perform tasks better than other, more conventional technologies (including KBES). When embedded in a system, ANNs exhibit high fault tolerance to system damage.

4.1.4.1 ANN Application Activities

As ANN systems have been developed over the years, their activities have been grouped into the 12 categories as follows:

a. Maintenance, monitoring, and control.
b. Robust pattern detection (spatial, temporal, and spatial-temporal).
c. Signal filtering.
d. Data segmentation.
e. Data compression and sensor data fusion.
f. Database mining and associative search.
g. Adaptive control.
h. Optimization, scheduling, and routing.
i. Complex mapping and modeling complex phenomena.
j. Adaptive interfaces for man-machine system.
k. Quality control.
Training.

These activities are not used to categorize applications because almost all NN systems perform two or more of these activities. For instance, a signal filtering neural system usually contains alarm processing, diagnosis, and debugging activities. Some applications of well known NN architectures are shown in table 4.1.4-1.

4.1.5 Expert Neural Networks (ENNs).

ENNs combine KBES and ANN to provide solutions that neither system alone can provide. Both KBES and ANN have some disadvantages over other AI applications. For example, ANN cannot provide explanations and KBES usually requires domain expertise, which may be scarce. By combining these two technologies one can complement their capabilities and build a more desirable system.

TABLE 4 5-1 SOME WEL KNOWN NETWORK APPLICATIONS

Network	Year(s)	Developers	Primary Applications	Advantages	Disadvantages
ADALINE/MADALINE	1960	B. Widrow	Adaptive signal filtering, adaptive equalization.	Fast, easy to implement, can be done using analog or VLSI circuitry.	Linear relationship between input and output. Only linear separable classification spaces possible.
Adaptive Resonance Theory	1963	G. Carpenter & S. Grossberg	Pattern recognition	Able to learn new patterns, form new pattern categories, and retain learned categories.	Nature of categorical exemplars may change with learning
Back-Propagating Perceptrons: Basic	1974-1986	P. J. Werbos, D. Parker, D. Rumelhart	Pattern recognition, signal filtering, noise removal, signal/image segmentation, classification, mapping, adaptive robotic control, data compression	Fast operation. Good at forming internal representations of features in input data or classification and other tasks. Well studied. Many successful applications	Long learning time.
Back-Propagation of Utility, Function, Through Time	1974	P. J. Werbos	Maximize performance index or utility function over time, neurocontrol (e.g., robotics).	Most comprehensive neural approach for model-based prediction and/or control.	Can use only after differentiable model identified, must adapt off-line if model is dynamic, and assumes model is exact.
Neocognitron	1975-1982	K. Fukushima	Recognition of hand-drawn character and other linear-outing figures.	Able to perform scale, translation and rotation invariant pattern recognition.	Requires many processing elements and layers, complex structures, scaling issues for real-world use still need to be resolved.
Brain-State-in-a-Box	1977	J. Anderson	Autoassociative recall	Possibly better performance than Hopfield network.	Incompletely explored in terms of performance and applications potential.
Learning Vector Quantization	1981	T. Kohonen	Autoassociative recall (pattern completion given partial pattern), data compression	Able to self-organize vector representations of probability distributions in data. Rapid execution after training is completed.	Unresolved issues in selecting numbers of vectors to use and length of time for appropriate training. Slow in training.
Self-Organizing Topology-Preserving Map	1981	T. Kohonen	Complex mapping (involving neighborhood relationships), data compression, optimization	Able to self-organize vector representations of data with a meaningful ordering among the representation.	Unresolved issues in selecting numbers of vectors to use and length of time for training. Slow in training.
Hopfield	1982	J. Hopfield	Autoassociative recall, optimization	Simple concept, proven dynamic stability, easy to implement in VLSI.	Unable to learn new states (fixed weights for discrete Hopfield), poor memory storage, many spurious states returned.
Boltzmann Machine, Cauchy Machine	1984-1986	G. Hinton, T. Sejnowski, D. Ackley, H. Szu	Pattern recognition (images, sonar, radar), optimization	Able to form optimal representation of pattern features. Follows energy surface to obtain optimization minima.	Boltzmann machine has a very long learning time. Cauchy machine offers faster learning.
Boundary Contour System	1985	S. Grossberg, E. Mingolla	Low-level image processing	Biologically-based approach to excellent segmentation.	Complex, multilayered architecture
Recurrent	1987	Almeida, Pineda	Robotic control, speech recognition, sequence element prediction	Best network so far for classifying, mapping time-varying information.	Complex network, may be difficult to train and optimize.
Time-Delay	1987	D.W. Tank & J. J. Hopfield	Speech recognition	Performance equivalent to best conventional methods, faster operation.	Fixed window of temporal activity represented, responds awkwardly to differences in scale of input.
Bidirectional Associative Memory	1987•.	B. Kosko	Heteroassociative (content-addressable) memory	Simple, clear learning rule, architecture, & dynamics. Clear proof of dynamic stability.	Poor storage capacity, poor accuracy in retrieval.
Radial Basis Function Network	1987-1988	Multiple Researchers	Classification, mapping	Network with single hidden layer of RBF neurons. Performs equivalent to basic back-propagation network with two hidden layers.	Not yet known.
Functional Link Network	1988	Y. H. Pao	Classification, mapping	Only two layers (input and output) needed. Faster to train.	No clear way to identify functions for functional links.

Combining KBES and ANN technology is not easily achieved, but the following list describes methods to accomplish this task:

a. Divide and Conquer.
b. Embedded NN.
c. Explanation by Confabulation
d. Artificial Expert.

Several applications have been reported in the International Joint Conference in Neural Networks Proceedings. Almost everyone involved with ANN is currently trying to develop ENN technology.

4.1.5.1 ENN Application Activities.

Most ENN applications are emerging from the activities in which explanation is essential. These include:

a. Quality control.
b. Fraud detection.
c. Maintenance, monitoring, and control.
d. Adaptive signal processing.
e. Prediction.
f. Target recognition.

4.1.6 NLP.

NLP consists of both natural language generation and natural language understanding. Natural language generation involves tasks such as composing sentences and paragraphs according to rules of grammar. It also involves the selection of the most suitable words from a set of semantically similar or equivalent words. As in any written or oral communication, there are many possibilities with varying degrees of aesthetic, styles, and ability to communicate effectively and accurately. Creation and formalization of rules to perform these functions are formidable tasks. The grammatical rules alone, which impose syntactical constraints on different parts of the sentences, are difficult to define due to the infinite number of possibilities. These complexities make generation of the natural language difficult.

The natural language understanding may come from speech or text, and involve processing in the direction opposite to that of language generation. Besides the technical difficulties associated with speech processing, the task is rendered more complex by changes in voice inflection and emphasis. Often, speech contains partial sentence structures, and the meanings associated with fragmented structures must be inferred by context. There are other

problems, such as resolving ambiguities associated with sentences, which can be parsed in multiple ways. This satisfies the syntactical and sometimes semantic rules, as well as the ambiguities resulting from use of words with multiple meanings.

Though NLP has been researched for a long time, the problems have not been resolved. However, NLP is very important, and sufficient headway has been made to generate natural language dialogues in restricted domains and limited interactions.

4.1.6.1 NLP Application Activities

Over the years, NLP techniques have been used in information retrieval, education, training, and building UIs. A common activity of NLP is processing documents to report the system's activity. Subsequently, this activity is matched against the system's requirements to determine system performance. Another activity area of NLP is training, where students are taught with the help of NLP.

4.1.7 Intelligent Databases (IDBs)

IDBs are one of the recent advances in database technology. With the amount of information all over the world, IDBs have become a necessity because static databases are not efficient at retrieving information from large distributed databases. IDBs provide the following functions:

a. Tools for data analysis, discovery, and integrity control give users the ability to extract knowledge from, and apply knowledge to, the data.

b A natural interface to interact with the information

c. Extraction of knowledge instead of data, and use of inference to identify what a user needs to know.

In IDBs, the updating of information is performed as an intrinsic task by the database itself. The enhanced data and control structures needed by the database are provided by using the paradigms of ES technology.

Hypertext provides ways for more dynamic databases. Information is added dynamically without any concern for the prior structure of the database. This approach is in contrast to the highly structured approach used in static databases. Combining the efficiency and structure of relational databases with the dynamics of hypertext is a major challenge.

The dynamics of databases is increased further by using knowledge-based systems. This gives the database the ability to reason and to infer new relationships. It also provides the capability to self-modify databases and the ability to determine the interest of the user.

Indexing poses a great problem in self-modifying databases. The indexing process used must be based on concepts rather than keyword labels.

4.1.7.1 IDB Application Activities

The use of IDB is starting to grow in realistic applications. They are being used in areas that require both distributed databases and ESs. With the arrival of object-oriented programming languages, object-oriented databases have also appeared. These provide greater capabilities for building IDBs. The following are the areas in which IDBs are being used:

a. Network management that relies on different databases.
b. Building intelligent UIs.
c. Document management.

4.1.8 FL

FL is a means of managing pervasive uncertainty and impreciseness. Our day-to-day conversations are interspersed with terms such as, "often," "almost," "more or less," "very," "very much," "always," "probably," "most probably," "possibly," "never," "almost never," and others. These terms, or qualifiers, lack precise meaning. However, they are immensely useful in communication.

FL is based on the assignment of real numbers (as opposed to integers) between zero and one, inclusive to the objects belonging to a concept. For example, 85 (years) may be assigned a value of one representing the concept old, and 35 may be assigned a value of 0.3. However, a shift of context, such as the age of athletic competence, may result in an assignment of a much higher membership value of 0.7 to 35 years. Similar context shifts may be observed between people accustomed to different conditions. For example, what is warm to Eskimos may be very cold to someone from Florida. These variances among different people are often considered by a banded membership function. In other words, an object is assigned a range of membership values rather than a single value. FL has all the set theoretic operations defined (e.g., union, intersection, and negation).

However, FL does have drawbacks. The operations defined over fuzzy space are order dependent, and computation intensive. With the arrival of specialized FL chips making several thousand fuzzy computations concurrently, this technology should make great strides in maintenance, monitoring, and control. Another drawback is the subjectiveness of the assignment of numbers to objects or concepts.

4.1.8.1 FL Application Activities.

Several Japanese companies are marketing consumer appliances and industrial equipment employing controllers based on FL.

FL is being used in aircraft landing operations, helicopter landing, energy management systems, and communications network management. Recently much attention has been paid to combining ANN with FL. Some excellent results have been reported in signal processing applications.

4.1.9 ML.

Individual learning or ML involves improved performance of the tasks undertaken by the individual or system. The improvement comes through efficient use of resources, acquisition of knowledge, and adaptation to the environment. ML has become an important field of research in AI.

ML has great potential since, if we are successful in making one machine learn, we can transfer the expertise easily to other machines. This is unlike human learning in that each individual has to undergo the learning process by himself or herself. The following are various forms of learning processes:

a. Direct implantation of new knowledge.
b. Learning from instruction.
c. Learning by analogy.
d. Learning from examples.
e. Learning from observation and discovery
   Learning by acquiring.
g. Learning by restructuring knowledge.

In each instance the acquired knowledge may be represented as:

a. Decision trees.
b. Production rules.
c. Formal logic-based expressions.
d. Formal grammars.
e. Graphs and networks.
   Frames and schemas.

4.1.9.1 ML Application Activities.

ML has been applied successfully in such diverse fields as: agriculture, chemistry, cognitive modeling, computer programming, education, ESs, image recognition, medical diagnostics, music, natural language understanding, planning and problem solving, robotics, sequence prediction, and speech recognition. New techniques in ML are proving to be pivotal in scientific work where analysis of a large quantity of data is involved. ML will be an integral part of intelligent machines to be built in the future.

4.1.10 GA.

GA were invented to mimic processes observed in natural evolution. Evolution takes place due to the changes to chromosomes, organic devices for encoding the structure of living beings. A living being is created partly through a process of decoding information in the chromosomes. During the process of reproduction, chromosomes of two parents combine in a manner such that they exchange chromosomal material. The act of exchanging chromosomal material should result in preserving and combining the parental genetic material to enhance the total fitness measure of the offspring.

The operator that causes sharing of the genetic material is called crossover. There are two more operators that play a part in the evolutionary process. One is called mutation. The mutation operator selects a site in the chromosome, and replaces its value with another value. In binary string representation, it changes one to zero and zero to one. Inversion is the name of the other operator. For the inversion operator to be affected, two sites in the chromosome are selected and their values are interchanged. In other words, the alleles (which make up the chromosomes) switch positions. This is useful when the fitness function is sensitive to the relative positions of the alleles.

GA are implemented on the computer to perform in the following manner. A population base of individuals (chromosomes) is selected at 50 or 100. The chromosomes are initialized randomly. The fitness of each chromosome is evaluated. New chromosomes are created by mating current chromosomes, in other words, mutation and inversion operators are applied. Individuals with greater fitness values are given greater chances to procreate. Members of the population are deleted to make room for the new individuals. The new individuals are put in the population and are ready to procreate according to their fitness values.

GA are very much suited to adapt in a changing environment (provided the rate of change of environment is less than the rate of change of genetic material by reproduction; otherwise the system is unstable and oscillates). In a static environment, it is also good for optimizing, and this is where it has been increasingly used to solve many difficult problems that take inordinate amounts of time to be solved exhaustively.

4.1.10.1 GA Application Activities.

GA were introduced in 1970. Since then they have matured, and different versions of the algorithms have evolved to make them suitable in representation and approach to a wider variety of problems. Some interesting and representative applications are listed below:

a. GA approach to multiple fault diagnosis.

b. The use of GAs in the parametric design of aircraft.

c. Dynamic anticipatory routing in circuit-switched telecommunications networks.

d. Genetic synthesis of NN architecture.

e. Schedule optimization using GA.

Automated parameter tuning for interpretation of synthetic images.

g. Interdigitation: a hybrid technique for engineering design optimization employing GAs, ESs, and numerical optimization.

h. The traveling salesperson and sequence scheduling: quality solutions using genetic edge recombination.

This is a mere sample of scores of applications reported in the literature and biennial conference proceedings. [1-9]

4.1.11 DAI.

AI systems' solutions and actions are easier to comprehend since a more humanistic-like approach is used to produce them: AI systems are often partners in the problem-solving process. DAI systems are a class of systems that allow several autonomous processes, called agents, to perform globally coherent intelligent acts solely through local computation and interprocess communication.

4.1.11.1 DAI Application Activities.

DAI is being used in areas where the system does both local and remote processing. It is being used in network management, congestion control, and routing. It can also be used in weather forecasting, airline scheduling, and maintenance of AF. If a technician is repairing a system in Los Angeles, he or she can query information relating to that system from the knowledge base at another facility to help solve the problem.

4.2 CRITERIA FOR SELECTION OF AI APPLICATIONS.

The following questionnaire was used for the selection of AI applications for maintenance, monitoring, and control. This questionnaire was prepared for on-site interviews to address the requirements of the selection criteria.

The answers to the 119 questions for selection criteria formed a basis for a two-tiered analysis:

a. Top-level analysis (this was a quick analysis)
b. Detailed analysis.

The analysis was based on:

a. The project goals.
b. Task appropriateness of the AI technology.
c. Assessment of requirements and available resources.
d. Other non-technical considerations.

In this study, the assessment of available resources was not clearly delineated since the project is in the identification stage. Also, the project payoffs are not in terms of dollar values. The answers were obtained by the subjective interpretations of the on-site observations, as well as the on-site interviews. There was a positive reaction to possible AI applications that would meet the organizational goal of making the maintenance of AF easier and more reliable. A set of simplified criteria selected for ranking the AI applications is presented in section 4.4.

4.2.1 Top-Level Analysis.

4.2.1.1 The Definition of Success.

a. Are the goals and objectives of the application clearly defined?
b. Has a clear definition of success been outlined?
c. Is the application supported with FAA goals?
d. What are the advantages of the application?
e. Is the goal a production system or a research system?
Are conventional computing techniques inadequate for solving the problem?
h. Does a need to capture the expertise exist?
i. Do the expected benefits outweigh expected costs?

4.2.1.2 The Appropriateness of the Technology.

a. Is the AI (adopted technology) approach necessary?
b. Is the AI approach sufficient?
c. Is the task similar to another task for which a successful solution exists?
d. Is the task similar to another that has proved difficult for the technology?

4.2.1.3 The Availability of Resources.

a. Is the necessary domain knowledge available?

b. Is the domain knowledge necessary?

c. Is the necessary technical and management manpower available?

d. Is the necessary funding available for hardware and software tools and related support, for training staff, and for building, validating, and fielding the final product?

4.2.1.4 Nontechnical Considerations.

a. Is the organization prepared to develop an AI application?

b. Is the problem important?

c. Are there any situations that are expected to impede solutions?

d. Are the project assumptions and constraints well formed, realistic, and defensible?

e. Are the economic, ethical, and legal considerations of the project realistic and defensible?

f. What is the match between the overall goals regarding project payoff and the risk of failure?

g. Will the AI application/technology meet the real need?

4.2.2 Detailed Analysis.

4.2.2.1 Project Goals.

a. Do conventional computing techniques appear to be unsuitable or inadequate for solving the problem?

b. Are the advantages associated with the AI technologies compatible with the project goals?

4.2.2.2 Task Appropriateness.

4.2.2.2.1 Problem Solving Knowledge: The Source of the Knowledge.

a. Does knowledge exist?

b. Have the knowledge sources been identified?

c. Does at least one recognized expert exist today?

d. Is the expert's level of experience and base of experience sufficient?

e. Are the experts better than beginners in performing the task?

f Is the expert currently practicing the selected task?

g. Does the knowledge source have a reputation within the task domain that will lend credibility and authority to the KBES, even if it captures only a portion of the knowledge?

h. Does the expertise for each task come from a single expert?

i. Is the knowledge resident in individuals, or is it a community involvement?

j. Do various knowledge sources use essentially the same approach, or is there a significant difference or idiosyncratic variability between equally valid approaches?

k. Is the expert able, at the outset of the project, to specify many of the important concepts?

l. To what extent is the knowledge source cooperative, analytical in nature, and effective in communicating knowledge, judgment, experience, and methodology?

m. Are the experts and management willing to commit the necessary resources to the application development?

4.2.2.2.2 Problem Solving Knowledge: The Nature of the Knowledge.

a. How much knowledge is involved?
b. Is the knowledge diverse?

c. Is the knowledge incomplete?
d. Is the knowledge fragmented?
e. Is the knowledge inexact or uncertain?
f. Is the knowledge ill-specified?
g. Is the knowledge unreliable?
h. Is the knowledge changing?

4.2.2.2.3 Problem Solving Knowledge: Case Specific Data.

a. Are the data explicitly identified?
b. Are the data unreliable or uncertain?
c. Are the data incomplete?
d. Can the data be inconsistent or contradictory?
e. Are the data time dependent or time varying?
f. How much data are involved?

4.2.2.2.4 Problem Solving Knowledge: A Knowledge/Data Comparison.

What are the relative quantities of problem solving knowledge and case specific data involved in the task?

4.2.2.2.5 Task Characterization: Definition and Bounding.

a. Is the task too easy or too difficult for AI technology?

b. Have conventional, algorithmic programming approaches been proven unsatisfactory?

c. Does the task require a major breakthrough in AI technology?

d. Is the task defined clearly and unambiguously, with precise definitions of input and output?

e. Is the skill required by the task taught by experts, or is it discussed in written materials?

How stable is the task definition?

g. Does the task have distinct boundaries?

h. Is the task narrowly defined?

Is the task largely and effectively separable from its contextual tasks?

j. Is the task decomposable?

4.2.2.2.6 Task Complexity and Characterization.

a. Does the task lend itself to incremental prototyping and modifications?

b. Are conventional programming tasks involved?

c. Are human faculties or skills involved in the task?

d. Does the task require expertise?

e. Does the task require primarily cognitive processes?

f. Is the task concerned primarily with reasoning about symbolic information?

g. Does the task require guessing as part of the problem solving effort?

h. Does the task require reasoning about the status or abilities of the problem solver (self-referencing)?

i. Does the task require the use of heuristics for handling a large number of possibilities, or for handling incomplete or uncertain information?

j. Does the task require a significant level of explanation or justification of results?

k. Is the task domain characterized by the use of expert knowledge, judgment, and experience?

l. Are multiple lines of reasoning necessary or useful for the task?

m. Does the task involve mostly task-specific knowledge, or a more fundamental general type of knowledge, for example, common sense, generic knowledge, or general problem-solving knowledge?

n. What is the general character or class of problem?

o. Is it unusual for the task to involve novel situations, or faults that experts have never seen before?

p. Does the problem solving task involve subdomains that are understood in widely varying levels of detail?

q. Are diverse levels of abstraction useful in the problem-solving task?

r. How many different areas of knowledge, or fields of expertise, are required to perform the task?

s. How many types of problem-solving behavior are necessary for the overall task?

t. Must the task find one solution, the best solution, or all plausible solutions?

u. Does the task involve selecting between alternative, pre-enumerable solutions, or constructing a complex, nonenumerable solution?

v. Is the interaction mode of the task primarily conversational (consultational or query-response), or transparent to users (for example, for unassisted decision-making or control)?

w. Will results be reviewed for each case, or will they automatically trigger other actions or events?

x. Are partial or occasional results useful, and are some potential errors tolerable?

y. Are task decisions or solutions generally evaluated as either right or wrong?

z. Are critical task decisions normally made from between very close alternatives, or made on the basis of levels of belief?

aa. Does the task involve significant real-time interaction with other programs or devices?

bb. Does the task require unusually large amounts of space or data storage?

cc. Does the task require the construction of an unusually complex user interface?

dd. Can an evaluator be developed for a partial solution, or for each decomposable task?

4.2.2.3 Assessing Requirements and Resources.

4.2.2.3.1 The Development Phase.

a. What is the availability of human, hardware, and software resources for development?

b. What is the cost of human, hardware, and software resources for development?

c. Are the resource personnel adequately trained for their roles in the KBES development effort?

d. Do the available hardware and software environments exhibit appropriate properties for developing a KBES solution to the candidate task?

4.2.2.3.2 The Fielding Phase.

a. Has a set of users been explicitly identified?

b. Are the users generally cooperative and patient?

c. Will the users commit the resources necessary to field the KBES?

d. To what extent will users welcome the complete system?

e. Will introduction of the KBES disturb current operations and practices, and can the system be phased into use gracefully, using progressive releases?

f. Has ongoing maintenance been planned for?

4.2.2.4 Nontechnical Considerations.

4.2.2.4.1 Evaluation.

a. Is a test available to determine correctness or incorrectness of results?

b. To what extent can validation criteria and procedures be defined for the developed AI application?

Do specific examples of problems and their solutions exist?

d. Would experts agree on whether the results are correct?

4.2.2.4.2 Economics.

a. Is the expected payoff measurable?

b. Is the expected payoff reasonable?

c. Can an opportunity measurement be made before the system is implemented, and an opportunity capture measurement be made after the system is fielded?

d. Is the cost, based on frequency and severity of wrong decisions, projected to be reduced as a result of fielding the AI application?

4.2.2.4.3 Expectations and Understanding.

a. Do all involved individuals have realistic expectations of the AI application development effort and solution?

b. Do all key management individuals support the KBES development goals and directions?

c. Has the task been agreed upon jointly by the system developers and users?

d. Have domain managers previously identified the need to solve the problem?

e. Is the project strongly supported by a senior manager for protection and follow up?

4.2.2.4.4 The Business Culture.

a. Is the need for the task expected to continue without significant change due to FAA directions for several more years?

b. Is the project on a critical path for any other development, or does it have any absolute milestones for completion?

4.2.2.4.5 Timing.

a. Is this the right time to be performing this task?

4.3 APPLICATION IDENTIFICATION.

The understanding of FAA AF maintenance operations described in section 3 was the result of the first step of the AI application selection process shown in figure 4-1. The second and third steps of the process, developing a list of possible applications, and identifying the best available applications using the analysis criteria (in section 4.2), respectively, are described in this section.

The following list of potential activities for each system was identified: (see figure 4.3-1)

a. CM
b. Alarm processing
c. Monitoring
d. Administrative functions
e. Information retrieval
f. Problem resolution
g. Certification
h. Training
i. PM

4.3.1 CM.

CM is initiated when a piece of equipment or a facility does not provide its expected level of service. The fact that the system or equipment is not performing as expected may be noticed by the system or equipment itself, or may be noticed by the user. In the former case, usually an alarm will go off. After users or monitors are aware of the problem in the system, they may initiate actions to take the system off-line, and put the backup system on-line for primary use. CM may also be performed when a facility is beginning to deteriorate, but is still performing its intended function.

CM is essentially a repetitive sequence of (1) hypothesize, (2) test, and (3) repair or replace the defective parts. The initial hypothesis is generated from the information associated with the alarm, and any other information available. A test, or a sequence of tests, is selected in order to confirm the hypothesis and narrow the problem further. After the problem is thought to be narrowed down to the line replaceable unit (LRU) level, the part is replaced or repaired. If the original symptoms go away, and the equipment appears to function normally, the CM task is complete. If some symptoms remain, a new hypotheses must be generated, and a new set of test procedures must be initiated.

Applications / AI Technology	CM		Alarm Processing	Monitoring	Administrative Functions	Info. Retrieval	Problem Resolution	Certification	Training	Preventive Maintenance
	CM1	CM2								
Knowledge Based Expert System (KBES)	X	X	X	X	X	X	X	F	X	
Artificial Neural Networks (ANN)		X	X	X		X	X	F	X	
Expert Neural System (ENS)			X	X			X	F	X	X
Fuzzy Logic (FL)	X	X	X	X						
Natural Language Processing (NLP)						X	X		X	
Intelligent Data Base (IDB)	X	X				X	X			
Distributed Arificial Intelligence (DAI)	F	F					F			F
Genetic Algorithm (GA)			X							
Machine Learning (ML)	X								X	
Hypertext					X	X			X	

Legend:

F - Future

FIGURE 4.3-1. TECHNOLOGY MATRIX

CM has been subdivided into two applications:

a. Corrective Maintenance 1 (CM1)
b. Corrective Maintenance 2 (CM2)

The differences between the two applications are primarily in the type of knowledge available for each, and the resultant problem solving approach recommended or undertaken for its development. CM1 is primarily for new equipment, such as the Digital Bright Radar Indicator Tower Equipment (D-BRITE) and ASR-9. Since the equipment has only been in the field for a short period of time, little expertise is available. CM2 is primarily for older equipment that has been in the field for an extended period of time. Lack of hands-on experience will require the technicians to rely more on fundamental technical knowledge.

This difference will necessitate fielding the CM1 application through a model-based ES design, and a rule-based ES for the CM2 application. The other important difference between the two applications is that the newer equipment contains automatic self-diagnostics to assist the technician in the diagnostic process.

Two examples in the CM scenario are given below:

Scenario 1:

The PCS is designed to power equipment without interruptions. The alternating current (AC) power is provided to the facility by the PCS. The input to the PCS is AC power from the commercial utility company; or in the case of a commercial power failure, power from engine generators. The AC input power is converted to direct current (DC) power and then, through six-legged inverters, converted back to the AC power supply. In case of interruption in the commercial power supply, the DC voltage comes from batteries, and is then inverted through the same inverters to give AC power at the output.

On one occasion, there was a malfunction in the PCS. As a result, there was no power available at the output of the PCS, even though power from the commercial utility company was available. Alarms sounded from the PCS, as well as from all the facilities that had no power.

The first step for providing power to the facilities is to bypass the PCS, and supply the utility or engine generator power directly to the equipment. This restores operation to all the services and facilities. The next step is to initiate CM on the PCS. The technician identified a failing leg of an invertor by running some tests, and probing some data points. Since the invertor leg is not an LRU, the fault was further isolated to a card by probing the data paths. At this point, the faulty card (or circuit) was replaced. The invertor was repaired, and returned to service with minimal interruptions to services and user operations.

Scenario 2:

Radar data are fed to the CDC and the Direct Access Radar Channel (DARC) systems. Both of these systems have redundant capability. DARC itself is a backup to the CDC system. The radar data are processed by these systems, and fed to the Plan View Display (PVD). PVDs are used by ATC to get information about the aircraft (e.g., aircraft type, altitude, and separation).

Suppose ATC loses all radar data on a PVD. Two alternative causes are possible:

a. The PVD has failed.
b. The PVD is not receiving data from the CDC.

The CDC and DARC perform almost identical functions and both inputs are available to the PVD. If, at the moment of failure, the active input was the CDC, then ATC will change the input to DARC. If the display is still not on, then there is evidence that the PVD is malfunctioning. In this case the sector controlled by this PVD is distributed to other overlapping sectors, and the PVD is repaired. If, on the other hand, the PVD displays data from DARC, this indicates that the PVD is functional and that the CDC is not sending data to the PVD. CDC personnel are then contacted. Tests will be performed to determine how many channels are bad. If six channels are bad then it may be that the Display Character and Vector Generator that feeds data to the six PVDs is bad. If only one PVD has a problem, then it may be a single display generator card. In other words, a sequence of hypotheses and tests continue until the fault is isolated to the LRU level.

4.3.1.1 CM1.

4.3.1.1.1 Description.

The following description is for CM1 applications for new equipment such as the ASR-9 and D-BRITE. This equipment is new and fielded at only a few sites. It also has a long useful life left. There is little equipment-specific expertise or history regarding typical failures and remedies, however, deep level expertise is available for the theory of operations from those trained at the FAA Academy or CBI. Expertise is also available for basic electronic and mechanical trouble-shooting skills. The diagnosis has to be made from principles given by manufacturer-supplied self-diagnostics. Successful AI application is critical. Success will be measured by reduction in Mean Time To Repair (MTTR), as well as savings from the reduction inventory. Equipment-generated (encoded) readouts can be made more readable by decoding into English-like text, thus improving human factors and technician performance.

A Problem Resolution File (PRF) can be stated, incorporating the field experience for the benefit of other technicians in the field. KBES development in this area is most challenging. The manufacturers' self-diagnostic aids can be expected to be adequate to trouble-shoot 70 percent of the problems at the LRU level. An additional 10 percent of the faults can be diagnosed by the technicians, while the remaining 20 percent or so of the problems represent those that were not anticipated or accounted for by the manufacturers. The KBES must do better than the manufacturer as well as the technicians. Even when such a system is designed and developed, it will be difficult to verify and validate the KBES system. Despite challenges and difficulties in developing such a KBES, it remains a critical and desirable application to be pursued. Other technologies such as ANN, ML, and IDB can be used for creating the PRF.

There are two primary ways a knowledge-based diagnostic system can be developed:

a. Model-based diagnostic system.
b. Associative diagnostic system (Rule-based diagnostic system).

Each of these has its own advantages and disadvantages.

In the model-based diagnostic system, a model is created for each type of component in the equipment. The component may be defined down to the level of assembly at which the fault needs to be identified. In other words, depending on whether chip level or card level maintenance is desired, the models of components are constructed respectively. The model essentially describes input-output behavior of the component. The model may be a simple one giving static or steady state behavior, or may encompass sophisticated techniques representing time varying responses. The interconnection of components is also represented. A model-based approach to diagnostics is more thorough than an associative approach, and is capable of spotting faults that have not been encountered before. However, model-based systems tend to be large, sophisticated, and slow because analysis needs to be performed at each level of the diagnostics.

An associative diagnostic system, on the other hand, depends largely on the solutions for problems encountered before. Its basic knowledge consists of statements such as, "if X output is bad, then suspect components W, Y, and Z." The technician has to do the rest of the work. In addition to the knowledge-concerning problems encountered previously, the system may also incorporate knowledge about failures and probable causes based on hypothetical reasoning. Such knowledge is best obtained from the manufacturer who designed the equipment, and are in a better position to anticipate failures and probable causes.

Since the equipment has not been in the field a sufficient amount of time, a diagnostic system, based on symptom-fault-remedy data (associative model), will not be adequate most of the time. Most fault conditions must be diagnosed and repaired based on embedded deep knowledge. It is likely that an unseen fault will occur, and that the new fault cannot be categorized according to one of the cases previously encountered. The fault coverage by simulated symptom-fault pairs can be expected to be satisfactory if fault simulations are done systematically and thoroughly.

Domain knowledge for new equipment is available at many levels:

a. In the associative model, important parts of the knowledge base come from observed, recorded, and analyzed symptom-fault-remedy data. A large amount of knowledge must be built up by following model-based diagnostic techniques.

b. Another kind of knowledge consists of component level or signal level details available in the manufacturers' schematics. This allows the technician to trace a faulty signal back to the origin of the fault.

c. Knowledge from self-diagnostics is available, together with the interpretations of the test results and the recommended actions. Built-in test equipment will present knowledge in the form of system status and current operating parameters.

d. Breakdown of equipment into physical modules, the function of each module, and the interrelationships between various modules also constitute knowledge that is useful in replacing a defective part at the most economical level of assembly.

e. The breakdown of equipment into functional modules (within physical modules), the interrelationships between different functional modules, and key signal paths also constitutes knowledge.

f. Systems theory knowledge allows the educated user to expect correct system behavior, discover possible anomalies, and hypothesize and diagnose reasons for the anomalous behavior. In the associative model this knowledge is of less importance.

A generalized knowledge base, developed in terms of heuristics, may be very effective in making the problem tractable. However, this approach may also introduce some uncertainty in the solution paths, as the following example illustrates.

Higher level heuristic: If any DC voltage is missing, check input and output of the DC power supply. This heuristic can account for many kinds of failures compared to specific symptom fault conditions such as the one shown next.

Specific symptom fault condition: If +12 volts is missing, check the output transistor of the +12 volt power supply. Knowledge encoded at this level is more useful, leaving fewer analytical tasks to be performed by the technician.

In order to cover as many cases as the heuristic covers, many such symptom-fault conditions need to be incorporated. Heuristics save knowledge representational space, but provide more general advice.

4.3.1.1.2 Criteria for Assessing the AI Application for CM1.

The AI application for CM1 will be deemed successful if it meets the following criteria:

a. It can assist a technician in locating and repairing faults that the self-diagnostics or technician's skill could not capture and identify.

b. During the verification and validation phase, the application can locate simulated faults that are found and identified by self-diagnostics or by the technician.

c. Application allows a less experienced technician to repair the equipment in about the same amount of time as an expert.

d. Its use results in lower costs for parts.

e. The application is aligned with the organizational goals introducing modern technology into the FAA, and providing quality services to the users at the least possible cost.

4.3.1.1.3 The AI Application for CM1.

The AI application will be a production system. A single AI system should be designed for each piece of equipment, such as the ASR-9 and the Second Generation VORTAC. A prototype system can be built to isolate faults at a higher level of assembly rather than the actual desired level of assembly. The user interface, as well as the capability to perform as specified, will be tested.

Conventional computing techniques are inadequate due to the difficulty in updating or revising the knowledge base. The ASR-9 and Second Generation VORTAC are new systems, therefore, it would be advantageous to incorporate learning into the knowledge-based ES. ANN, GA, and symbolic learning methods are candidates.

The knowledge to be captured is a mixture of knowledge from the experts, and knowledge from maintenance handbooks containing principles of operation, system description, description of diagnostic tests available, and interpretation of normal and anomalous test results and observations. To develop a successful application, there is a need to capture all of this knowledge.

Knowledge-based technology is suited for this application since it does not share the difficulties associated with ANN and GA (e.g., problem and knowledge representation). Work on model-based diagnostic systems is also reported. [12]

Knowledge required to construct the system is freely available from experts as well as books, manufacturers' handbooks (technical instructions), and schematics.

In the MCC environment, KBES will be an asset. Part of the KBES may be implemented in the MCC environment, providing more central control and diagnostic capability, that will help in planning CM site visits. If KBES is not implemented, CM may result in unnecessary replacement of higher level assemblies. This may have an adverse effect on the technician's morale. The technician must be given as much assistance as possible in isolating faults to the LRU level, and in the process, enhance his or her knowledge about the system.

Currently, situations are not expected to impede the AI application. However, adequate time needs to be allocated for knowledge acquisition and training of AI specialists to understand and learn the system for which the application is being developed. For CM1, the conventional computing techniques appear to be unsuitable or inadequate.

The maintenance task is such that experts are better performers than are beginners. The knowledge is fairly diverse across different equipment and cannot be quantified now. It is also diverse within the same equipment having different kinds of subassemblies (e.g., electronics, mechanical, and pneumatic) and within electronics, different technologies such as Transistor-Transistor-Logic (TTL), Metal Oxide Semiconductor (MOS), and Complementary Metal Oxide Semiconductor (CMOS).

The level of inexact or uncertain knowledge depends on the knowledge representation chosen. Knowledge encoded in high level heuristics is more uncertain and inexact when compared to explicit case-by-case knowledge representations.

Systems theory knowledge will be reliable, as will the knowledge in schematics. Knowledge gathered from the technicians' experiences will be more statistical in nature.

In general, the data required to identify and locate fault conditions will be incomplete, in the sense that additional data needs to be collected in order to locate and rectify all fault conditions. The quantity of data may be small and specific, often directly relating to the

fault condition. Problem solving knowledge tends to be huge compared to fault condition data. The preliminary data are in the forms of alarms and associated information. Other information directly relevant to problem solutions includes readouts on the instrumentation panels.

The task of advising technicians using CM1 procedures is possible for a knowledge-based system. While breakthroughs are not needed in knowledge-based system technology, good knowledge representations and inference mechanisms need to be adopted to efficiently find sound solutions.

The proposed application is not intended to replace human beings, but merely to serve as an advisor, and to assist in analytical tasks. The task is also concerned primarily with reasoning about symbolic information rather than numeric computations. Hypothesizing is heavily involved in the task. This is inevitable in the following kinds of situations.

If A, then C (knowledge)
If B, then C (knowledge)
C (data)

At this point, a hypothesis about A or B is made, depending on its intrinsic probabilities, as well as additional evidence.

There is a large number of possibilities, and information is intrinsically incomplete because gathering additional information is time consuming. Information gathering has to be guided by optimal use of the information already available. This can be achieved through the use of heuristics. The explanations and justifications will be of great help to assist the technician in the diagnostic process.

The task domain is characterized by the use of expert knowledge, judgment, and experience. An expert can take shortcuts based on heuristics generated as a result of extensive experience. They also make correct judgments in the presence of incomplete and uncertain data. Multiple lines of reasoning are frequently used in the diagnostic task. A symptom may occur as a result of more than one type of fault. In this case one fault is hypothesized and an attempt is made to locate the fault. In case of failure, the other alternatives are pursued to isolate the fault condition.

The diagnostic task involves task specific knowledge, as well as general problem solving knowledge. In diagnostic tasks it is not unusual to find a unique problem. However, for equipment such as PVDs that have been in the field for a long time, it is rare to encounter an unseen fault.

Diverse levels of abstraction play an important part in diagnostic tasks. Higher levels of abstraction make the knowledge encoding compact and manageable in size. Lower level abstraction at the situation description level allows the application to be related to the particular task at hand.

Different types of problem solving behavior, such as data driven, goal driven, symbolic, fuzzy, and to a small extent, numeric, are necessary for the overall task. In general, there is one solution for each problem. Several plausible solutions may be acceptable if remedial action is of the same order of expense as finding the actual solution. Tradeoffs occur between time spent in diagnosis, extra cost borne by unnecessarily replacing parts, and potential gain in experience if the diagnosis is performed to a unique level. The solution is not one of several pre-enumerable solutions, but a complex nonenumerable solution.

Potential misdiagnoses are usually tolerable, since they may lead to remedial actions. The associated costs are the additional time to diagnose the problem, and the time and money involved in unnecessarily replacing a part. Partial results are useful in isolating the cause of the real problem. The task decisions or solutions generally are evaluated as either right or wrong. If the remedial action removes some or all of the symptoms, the decision is right.

The UI should be designed so that I/O is not obtrusive to the main task of diagnosis. A good interface will anticipate the information required, possible answers, and display the choices on the screen to allow the technician to select an item. Similarly, output information may be presented based on perceived importance.

Currently available software and hardware environments (Tandem-based MPSs) are not conducive to KBES deployment. Acquisition of a platform that can be integrated with the existing setup is essential. During the phasing in of the AI system, current operations will be selectively interrupted. The system should be designed to allow a return to existing operations and practices, as required.

Specific faults can be simulated and traced through the system, and the performance may be evaluated as to the accuracy of the diagnosis as well as the quality of reasoning. The solution is the system's ability to find the reasons for the fault's occurrence.

Long term payoffs will include improved MTTR, decreased cost of repairs, and an increase in the average number of systems maintained by a technician. A prototype system may be constructed to evaluate opportunity measurement.

4.3.1.1.4 Applications Identified.

a. Corrective Maintenance Advisor 1 (CM1)
b. Problem Resolution Expert System (PRES)
c. Intelligent Decoders for Equipment Readouts (IDER)

4.3.1.2 CM2.

4.3.1.2.1 Description.

There are many older systems such as Distance Measuring Equipment (DME), VORTACs, glideslopes, and localizers, that have considerable useful life remaining. It is recommended that a PRF be created (see 4.3.6.1.1.1) and distributed to the technicians for reference during CM activities. Apart from this PRF, explicit KBES should be developed to assist diagnosis. The rule-based ES would be appropriate to these systems. In addition, machine readouts can be improved so that they are intelligible without the user having to consult manuals for the purpose of decoding the information.

Since the equipment has been in the field for some time, a rule-based ES will be adequate most of the time. The coverage can be expected to be satisfactory if the symptom-faults are recalled systematically by going through individual parts of the equipment, as well as through the maintenance log entries for the equipment.

As with CM1, domain knowledge for CM2 is available at many levels:

a. In the associative model, an important part of the knowledge base comes from observed, recorded, and analyzed symptom-fault-remedy data. Attention needs to be paid to defining the domains of symptoms, faults, and remedies. These may be represented in various levels of detail, and a level judged to be most effective should be selected.

The symptoms are described as:

1) Deviation in one or more parameter values that are either monitored or measured when warranted, such as during PM or CM procedures.

2) Loss of one or more signals is a special case of deviation in parameter values, but may be separated because of the different approaches adopted to isolate the fault, based on the information. When a signal is lost, its loss can be traced back to the fault area that directly causes a signal to be abnormal. (A fault is an abnormality in a component, part, connection, or subassembly that causes abnormal behavior of the whole system. The detrimental effect of a fault may be masked in a redundant circuit or a subassembly. The remedy is a procedure, including adjustment or replacement of components or subassemblies, to rectify the abnormal behavior of a subassembly or a piece of equipment.)

3) Any ancillary observations such as burnt resistors, blown fuses, shorted transistors, and a host of other conditions. These observations are ancillary, and not primary in the sense that they are usually made after CM procedures are initiated, in response to observations of other symptoms.

b. Another kind of knowledge is component level, or signal level, details available in the manufacturers' schematics. This allows the technician to trace the suspect signal back to the origin of the fault.

c. Knowledge from self-diagnostics is available, together with the interpretations of the test results and the recommended actions. Built-in test equipment will present knowledge in the form of system status and current operating parameters.

d. The breakdown of equipment into physical modules, the function of each physical module, and the interrelationships between various physical modules, also constitute knowledge that is useful in replacing a defective part at the most economical level of assembly.

e. The breakdown of equipment into functional modules (within physical modules), the interrelationships between different functional modules, and key signal paths, constitute still another form of knowledge.

f. Systems theory knowledge allows the educated user to expect correct system behavior, discover possible anomalies, and hypothesize and diagnose reasons for the anomalous behavior. In the associative model, this knowledge is of less importance.

A generalized knowledge base developed in terms of heuristics may be very effective in making the problem tractable. However, this approach may also introduce some uncertainty in the solution paths.

4.3.1.2.2 Criteria for Assessing the AI Application for CM2.

The assessment of the AI application that has been selected for CM2 will be the same as those in section 4.3.1.1.2.

4.3.1.2.3 The AI Application for CM2.

The AI application for CM2 will have the same criteria as those listed in section 4.3.1.1.3.

4.3.1.2.4 Applications Identified.

The applications identified are the same as those listed in 4.3.1. .4.

4.3.2 Alarm Processing.

4.3.2.1 Description.

AF provides services to Air Traffic (AT), thus, AF systems and equipment are spread out over a wide geographical area. Each of these resources plays a vital role in providing reliable, coherent, and consistent services to the users. The services provided by AF are interdependent. If one facility or piece of equipment is out of service, it affects the importance and performance of the other services. When equipment is not functioning according to the specifications, either the users notice the degradation in the services or alarms will sound. The alarm indications are sent to different places, depending on which equipment or facility generated the alarm.

A good alarm processing application would receive the alarms at a central location, prioritize the alarms, and process them in order of priority. Processing the alarms would involve coordination with appropriate personnel (see figure 4.3.2.1-1). The alarm processing application would gather and consolidate as much relevant information as possible and convey it to appropriate personnel. This would allow problem-specific preparation to take place in an effective manner.

There are several problems with the current design of alarm processing in the current environment. The alarms are not received at a single site but at various locations, depending on the equipment generating the alarms. Also, many alarms indicate only the existence of a possible malfunction in the equipment without giving details of the malfunction. With the continued implementation of RMM, most alarms will be centralized at the MCC. The RMM equipment may also allow specific identification codes to be attached to the alarms, enabling a better initial assessment of problem situations leading to improved diagnosis and site visit preparation. The central alarm processing software will be complex, since it must be compatible with a variety of equipment at different locations. For example, there are a number of vendors for power conditioning systems, localizers, glideslopes, and runway lights, and each piece of equipment may generate different types of alarms, having different diagnostic information content.

The process of resolving alarms is usually simple. In the case of a single alarm the non-functioning of the suspect facility is assessed. Services are restored through alternate provisions if possible, and action to put the facility into service is initiated. In case of multiple alarms, the alarms are prioritized and resolved in decreasing order. Alarms concerning critical facilities are resolved first. The prioritization may be changed if there is reason to believe that the alarms for the critical facilities are a consequence of a fault condition on another equipment or facility. Any alarms that indicate disruption in facility services are of high priority. The criticality of the services may vary intrinsically depending on external conditions, such as weather. In general, AT makes decisions regarding the priority and criticality.

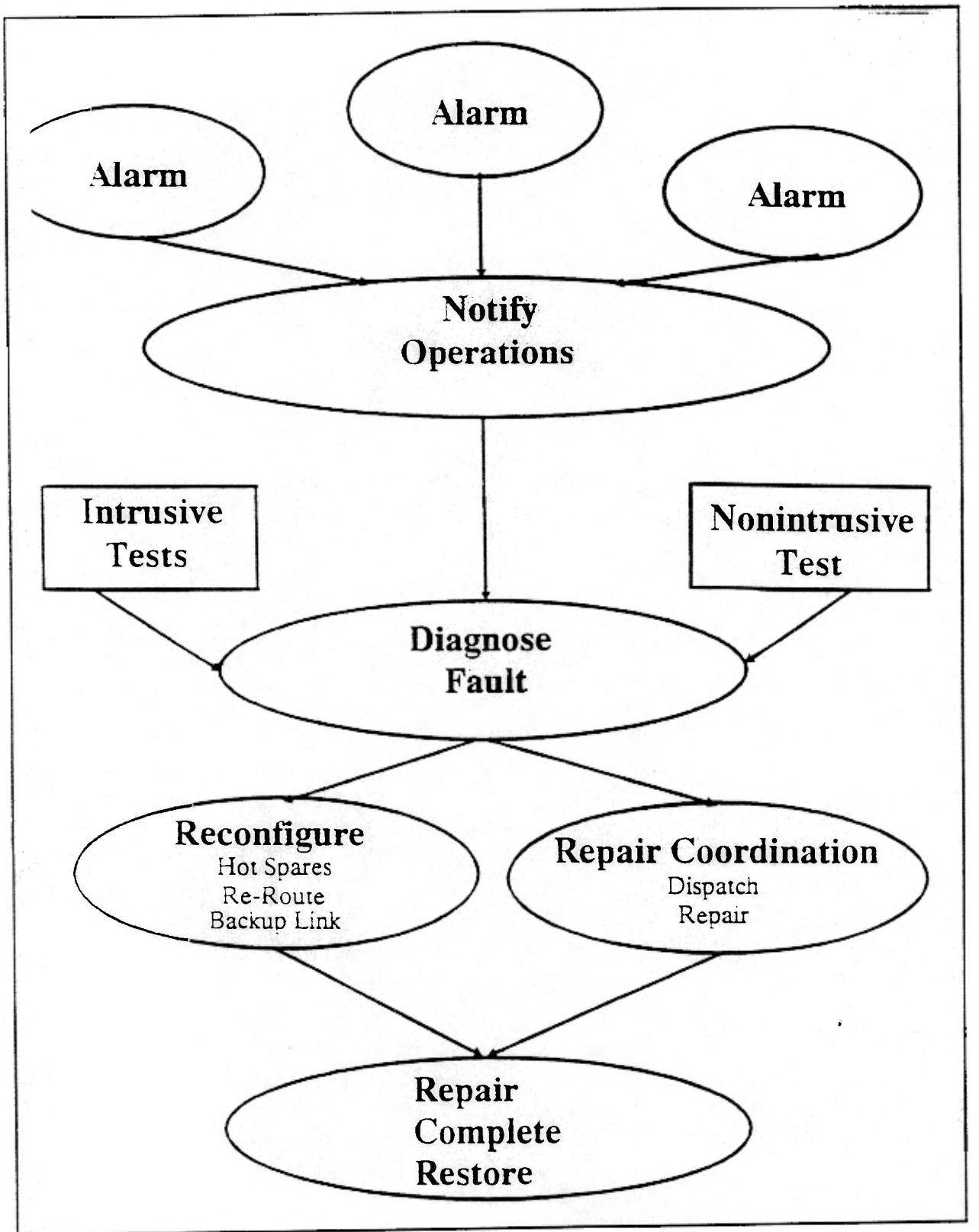

FIGURE 4.3.2.1-1. ALARM PROCESSING

Out-of-tolerance conditions can cause a reportable outage, which is a disruption in service, for an interval greater than 59 seconds. For any facility, unscheduled outages are to be limited to an absolute minimum. Therefore, the immediate response to an alarm is to restore the service through an alternate route or channel, and then schedule CM for the equipment causing the problems.

Another important area in the alarm processing application is resolving intermittent alarms. Intermittent alarms are relatively rare, but they are very difficult to resolve, since the condition that causes the fault does not necessarily exist at the time of debugging. To isolate intermittent faults and resolve intermittent alarms, continuous monitoring of the equipment, and recording of key parameters are highly recommended. In this way, the electronic technician will have all the relevant history of the equipment prior to and during the fault condition, thus facilitating fault isolation to a marginal LRU that might be a cause of the intermittent fault condition.

Occasionally, multiple alarms are received. Sometimes these alarms may be related, i.e., a condition causing one alarm may also automatically cause another alarm. A KBES may be designed to assist a less experienced technician by indicating which alarm to address first.

If a facility or piece of equipment requires reconfiguration, AT must be advised since they, as users, are in the best position to assess the impact. Reconfiguration involves a small fraction of equipment in use, and most reconfigurations result in making the backup facilities primary. Neither the analytical nor the physical process of reconfiguration is very difficult. An ES could be developed to assist the user in the process of equipment reconfiguration.

Currently, alarms are received at different places in different forms. The System Maintenance Monitor Console (SMMC) receives alarms regarding abnormal status in CCCH, CDC, DARC, and communications. Environmental alarms are generally reported by users. For example, problems with air-conditioning are reported when the temperature becomes high. In the ARTCC, there is an elaborate system for monitoring the environmental systems. Similar systems are being implemented for GNAS systems, and alarms may be designed to signal when problems occur, and not when they are observed by users. This will eliminate the delay between problem occurrence and problem perception. This type of automatic alerting system will eliminate the delay between the occurrence of the problem and the perception of the problem.

It is highly recommended to have all alarms report to a central location, such as the MCC or SMMC. The MCC operator or NOM can then initiate appropriate actions, such as reconfiguring equipment and scheduling CM. The MCC and SMMC are good locations at which to process the centralized alarms. For this to be possible, the equipment will have to be fitted with RMM capability. One related AI application that will improve services is monitoring the equipment. This is discussed in section 4.3.3.

4.3.2.2 Criteria for Assessing the AI Application for Alarm Processing.

The application will be deemed successful if the alarms are resolved in less than 60 seconds, thereby reducing the total number of reportable outages. The software or firmware will need to designate the backup equipment as primary, and advise AT about the reconfiguration. Subsequently, CM must be scheduled to repair the malfunctioning equipment.

4.3.2.3 The AI Application for Alarm Processing.

The AI application will be a production system, and a single AI system will suffice for all equipment. The knowledge bases would be extensive, and include relevant information for distinct types of equipment.

To develop a successful application, there is a need to capture different kinds of knowledge. The knowledge sources are identified as maintenance books, NOMs in the ARTCC environment who resolve alarms, GMCC NAS Area Specialists in the MCC environment, and all other personnel who resolve alarms within their jurisdiction.

Various technologies, such as ANN, FL, and KBES, are suitable here. ANNs will allow generalization of training examples, thereby handling unseen cases effectively. FL will decide in which cases to react immediately, and in which cases to defer decisions. A KBES could also be performing similar tasks. Similar applications have been reported. [13-16]

The application is recommended for implementation in the RMMed environment where MCCs will be receiving most of the alarms. Currently, situations are not expected to impede AI applications, however, adequate time needs to be allocated for knowledge acquisition, and for training of AI specialists to understand and learn the system for which the application is being developed.

For the application of alarm processing, the conventional computing techniques appear to be unsuitable or inadequate. The alarm processing task is such that the experts are better performers than the beginners. The experts are currently performing the task for which the alarm processing application is being proposed. Each expert has approximately the same approach, although some variability is expected.

Knowledge is going to be steady rather than in a state of rapid change. The reason is that the equipment has been in the field for some time, and the design has stabilized with little to no changes that would alter lower level (schematic level) knowledge. In general, the alarms and associated information will be incomplete, and additional information will need to be collected in order to determine the reason for the alarm being activated. The task of resolving the alarm is neither too easy nor too difficult for a knowledge-based system.

No breakthroughs are needed in knowledge-based system technology. However, good knowledge representation and a good inference mechanism needs to be adopted for finding sound solutions efficiently.

Different types of problem-solving behavior, such as data driven, goal driven, symbolic, fuzzy, and, to a small extent, numeric, are necessary for the overall task.

In general, there are several correct ways to resolve an alarm. One is to put a backup facility into operation, and dispatch a technician to perform CM. Another is to acknowledge the alarm and operate in the degraded mode of service. This is acceptable if the service is not essential or critical. Potential misdiagnoses are not tolerable since they lead to continuation of degraded services. Partial results are useful in narrowing down the cause of the real problem. The task decisions or solutions are generally evaluated as either right or wrong. If the remedial action removes some or all of the symptoms, the decision is right.

If the AI application makes most of the decisions autonomously, the UI does not have to be extensive. The UI only has to advise the user of the action taken, and provide a means of overriding the system action.

Currently available software and hardware environments (Tandem-based MPS subsystem) are not conducive to system deployment. Acquisition of a platform that can be integrated with the existing setup is essential. During the phasing in of the system, current operations will be disturbed somewhat. The system can be designed so that it is possible to revert to existing operations and practices, as needed.

Some alarm situations may be simulated and the reasoning traced through the system. Performance may be evaluated based on the accuracy of the diagnosis, as well as the quality of the reasoning. Long term payoffs will include a reduced number of outages, well-prepared site visits for repair, and reduced MTTR for equipment.

The system may be constructed incrementally to include the alarms processed by the application at the MCC one-by-one, thus providing the ability to evaluate the system as it is being built.

The need for the task is expected to continue without significant change due to FAA directions for several more years. The delay or non-implementation of this application will not adversely affect the development of other projects. It is recommended that a significant number of facilities be RMMed prior to implementation of this application.

4.3.2.4 Applications Identified.

a. Alarm Processor Expert System (APES)
b. Multiple Alarm Processor (MAP)
c. Reconfiguration Expert System (RES)

4.3.3 Monitoring.

4.3.3.1 Description.

Monitoring involves comparing observations to predictions, and hypothesizing the state of the equipment using sensor data and interpreted data. It is an integral part of alarm processing.

There are two applications in the monitoring area, as follows:

a. Data acquisition. The first AI application is to monitor and capture the state of the equipment (in terms of key parameters and other suitable data points) at the time when an alarm occurs. This will provide a technician with the relevant history of the equipment prior to and during the fault condition, thus facilitating the job of isolating the fault to a specific LRU. This function is already incorporated into newer equipment such as the Second Generation VORTAC and ASR-9. As a matter of fact, there is too much data provided, and the technicians would prefer to see only the relevant data. A simple KBES application should be developed that suppresses irrelevant data, and presents only the data that are relevant and desirable. Menu driven options may be provided, allowing the technician to selectively display and print suppressed data. NNs and FL are also strong candidates for this application.

b. Analysis and report generation for anticipatory fault conditions. The second AI application would monitor and analyze key parameters periodically and automatically, and report unusual trends in a parameter so that the AI application may serve as an early warning system. At the simplest level this application will alert appropriate personnel (by means of an alarm or printout) whenever any key parameter is outside the allowable range. In this case, the technician will identify parameters that are out of tolerance, take appropriate corrective action, and have maintenance scheduled. This is important because the user may not notice degradation in service until much later. Another variation of this application is to alert the technician about parameters that are degrading systematically, even though they are still within the allowable operating range. Thresholds for reporting these alarms may be set to avoid receipt of too many false alarms. KBES, ANN, and FL are the candidates for this application.

4.3.3.2 Criteria for Assessing of the AI Application for Monitoring

The application will be deemed successful if the state of the equipment is captured at the time of the alarm, thus giving the technician more information for fault diagnostics. The application will also be deemed successful if it helps to predict failures before they occur, by analyzing trends in the key parameters.

4.3.3.3 The AI Application for Monitoring.

The AI application will be a production system. A single AI system with a different knowledge base for each piece of equipment will suffice for all equipment. The knowledge bases would be extensive, and include relevant information for distinct types of equipment. Adequate knowledge about monitoring is available from NOMs, MCC Specialists and maintenance handbooks.

Various AI technologies, such as ANN, FL, and KBES, are suitable for monitoring. ANN will allow for generalization of training examples, thereby handling unseen cases effectively. FL will decide in which cases to react to immediately, and in which cases to defer the decisions. The KBES could be performing similar tasks. Other applications have been reported. [5-16] After an adequate number of systems have been RMMed, this KBES application is recommended. In the extensively RMMed state, the system will be able to sample the key parameters at a regular interval.

Currently, situations are not expected to impede AI applications, however, adequate time needs to be allocated for knowledge acquisition, and for training AI specialists to understand and learn the system for which the application is being developed.

For the application of monitoring, conventional computing techniques appear to be unsuitable or inadequate. Knowledge exists to perform monitoring tasks for which this application is suggested. The primary knowledge sources identified are the SEs and the maintenance handbooks.

Knowledge is going to be steady rather than in a state of rapid change. This is because the equipment has been in the field for some time, and the designs have stabilized with limited change orders expected that would change lower level (schematic level) knowledge.

The monitoring is neither too easy nor too difficult for an AI system, and no breakthroughs are needed in AI technology in order to develop this application. However, a good knowledge representation and a good inference mechanism should be adopted for efficiently capturing the state of the equipment, and detecting potential problems that may result in a failure of the equipment in the future.

Monitoring cannot be further decomposed into simpler tasks. There is not a significant amount of hypothesizing involved in the task of capturing the state of the machine at the time when the alarm occurs. However, there is some reasoning present in analyzing the trends in the key parameters, and predicting probable equipment failures. The explanations and justifications will be of great help to the MCC specialist and NOM in assisting him or her in the monitoring process.

Incorrect capturing of the equipment state is not tolerable since it may mislead the technician. An incorrect prediction regarding equipment failure is also undesirable, since it may generate an unacceptable level of false alarms.

The UI must present the state of the equipment to the user, in terms of key parameters, at the time an alarm occurs. In the case of predicting a failure, the AI application must present the history of relevant parameters.

Currently available software and hardware environments (Tandem-based MPSs) are not conducive to system deployment. A better platform, that can be integrated with the existing setup, is recommended.

During the phasing in of the system, current operations will be disturbed somewhat. However, the system can be designed so that it can return to existing operations and practices, as needed. Long-term payoffs will include a reduced number of outages, better prepared site visits for repair, and reduced MTTR for equipment.

The system may be constructed incrementally to capture the state of the equipment, or sample the key parameters of the equipment one-by-one, thus evaluating the system as it is being built.

4.3.3.4 Applications Identified.

a. Intelligent Filter (IF): Modern equipment, such as the Second Generation VORTAC and ASR-9, generate large quantities of data when error conditions are sensed during operations. A NN is recommended for presenting only the relevant data, so that technicians do not have to sift through unwanted data.

b. Fault Anticipator (FA): NNs can also be used to detect and analyze trends in the key parameters and forecast probable system failures, thus enhancing PM and reducing the number of unscheduled service interruptions and failures.

c. Expert Monitoring System (EMS): This will be an ENN-based application combining the KBES and ANN technologies.

4.3.4 Administrative Functions.

4.3.4.1 Description.

This section describes some of the administrative functions that are performed by the technicians and unit supervisors within the framework of AF maintenance. The administrative duties in AF maintenance consist of:

a. Completion of Form 6030-1. For every CM and PM action, technicians must complete a Facility Maintenance Log (Form 6030-1) or its automated equivalent. The technician records arrival and departure dates and times, and whether PM or CM was performed. Additional details, such as problem descriptions, symptoms observed, and actions taken can also be recorded, with the entries being initialed by the responsible technician. The logs are preserved for three years (yellow copy at site, white copy at the sector or sector field office).

b. Completion of Form 6000-8. For every CM and PM action, technicians must complete a Technical Performance Record (Form 6000-8) on which key equipment parameters are recorded. Occasionally a potential problem is spotted by looking at these forms, and additional maintenance is scheduled at the discretion of the technician in consultation with his or her supervisor.

c. Completion of other forms such as FAA-4650-10, FAA-6040-4, and 6040-3. The Warranty Failure Report (FAA-4650-10) identifies and describes the nature of failure, its probable cause, and suggestions for correction. The Equipment Failure Report (6040-4) is completed on an as required basis. Data are used to provide feedback for equipment improvement. The form is used on a special case basis and is not available at all facilities. Facility and Service Outage Report (6040-3) is used to report facility and services outages, and is then forwarded through regional offices to the National Airspace Performance Reporting System, which analyzes these reports. These reports are available on the MMS as Log Interruption Reports.

d. Maintenance Scheduling. The unit supervisors schedule PM and certification visits. Currently, the MMS can generate reports for all the equipment for which maintenance is due in the forthcoming period (week, 15 days, or a month). However, the unit supervisor has the responsibility of actually allocating tasks to the technicians. Overlapping coverage is necessary to allow scheduling of PM requiring two people. Factors taken into account when developing work schedules include assuring a minimal impact to the users, meeting the PM schedule deadlines, maintaining approximately equivalent workloads across technicians, and the experience and capabilities of the technicians.

In the future, if a technician will be responsible for a greater number of facilities and equipment, there will be more conflicts in scheduling tasks. For this reason, an integrated software package may be designed that schedules not only the PM tasks, but also personnel assignments. Coordination with AT will continue and planning ahead will result in fewer conflicts with user requirements. Also, contingency planning may be accomplished with commercial off-the-shelf (COTS) items such as SuperProject Plus and similar products. Paperwork completed by technicians will be limited to completing Form 6030-1 and trend analysis forms. There will be no additional paperwork apart from ordering required parts, updating the manuals, etc.

The manual entries on Form 6030-1 are not currently consolidated to generate a nationwide report for a system. However, with MMS, failure reports can be consolidated across the nation for an equipment type, if desired. An application to enhance CM would be to create a PRF for each type of equipment. This file may be created from scratch, or by accessing the MMS entries and rearranging the contents to serve the purpose. A PRF will be set up for each system type, where symptoms, faults, and corrective actions are logged for the benefit of technicians faced with similar problems. An AI application of creating a PRS is discussed in section 4.3.6.

Before going to a site for CM, a technician can study the symptoms, visualize the problem, and develop a strategy to troubleshoot the problem. It would be beneficial to have a checklist, which can be easily prepared by a computer. Such a list will be particularly useful for equipment that needs to be repaired with special tools.

4.3.4.2 Applications Identified.

In the area of administration functions, five potential applications were identified:

a. Automatic monitoring of the parameters contained in Form 6000-8 form. application has been discussed in greater detail in section 4.3.3.

b. Conversion of all paper forms to an electronic version. This application has been discussed in greater detail in section 4.3.5.

c. Consolidation of Form 6030-1 and MMS log entries to generate a PRF. application has been discussed in greater detail in section 4.3.6.

d. Providing an automatic checklist for a technician going to a site. An automated checklist can be generated on a laptop computer.

e. Scheduling of the technicians can be done with COTS software such as SuperProject Plus or Microsoft Project.

4.3.5 Information Retrieval.

4.3.5.1 Description.

Based on the interview sessions with the SEs, the technicians and the supervisors, it is recommended that the maintenance documentation, such as technical instructions (TI) and schematics, be transferred to electronic media. The electronic documentation will be easier to maintain and update. The Boeing Corporation has undertaken a similar project. A typical 300 page manual will need 5-10 MB of storage (without pictures). A 300 MB removable hard drive or a built in hard drive can contain as much information as is contained in 30 maintenance volumes. Bulkier documentation can be put on writable optical diskettes.

After the documentation is on electronic media, the aim of the ES will be to:

a. Retrieve exact text from the on-line document.

b. Allow a technician to ask the ES a question, and the ES would retrieve the exact text.

c. Incorporate graphics into the scope. (This would be a long-term project.)

Some of the following difficulties may be encountered, but overcome with an ingenious approach:

a. Foldout diagrams giving the entire picture of a system component will be difficult to represent on a single screen. Bigger screens will alleviate this problem.

b. High resolution pictures (bitmapped raster-scanned images) will require large amounts of storage.

Electronic documentation will be used by all technicians in both the ARTCC and GNAS environments.

4.3.5.2 Criteria for Assessing the AI Application for Information Retrieval.

The AI application for information retrieval has a well-defined goal of moving all documentation to paperless media. Success or failure will be measured in terms of the following:

a. Ease of maintaining (updating) the documentation.
b. Ease of access and use of the documentation.
c. Time saved in searching for a required segment of the documentation.
d. Ease of making comments in the margins of the documents.

4.3.5.3 The AI Application for Information Retrieval.

The advantages of the AI application for information retrieval include:

a. Automatic updating of manuals from a central location.
b. Documentation occupying less space.
c. Portability.
d. Reusable media.

Expected benefits versus expected costs will have to be assessed from prototype efforts in one area (or equipment).

There are advantages associated with electronic documentation, and this technology is essential. A similar application is being pursued by the Boeing Corporation, as well as many other companies dealing with maintenance operations. The existing approach is adequate, and will be satisfactory in future FAA operations.

A list of all the documents used by the technicians may be compiled to estimate the volume of data to be transferred to the electronic media, and determine the required size of the media. The transfer of documents to electronic media is a one-time task, and periodic updates can be made to the documents. The level of difficulty and amount of time required to perform the task will depend on the method used to transfer the document contents to electronic media. Document transfer using scanners will be fast, but may be prone to errors. Manual or semiautomatic transfer may allow graceful inclusion of figures, pictures, and tables.

The document transfer task and expert information retrieval are far from trivial. They are on the leading edge of AI and hypertext technologies. The tasks do not lend themselves to incremental prototyping and modifications. Information retrieval involves real-time interaction with the users of the system. The task requires construction of a complex UI.

Introduction of the application will not have any adverse affect on the current operations and practice, and the system is expected to be phased into use gracefully, using progressive releases. The information retrieval system may be tested by attempts to retrieve selected portions of the text. The user confidence and feedback will verify and validate the application.

4.3.5.4 Applications Identified.

Expert Maintenance Manual.

4.3.6 Problem Resolutions.

4.3.6.1 Description.

A technician receives a call to repair a system or equipment problem. Usually the technician receives additional information regarding the symptoms that serves as a basis for the belief that there is something wrong with the equipment. The technician then carries out the diagnostics, fault detection, fault isolation, and repair. After the repairs are completed, the system or equipment becomes operational. He or she then completes Form 6030-1, or fills out an MMS log entry, which is retained for 3 years. If the process of gathering information during fault detection, fault isolation, and repair could be captured using an intelligent system, it could save technicians time during diagnostic activities.

Three applications are recommended, based on the problem resolution process previously described:

a. Problem Resolution Classifier (PRC).
b. PRES.
c. Expert Neural System Help Desk (ENSHD).

In each case, the technician or user will enter the symptom(s) and any other available information. The PRF database and its corresponding knowledge bases will be used for developing the final recommendations.

4.3.6.1.1 PRC.

A PRC is designed to track problems and their associated resolutions (see figure 4.3.6.1.1-1). The PRC will use the database developed, using 6030-1 forms, the PRF, and MMS entries. The PRC is a simple NN-based system trained with data from the PRF. It will advise technicians which courses of action to take, such as repairs.

4.3.6.1.1.1 PRF Database.

PRFs may be created from existing records, and distributed to the technicians for reference during CM activities. It is recommended that the PRF be updated either automatically from entries in the MMS system or entered manually at the end of each CM activity. Entries in the MMS system are recommended, since the MMS system can be made to automatically classify entries according to equipment type. The technicians will need to be instructed as to the correct way to enter the data, so that the MMS can correctly index symptoms, faults and remedies. Also, the MMS will have to be modified so that duplicate entries are not produced in the PRF.

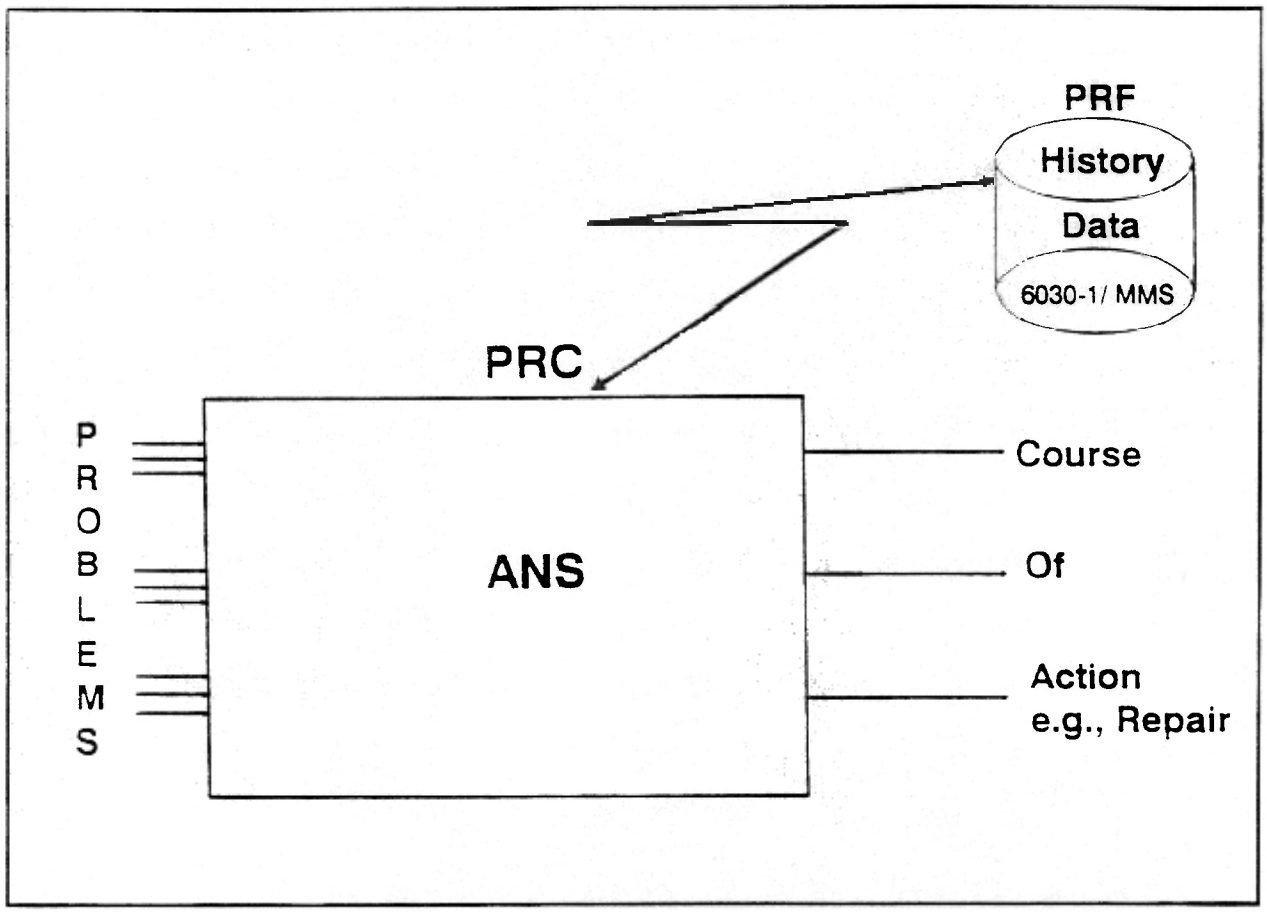

FIGURE 4.3.6.1.1-1. PROBLEM RESOLUTION CLASSIFIER

4.3.6.1.1.2 Assumptions.

It is assumed that the contents of Form 6030-1 or MMS entries will provide the bulk of the information that will go into the file. The experts will also contribute to the file.

4.3.6.1.2 PRES.

PRES is an automated diagnostic ES that will aid in diagnosing and resolving faults in a more comprehensive manner (see figure 4.3.6.1.2-1). It will also provide explanation (how and why), and hypothetical reasoning (what if) capabilities to the user.

PRES will contain knowledge from the manufacturer's trouble-shooting guide (declarative knowledge), and technicians' problem solving knowledge (experiential knowledge base). It will also interface with the PRF to extract or modify data from the experiential knowledge base. A natural language front end will provide answers to queries.

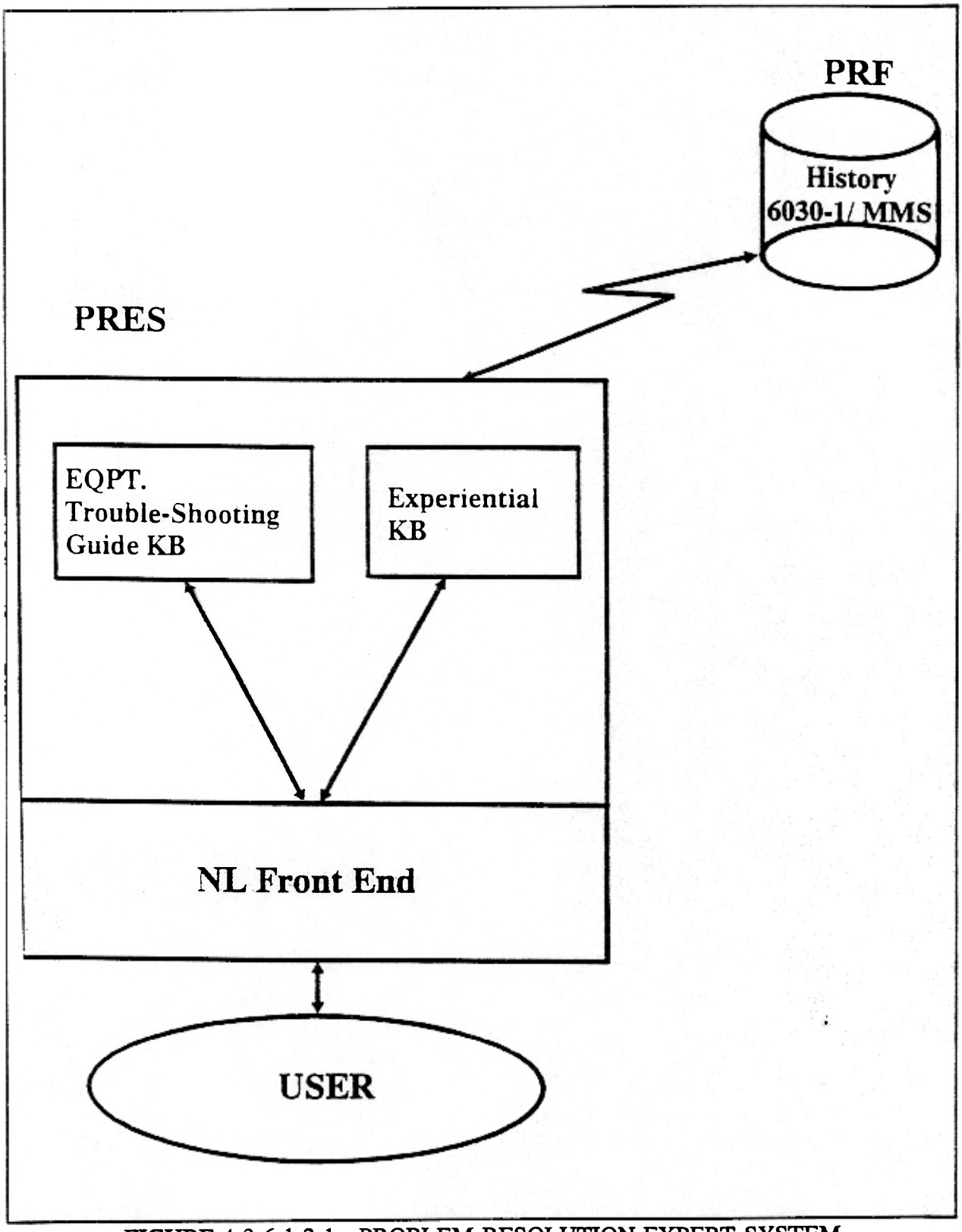

FIGURE 4.3.6.1.2-1. PROBLEM RESOLUTION EXPERT SYSTEM

4.3.6.1.3 An ENSHD.

This system will be a combination of the PRC and the PRES previously described. Depending upon the nature of a problem, the HelpDesk can be used as a tracker, or as an intelligent ES. A schematic is shown in figure 4.3.6.1.3-1.

4.3.6.1.3.1 Potential Problems.

In order to retrieve a symptom-fault-remedy from the PRF, the technician must enter precise symptoms. Otherwise, a flexible pattern-matching algorithm must be used to make imprecise inputs acceptable. While building the PRF, care must be taken that multiple records for the identical symptom-fault-remedies are not input and retained.

4.3.6.2 Criteria for Assessing the AI Application for Problem Resolutions.

The AI application for problem resolutions will be deemed successful if a less experienced technician can repair a system or equipment in the same amount of time as an expert. Other success criteria will include a user friendly interface that tolerates input errors (a necessary condition given that technicians are not keyboard operators), successful recall of relevant cases in the database, and ease of inputting new cases for future benefit.

4.3.6.3 The AI Application for Problem Resolutions.

The goal is a production system. The prototype system will be designed to read MMS-created files and entries from 6030-1 forms. These entries will be stored and retrieved according to specific function keys assigned by equipment and malfunction type. A menu-driven interface may be provided for the retrieval of symptom-fault-remedies.

The knowledge to be captured is a mixture of expertise, maintenance handbook information, and interpretation of normal and anomalous test results and observations.

All AI knowledge will be represented in the same form, (i.e., symptom-fault-remedies) however, the content of the knowledge is fairly diverse. Within the same equipment,

different kinds of subassemblies, (e.g., electronics, mechanical, and pneumatic) will have different knowledge associated with it.

The knowledge captured for the symptom-fault-remedy mode is primarily restricted to field experience. A PRF may be constructed from the maintenance log entries for equipment located throughout NAS. The knowledge captured from these entries will usually be complete (i.e., observed symptoms are recorded along with what was wrong, and what corrective action was taken).

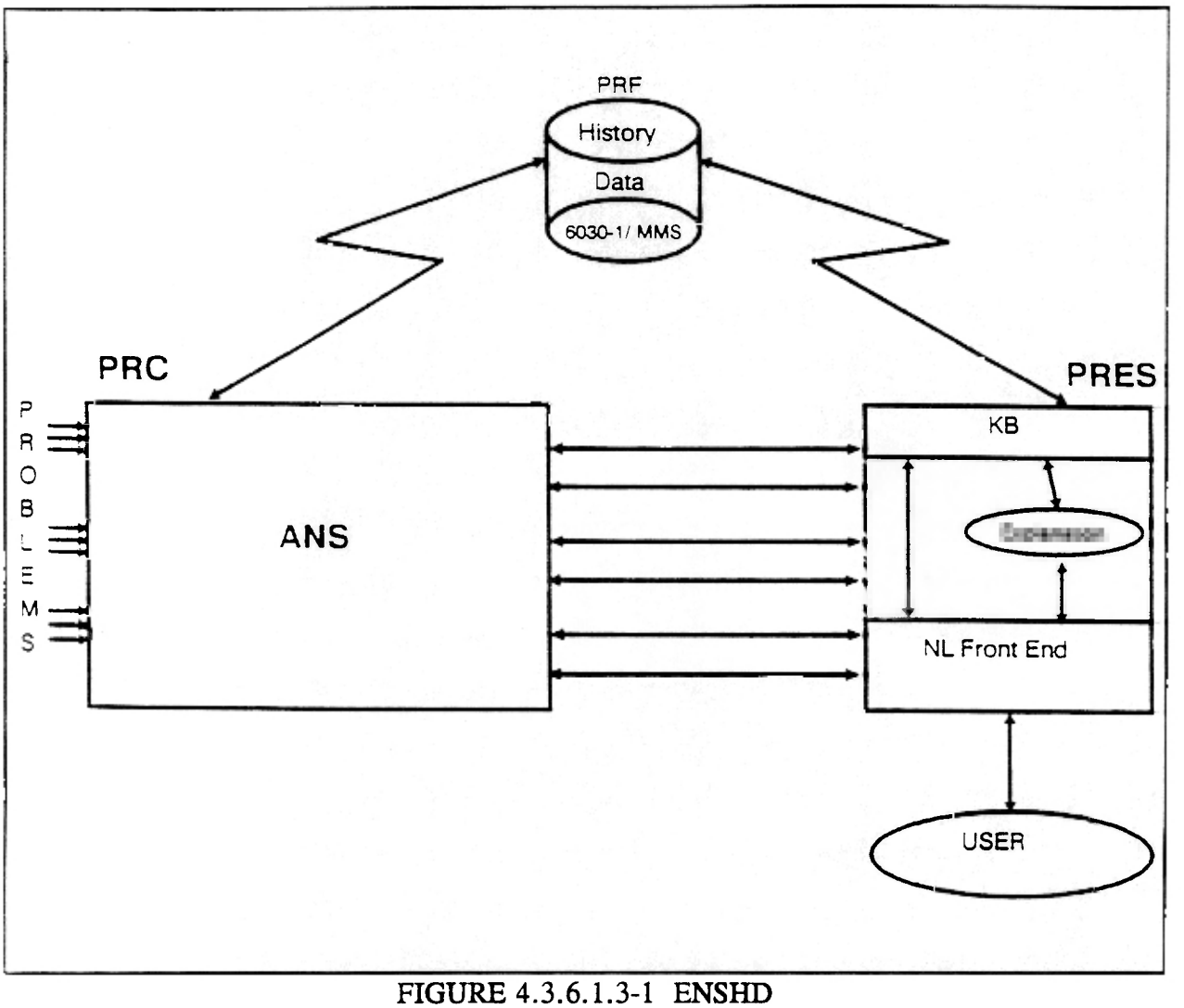

FIGURE 4.3.6.1.3-1 ENSHD

A PRF will be only partially useful since there is no field experience for new equipment. Manufacturers may be able to help during the initial effort by providing data regarding most probable failures, symptoms, and remedies. This "starter" database can be updated as field experience grows.

Since the same symptoms may occur for different faults, symptom-fault-remedies may not be unique for each symptom. To this extent there will be some uncertainty as to which action to take (i.e., which symptom-fault-remedy to follow). In this case, one fault is hypothesized, and an attempt is made to locate it. In case of failure, the alternative hypotheses are pursued to isolate the fault condition.

It is not unusual to find a novel situation. This makes it advisable to have knowledge encoded at a level higher than that of situational description. This will allow the user to generalize about a situation of interest that has not been directly encountered before. Explanations and justifications will assist the technician during the diagnostic process, therefore, it will be helpful to add remarks to the symptom-fault-remedies.

In general, there is a single solution. Several plausible solutions may be acceptable if corrective action, based on all of them, is on the same order of expense as finding the actual solution. Tradeoffs occur between time spent in diagnosis, and extra cost borne by unnecessarily replacing parts. They also occur with potential gain in experience if the diagnosis is done to the most specific level.

In general, the data used for fault isolation may not be adequate to diagnose the problem immediately. In short, knowledge will be reliable to a great extent, but there will be some uncertainty for unusual or complicated faults. The unusual and complicated faults should be covered by embedded deep knowledge.

Deep knowledge can best be explained by exemplifying and contrasting shallow knowledge. An example of shallow knowledge is that of a layman who takes an aspirin when he has a headache. The remedy works most of the time, however, it is the doctors and the pharmacists who know the way in which aspirin works to alleviate headaches. They can also distinguish different kinds of headaches, and other medical conditions for which they know different prescriptions and procedures. The knowledge possessed by the doctors is deep knowledge, and that possessed by the layman is shallow knowledge. It is likely that an unseen fault will occur or that a new fault cannot be categorized according to one of the cases previously encountered. It is these previously unseen cases that should be covered by embedded deep knowledge.

Diverse levels of abstraction are useful during the diagnosis. Higher levels of abstraction make knowledge encoding compact and manageable in size. Lower level abstraction at the explicit situational level allows the application to be related to the particular task at hand.

For observed, recorded, and analyzed symptom-fault-remedies, attention needs to be directed to defining the domains of symptoms, faults, and remedies. These items may be represented at various levels of detail, and a level determined to be most effective will be selected. The symptoms may be described as:

a. Deviation in one or more parameter values that are either monitored or measured, such as in CM or PM procedures.

b. Loss of one or more signals. This is a special case of deviation in parameter values but may be separated because potentially different approaches may be adopted to isolate the fault based on the information.

c. Auxiliary observations such as burnt resistors, blown fuses, shorted transistors, or a host of other conditions. These observations are auxiliary, and not primary, because they are usually discovered after CM procedures are initiated in response to observation of other symptoms.

The application requires a symptom-based indexing mechanism for storage, search, and retrieval of sound solutions. The overall construction of the PRF may be decomposed into several IDB files. This may add convenience to the construction and maintenance of the system. It is also advisable, however, that all these files be accessible through a single UI.

For the PRF, the UI is query-response time. The user may give the symptoms, and expect enumeration of possible fault conditions and their remedies. The diagnostic task involves significant real-time interaction with devices, and sometimes special software programs.

The design of the UI may not be straightforward. There are two aspects:

a. The UI is to be designed so that I/O is not obtrusive to the main task of diagnosis. One way to enter information is through keyboard entries. Electronic technicians are not keyboard operators, and may be inept at such a task. A good interface will anticipate the information required from the user, as well as possible answers to users queries, and project the relevant information on the screen. The technician can then select an item from a presented list.

b. Output information may be presented based on its importance and relevance to the technician.

Potential misdiagnoses are tolerable since they lead to corrective actions that do not correct the original problem, and the diagnostics simply continue. The costs are the additional time to diagnose a problem, and the time and money involved in unnecessarily replacing a part, if this occurs. Partial results are useful in narrowing down the cause of the real problem, and are helpful in accelerating diagnosis, as well as in intermittent fault situations where more focused monitoring may be initiated.

Task decisions or solutions are generally evaluated as correct if the action removes some or all symptoms. Decisions may be based on the level of belief (e.g., hypothesis-test selection), but in general are not from between close alternatives.

There are some inherent difficulties in applying the AI application. The data records are created and accessed by the MMS system on Tandem computers running the Guardian operating system. A new IDB application will have to be written that can either use the MMS records as they are, or can create its own database of records. In either case, the

MMS records will have to be accessed and interpreted at least once. This may involve security and other restrictions. Furthermore, if the IDB is designed to operate using the existing MMS records, there will be problems due to duplicate records for the same symptom-fault-remedies. Indexing symptoms will also be difficult.

The application is highly desirable, and a great asset in the MCC environment but, currently, the available software and hardware environments are not conducive to IDB deployment. There is a need for a good platform that can be integrated with the existing setup.

Current operations will not be disturbed with the introduction of a PRF. The AI application can be designed so that operations can revert to existing practices, as needed. The application will support central control and diagnostic capability, which will assist in the planning of site visits for repair problems. In the long term, the payoff may be revealed as improved MTTR, lower cost of repairs, and higher average number of systems maintained by an electronics technician. Another payoff of this application will be the ability of less experienced technicians to diagnose faulty equipment. Through this application, the national expertise will be available within each AF sector. These systems will also be able to preserve expertise in old and rare equipment.

The PRES development is an independent project and does not impede the development of other projects.

4.3.6.4 Applications Identified.

a. PRC
b. PRES
c. ENSHD

4.3.7 Certification.

4.3.7.1 Description.

The certification procedure reflects authorized verification by a technician that the equipment is operational, and within the preset tolerances and specifications. The issues concerning AI applications of certification tasks are very similar to those for PM.

The following observations concerning certification are based on site interviews, as well as on-site observations. A summary of the findings, together with comments and suggested improvements in the MCC environment, follows.

Since PM involves checking equipment parameters, it is frequently followed by certification to save additional labor. Equipment is also certified after CM in every case that involves changing or tuning of certification parameters. Typically equipment and service is certified monthly, but, depending on the equipment or service, it may be certified daily.

The final judgement that the facility is certifiable is based on some or all of the following, depending on the system:

a. Performing physical inspections. A check for worn parts and corrosion is performed, as well as other procedures such as checking of battery fluid levels and specific gravity.

b. Reading key parameters. If any parameters are found to be out of tolerance, they are brought back within the specified parameters.

c. Running self-diagnostics on the system. The CCCH, DARC, CDC, ARTS II, and ARTS III may be certified by running diagnostic tests alone. Much of this equipment is automated. Certification of other equipment often involves PM procedures, physical inspection, reading of key performance parameters, etc.

d. Performing PM procedures according to the TIs and manuals. This may include box by box functional testing, testing of backup systems, injecting test signals and observing output, simulating fault conditions, and observing system response.

e. Performing visual checks of equipment and service status indicators. Paradyne (and other) modem-error indications are provided by status lights on the control panels.

Many of the certification procedures are performed by following the FAA maintenance handbooks and TIs.

The maintenance handbooks are created and provided by the FAA, while the TIs are usually provided by the manufacturers. The maintenance handbooks are used for mandating PM and certification intervals. They also specify allowable tolerances for the key parameters, and the TIs provide sequences of operations (step-by-step procedures) for adjusting various parameters. Technicians in some areas prepare simplified reference sheets that describe the comprehensive procedures in a much smaller space (e.g., display generators and CDC area).

As equipment is RMMed, it will be possible to initiate self-diagnostic tests remotely from the MCC or work centers. This is currently being implemented, and will increase over time.

Questions were asked in order to identify certification tasks that are difficult to perform. There are no additional difficulties other than those associated with performing PM procedures. Most of these difficulties are physical in nature, and therefore, AI applications would be of little use in alleviating them.

At the current stage of MCC implementation, only a limited number of diagnostic tests or certification tasks can be initiated from the MCC. Therefore AI applications are not recommended at this time. Future equipment designs are taking remote test initiation into consideration, which will make it possible to certify more equipment remotely from the MCC or work center. In this end state, an AI application should be developed for automatic certification.

4.3.7.2 Applications Identified.

There are no applications identified for the present environment but, as more systems come under RMM, an AI application should be developed for certification.

4.3.8 Training.

4.3.8.1 Description.

A well-trained technician is an asset in the FAA work environment. A trained and experienced technician performs a given task quickly, efficiently, systematically, and thoroughly. The objective is to train technicians to meet current and future needs, in a dynamic environment, incorporating modern technology. There are several obstacles to overcome if this goal is to be met.

The technician's workload at the work centers precludes sufficient numbers of technicians being sent for training at the same time. Also, the frequency of training courses given at the FAA Academy, on new equipment, is low. Academy training cannot be totally replaced by existing CBI because the technicians get hands on experience at the Academy that CBI cannot provide. There is also theoricial material to be learned, which is best taught with two-way instructor-student communication. The CBI does not provide this, however, a compromise may be possible. Video or Personal Computer (PC)-based courses may be developed for preparatory courses as well as self-paced refresher training. This may allow shorter courses at the Academy, thus enabling more courses to be offered, as well as increased participation.

PC-based instructional material may be developed to cover simulated fault conditions, and desired responses to minimize outages and outage durations. These conditions may be rehearsed in site-specific configurations. Such training is going to be of increasing value since new equipment employing modern technology will be more reliable, thus offering little collective hands-on experience by way of CM. For this reason, intercommunications will play an important role. This can be achieved using a well designed PRF and a national bulletin board, sharing problems, solutions, and experiences between different sectors.

An intelligent tutoring system (also called an adaptive trainer) based on an Expert Neural System (ENS) will be of immense use to the technician. This system will adapt to a technician's individual capabilities. Such a system will have explanation (why, what, how, and what if) capabilities. Using explanation capabilities, a user can select certain types of information from the display, and the system will automatically reconfigure the way the information is presented. The main issue is implementing learning in such systems.

The key to building such a training device is the use of learning and scenario modeling techniques. The ENS would learn to make decisions by using a training set from the PRF (for a system or a piece of equipment). It would be given both a collection of data, and the decision it is intended to make for a particular collection. Several training sets will be used for training purposes. An intelligent tutoring system, once programmed, will be able to distinguish the same features in other data, and can make decisions about data for which it has not been programmed.

PC-based applications are useful by-products of ES developments such as CM applications and the problem resolution ES. The technician will be able to initiate simulations of fault conditions to test and refresh their knowledge with the help of system recommendations.

4.3.8.2 Criteria for Assessing the AI Application Selection for Training.

The application has a well-defined goal of supplementing FAA Academy training with PC-based training, and an intelligent tutoring system. It will be deemed successful if:

a. The PC-based instruction helps to reduce the Academy training duration without sacrificing the quality of the training.

b. The PC-based instruction keeps the technicians' knowledge current for the equipment they maintain.

c. Easy access to the training material helps train more technicians so that the equipment in a sector is covered by a greater number of technicians. This would help reduce the load imbalance on the technicians and increase the availability of expertise.

d. The PC-based instruction is easy to follow, and meets the need for self-paced training by accommodating individual differences in learning, as well as the amount of time available during the training.

e. The intelligent tutoring system is realistic, adaptable, flexible, and modular. It can be used on-line or off-line by technicians. A trained ENS will provide quick access to problem solutions.

4.3.8.3 The AI Application Selection for Training.

The advantages of the selected AI application are that:

a. Training will be more accessible.
b. More expertise will be available as a result of training more technicians.
c. Refresher training will be available to a technician on demand.

4.3.8.4 Applications Identified.

The following applications have been identified for possible AI application:

a. ES-based preparatory courses for Academy training on PCs.

b. Refresher training, including fault condition simulations on PCs.

c. An intelligent tutoring system using ENS technology, including learning and scenario modeling techniques, on a workstation.

4.3.9 PM.

PM is maintenance performed on equipment so that conditions that can cause imminent failures are recognized and rectified.

4.3.9.1 Description.

Most of the PM procedures are the same actions taken to certify equipment. The PM procedures are comprised of the following actions, depending on the type of system:

a. Physical inspections. The technician checks for worn parts, corrosion, and other deterioration.

b. Cleaning, lubrication. This keeps the equipment in good operating condition and appearance.

c. Reading key parameters. If any parameters are found to be out of tolerance, the technician adjusts them, or takes further action such as coordinating flight inspection.

d. Running self-diagnostics on the system. Some PM functions can be performed on CCCH, DARC, CDC, ARTS IIA, and ARTS IIIA equipment by running the system's self-diagnostic software to identify any potential problems.

e. Performing PM procedures according to TIs and handbooks. This may include box by box functional testing, testing of backup systems, injecting test signals and observing desired output, simulating fault conditions, and observing system response.

f. Performing visual checks of equipment and service status indicators. Paradyne (and other) modem-error indications are provided by status lights on the control panel.

Many of the PM procedures are performed initially by following the TIs. After considerable experience, the daily, weekly, and sometimes monthly PM procedures are performed without consulting the TIs. However, the quarterly, semiannual, and annual PM procedures are performed by consulting the maintenance handbooks and TIs, since there is less familiarity with those procedures.

Technicians in some areas prepare simplified reference sheets that describe comprehensive procedures in a much smaller space. Paperless documentation may be accomplished by putting the maintenance documentation in electronic media (see section 4.3.4).

The diagnostic and test equipment used by the technicians consists of standard multimeters, oscilloscopes, as well as specialized test equipment. The specialized test equipment required depends on the system maintained. New systems, such as the ASR-9, have embedded automated test equipment and specialized test equipment left on-site. Localizers and glideslopes have some specialized equipment that is carried to the site. On the other hand, the CCCH does not have much specialized equipment although it has a set of software-driven diagnostic tests.

Some systems, such as the CCCH, CDC, DARC, and ASR-9, have adequate self-diagnostics, while others, such as some PCSs and communication equipment (paradyne) have limited self-diagnostics. Self-diagnostics are initiated at power up, and as a part of PM procedures. As equipment is RMMed, it is possible to initiate the self-diagnostic tests remotely from MCCs or work centers.

Many PM procedures are difficult to perform for various reasons. These procedures include:

a. Maintenance procedures requiring coordination between two or more people. For example, flight inspections for radar and navigational aid facilities were considered to be difficult.

b. Adjusting the power supply voltage in the CDC to achieve load balancing. The setting is highly critical and unstable. Making adjustments to the long-range radar circuits containing vacuum tubes is a task that must be performed frequently.

c. Tasks requiring the cleaning of equipment.

d. Lubrication. These tasks are difficult because of inaccessibility of the equipment.

e. Servicing overhead display screens. These tasks are difficult because they involve lifting of heavy equipment.

The sources of difficulty in these PM procedures are not analytical in nature, and therefore are not considered as candidates for AI applications. However, it was brought up during the interviews that a system that could anticipate fault conditions in equipment would be beneficial to the technician. AI, therefore, may have some place in facilitating certain closely associated activities such as maintenance logging, monitoring, and certification.

4.3.9.2 Applications Identified.

There are no applications identified at present. A system for anticipating fault conditions is a future application.

4.3.10 Summary of Recommended Applications

4.3.10.1 CM1.

a. Description: CM1 will perform fault interpretation, fault correction, decision explanation, repair prescription, and fault anticipation functions on newly fielded equipment and systems.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, ML, FL, IDB, and DAI.

d. Architecture/Model: Model-based, Rule-based.

e. Platforms

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software:

a) Function Specific: IDEA from AI Squared, Inc., or CAIS from Rosh Intelligent systems.

b) General Shell: G2, ART, KEE, Nexpert, Level5, ADS

f. Implementation time (estimated): 75 weeks per knowledge base. One knowledge base per type of equipment. Total types of equipment estimated at approximately 70.

g. Comments: Other applications

CM1
2. PRES
3. IDER

4.3.10.2 CM2.

a. Description: CM2 will perform fault interpretation, fault correction, decision explanation, repair prescription and fault anticipation functions on older fielded equipment and systems.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, ANN, FL, IDB, and DAI.

d. Architecture/Model: Model-based, Rule-based, Back Propagation.

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software:

a) Function Specific: IDEA from AI Squared, Inc. or CAIS from Rosh Intelligent systems.

b) General Shell: G2, ART, KEE, Nexpert, Level5, ADS.

f. Implementation time (estimated): 65 weeks per knowledge base. One knowledge base per type of equipment. Total types of equipment estimated at 100 or more.

g. Comments: Other applications

1. CM2
2. PRES
3. IDER

4.3.10.3 Alarm Processing

a. Description: An alarm processing advisor will monitor alarms, perform low level processing and classification using ANS, and provide advice on diagnostics using KBES and FL.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

Applicable Technology: KBES, ANN, ENS, FL, and GA.

d. Architecture/Model: Rule-based, Back Propagation, ENS, FL (Imprecise/ Qualitative Concepts), and GA.

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software:

a) Function Specific: IDEA from AI Squared, Inc., or CAIS from Rosh Intelligent systems;

b) General Shell: G2, ART, KEE, Nexpert, Level5, ADS, Knowledge Craft from Carnegie Group, Goldworks III from Gold Hill Inc., ANITA(tm) from CCG Associates, Inc.

f. Implementation time (estimated): 75 weeks after all or most of the alarms are received at a central location such as the MCC or SMMC.

g. Comments: Other applications

1. Auxiliary KBES Applications:

a) APES
b) MAP
c) RES

4.3.10.4 Monitoring.

a. Description: Monitor will provide data acquisition, processing, and interpretation identify unusual trends, and alert technicians.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, ANN, ENS, and FL.

d. Architecture/Model: Rule-based, Back Propagation, Adaptive Resonance Theory (ART)

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software:

a) Function Specific: IDEA from AI Squared, Inc., or CAIS from Rosh Intelligent systems.

b) General Shell: G2, ART, KEE, Nexpert, Level5, ADS, Knowledge Craft from Carnegie Group, Goldworks III from Gold Hill Inc., Artificial Neural Information-processing Techniques and Analysis (ANITA(tm)) from CCG Associates, Inc.

f. Implementation time (estimated): 65 weeks after all key parameters of the equipment are wired to be received at a central location such as the MCC or SMMC.

g. Comments: Other applications

1. IF
2. FA
3. EMS

4.3.10.5 Administrative Functions.

a. Description: For administrative functions, ES will perform automatic monitoring of various forms, make an automatic checklist for a technician site visit, schedule maintenance activities, and update a PRF database.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, Hypertext.

d. Architecture/Model: Rule-based

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software: General Shell: G2, ART, KEE, Nexpert, Level5, ADS, VP Expert, Microsoft Project, TimeLine.

f. Implementation time (estimated): 65 weeks per system.

g. Comments: Five ES applications are recommended under ADMIN. Each can be developed separately, or an integrated system can be designed.

4.3.10.6 Information Retrieval.

a. Description: This ES will provide technicians access to on-line maintenance documentation. Based upon a query, the ES will pinpoint the relevant portion of a manual(s).

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, Hypertext, ANN, NLP, IDB.

d. Architecture/Model: Rule-based, Adaptive Resonance Theory, Back Propagation.

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software:

a) Function Specific: Search Express document imaging systems by Executive Technologies Inc.

b) General Shell: G2, ART, Nexpert, Level5, ADS, ANITA(tm) from CCG Associates, Inc., Neural Works Professional from NeuralWare Inc.

f. Implementation time (estimated): 75 weeks.

g. Comments: Making expert maintenance manuals available on line and also intelligently retrieving them for diagnostic purposes is not a trivial task, but there is an expressed need for such material.

4.3.10.7 Problem Resolution.

a. Description: This system will track maintenance problems, and their associated resolutions.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, IDB, ANN, ENS, NLP, and DAI.

d. Architecture/Model: Rule-based, Expert databases, Back Propagation, Adaptive Resonance Theory (ART), NLP Query.

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software: General Shell: G2, ART, Nexpert, Level5, ADS, ANITA(tm) from CCG Associates, Inc., Neural Works Professional from NeuralWare Inc.

f. Implementation time (estimated): 78 weeks per equipment knowledge base.

g. Comments: Other applications

1. PRC
2. PRES
3. ENSHD

4.3.10.8 Certification.

a. Description: The certification application will certify equipment each time it goes through PM as well as through CM. It will also interface with the PRS to obtain historical information on equipment and/or systems.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, ANN, ENS, and DAI.

d. Architecture/Model: Rule-based with explanation, Back Propagation.

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX and/or DOS Operating Systems.

2. Software: General Shell: G2, ART, Nexpert, Level5, ADS, Goldworks III, ANITA(tm) ART from CCG Associates, Inc.

f. Implementation time (estimated): 52 weeks.

g. Comments: This is a future application. Its implementation may require interfacing with the MCC and making decisions in a real-time environment.

4.3.10.9 Training.

a. Description: An Intelligent Adaptive Trainer will be used for training. It will have explanation and hypothetical reasoning capabilities.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: KBES, ANN, ENS, ML, Hypertext, and NLP.

d. Architecture/Model: Rule-based, Model-based, ART, Back Propagation, Example Based Learning.

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software: General Shell: G2, ART, Nexpert, Level5, ADS, Goldworks III, ANITA(tm) ART from CCG Associates, Inc.

f. Implementation time (estimated): 78 weeks per equipment training.

g. Comments: Other applications.

1. ES-based preparatory courses for Academy training on a PC workstation platforms.

2. Refresher training including fault condition simulations on a PC workstation platforms.

3. An intelligent tutoring system using ENS technology, and including learning and scenario modeling techniques on a PC workstation.

4.3.10.10 PM.

a. Description: PM will provide monitoring of the equipment and the system and will anticipate failures. It will also interface with the PRS to obtain historical information on equipment and/or systems.

b. System(s): Radar, Navigational aids, Computers, Communications, Environmental Systems.

c. Applicable Technology: ENS and DAI.

d. Architecture/Model: Rule-based with explanation, Back Propagation

e. Platforms:

1. Hardware: Intel 80486 based IBM PC compatible, SUN, RISC workstations running UNIX(tm) and/or DOS Operating Systems.

2. Software:

a) Function Specific: IDEA from AI Squared, Inc., or CAIS from Rosh Intelligent systems;

b) General Shell: G2, ART, Nexpert, Level5, ADS, Goldworks III, ANITA(tm) ART from CCG Associates, Inc.

f. Implementation time (estimated): 52 weeks.

g. Comments: This is a future application. Its implementation may require interfacing with statistical software packages, since it will involve some kind of prediction for comparison purposes.

4.4 RANKING OF AI APPLICATIONS.

After the second and third steps of the process were completed (shown in figure 4-1), the 10 principal applications were identified and ranked. The selection of an application is a critical task in the development of an AI system, therefore, a significant amount of effort should go into the selection process. To evaluate the potential of a possible application, a set of simplified criteria was developed. This criteria set was then applied to the applications identified.

4.4.1 Ranking Criteria.

Selection criteria for AI systems are based on the premise that an AI system should be considered only when development is possible, appropriate, and justified. The following criteria in each of these three areas are used for analyzing and ranking applications.

a. Possible. An AI system is deemed possible if the following criteria are met:

1. P1 - The task requires the use of heuristics, not common sense reasoning.

2. P2 - The task does not require knowledge from a very large number of areas.

3. P3 - The task is well understood.

4. P4 - There exists a genuine expert to work with the project.

5. P5 - The expert will commit a substantial amount of time to the development of the system.

6. P6 - Any requirement for real-time response will not involve extensive effort.

b. Appropriate. An AI system is deemed appropriate if the following criteria are met:

A1 - Conventional programming approaches to the task are not satisfactory.

2. A2 - The task is sufficiently narrow and self-contained.

3. A3 - The domain is fairly stable. Expected changes are such that they utilize the strengths of AI systems.

4. A4 - The effects of institutional development that will change the definition of the task can be foreseen and taken into account.

5. A5 - Managers have previously identified the need to solve the problem that the system attacks, and they support the system development.

6. A6 - Potential users would welcome the system.

c. Justified. An AI system is deemed justified if the following criteria are met:

J1 - Expertise is not available on a continuing basis.

2. J2 - The completed system is expected to have a significant, measurable payoff (e.g., an increase in productivity, reliability, and performance).

3. J3 - The need for the task is projected to continue for several years.

4.4.2 Application Ranking.

The selection of applications suitable to AI technology was accomplished through the application of the stated criteria to the potential applications identified. Ranking was initiated through the creation of matrices that compared each of the applications with the criteria developed for ranking the applications. Figures 4.4.2-1, 4.4.2-2, and 4.4.2-3 provide matrices that indicate the qualitative strength of each application. The symbols used to delineate each criterion are codes that are used in Section 4.4.1.

A numeric value was assigned to each criterion, and a value was assigned to each application for every criterion. Figure 4.4.2-4 shows the weights assigned to the criteria and the cumulative scores accrued by each application. The criteria depicting payoff, volume of transactions, scope of the task, expert availability, complexity of the task, and nature of the task were given the most weight. This figure clearly indicates the 10 application groupings to be implemented as an AI application.

4.4.3 Application Scope.

The fifth step of the process shown in figure 4-1 is the identification of applications ready for development. This sub-section identifies a segment of the CM application that is best suited for initial development.

	POSSIBLE					
	P1	P2	P3	P4	P5	P6
CORRECTIVE MAINTENANCE 1	Y	Y	N	Y	N	Y
CORRECTIVE MAINTENANCE 2	Y	Y	Y	Y	Y	Y
ALARM PROCESSING	Y	Y	Y	Y	Y	Y
MONITORING	Y	Y	Y	Y	Y	Y
ADMINISTRATIVE FUNCTIONS	Y	Y	Y	Y	Y	Y
INFORMATION RETRIEVAL	Y	Y	Y	N	N	Y
PROBLEM RESOLUTION FILE	Y	Y	Y	Y	Y	Y
CERTIFICATION	Y	Y	N	Y	N	Y
TRAINING	Y	Y	Y	N	N	Y
PREVENTIVE MAINTENANCE	Y	Y	N	Y	N	Y

FIGURE 4 4 2-1 APPLICATION RANKING FOR "POSSIBLE" CRITERIA

APPROPRIATE

	A1	A2	A3	A4	A5	A6
CORRECTIVE MAINTENANCE 1	Y	Y	Y	Y	Y	Y
CORRECTIVE MAINTENANCE 2	Y	Y	Y	Y	Y	Y
ALARM PROCESSING	Y	Y	Y	Y	Y	Y
MONITORING	Y	Y	Y	Y	Y	Y
ADMINISTRATIVE FUNCTIONS	N	Y	Y	Y	Y	Y
INFORMATION RETRIEVAL	Y	Y	Y	Y	Y	Y
PROBLEM RESOLUTION FILE	Y	Y	Y	Y	Y	Y
CERTIFICATION	Y	Y	Y	Y	Y	Y
TRAINING	Y	Y	Y	Y	Y	Y
PREVENTIVE MAINTENANCE	Y	Y	Y	Y	Y	Y

FIGURE 4 4 2-2 APPLICATION RANKINGS FOR "APPROPRIATE" CRITERIA

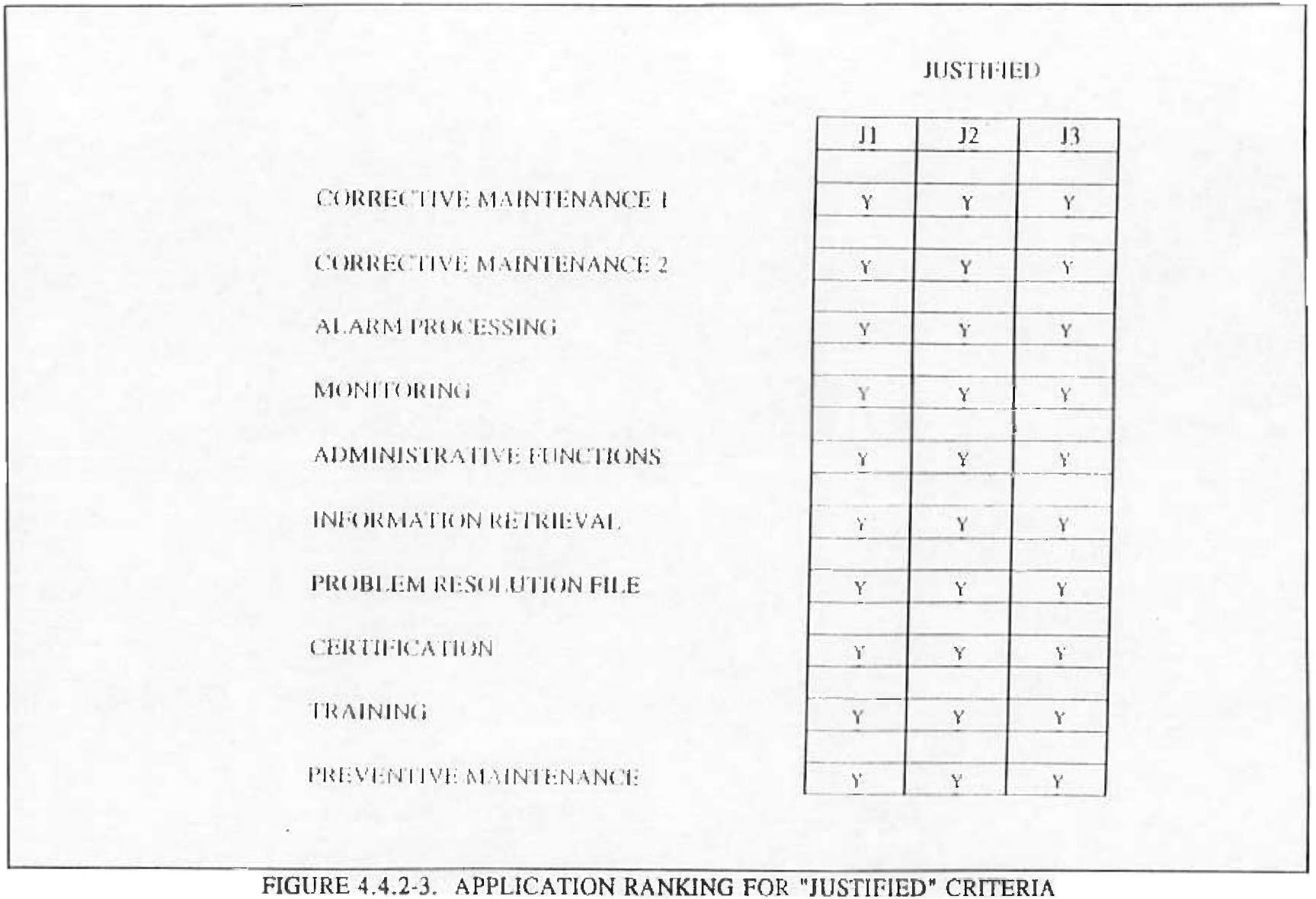

FIGURE 4.4.2-3. APPLICATION RANKING FOR "JUSTIFIED" CRITERIA

APPLICATION WEIGHTS

Applications / Criteria	Maximum Score	CM		Alarm Processing	Monitoring	Administrative Functions	Info Retrieval	Problem Resolution	Certification	Training	Preventive Maintenance
		CM1	CM2								
Payoff (12)	10	10	10	10	10	10	10	10	10	10	10
Expertise Being Lost (1)	10	10	10	10	10	10	10	10	10	10	10
Expertise Needed 24 hrs. (2)	10	10	10	10	10	10	10	10	10	10	10
Expert Available for Development (3)	10	8	10	10	10	10	8	10	8	8	8
Volume of Transactions (4)	10	10	10	10	10	10	10	10	10	10	10
Scope of Task (5)	10	8	10	10	10	6	10	10	5	8	10
Complexity of Task (6)	10	10	10	10	10	8	10	8	7	8	8
Nature of Task (7)	10	8	10	8	8	10	8	10	8	8	8
User Consideration (8)	5	5	5	5	5	5	5	5	5	5	5
Management Considerations (9)	5	5	5	5	5	5	5	5	5	5	5
Institutional (10)	5	5	5	5	5	5	5	5	5	5	5
Technology Maturity (11)	5	3	5	5	3	5	2	5	5	4	3
Total Score	100	92	100	98	98	94	93	98	88	91	92

Legend:

(1) J1
(2) J3
(3) P4, P5
(4) Refers to labor intensive activities, J3, A1
(5) P1, P6, A2
(6) P1-3, A2
(7) P1-3, A8
(8) A6
(9) A5
(10) A4
(11) Refers to C.G. knowledge and literature survey, A1, A3
(12) J2, A1

FIGURE 4.4.2-4. WEIGHT ASSIGNMENT

The CM application is extensive. As originally described, the ES will handle problems for every aspect of the FAAs AF CM operations. However, it is unreasonable to implement the entire ES in a single stage. An approach that includes several implementation stages is recommended.

5. DEVELOPMENT ISSUES FOR KBES.

CM2 has been identified as a potential ES application. This section discusses development issues for a diagnostic ES. The purpose of this section is to develop a feasible implementation plan for a diagnostic ES. General implementation issues, such as knowledge representation and interfaces, are addressed first. Second, technology issues are examined, focusing on software and hardware. Finally, a plan for implementation is generated, including milestones and estimates of personnel and time.

5.1 GENERAL ISSUES.

To develop an implementation plan, hardware, software, and ES tools issues must be addressed first. These issues focus on the knowledge to be captured and formalized in the system, the inferencing techniques that will manipulate the knowledge, and the interface between the ES and the user.

5.1.1 Knowledge.

Expertise in a task domain involves many different types of knowledge about that domain. The representation and reasoning facilities in an ES must be able to integrate knowledge into a coherent knowledge base that can effectively support the system's activities (see figure 5.1.1-1). The CM2 ES contains most of these types of knowledge. All knowledge types cannot be represented in the same structure, therefore, the representation must be investigated.

5.1.2 Knowledge Representation.

An important part of ES implementation is the choice of knowledge representation techniques. There are two purposes of analyzing knowledge representation early in the development cycle. The first purpose is to determine if the domain knowledge held by experts can be captured and formalized. The second purpose is to guide the selection of tools and techniques that have the proper capabilities. Figure 5.1.2-1 shows a variety of knowledge representation techniques that may be used in an ES.

Most knowledge in the monitoring and diagnostic areas may be generally categorized into two basic types: mental models and rules.

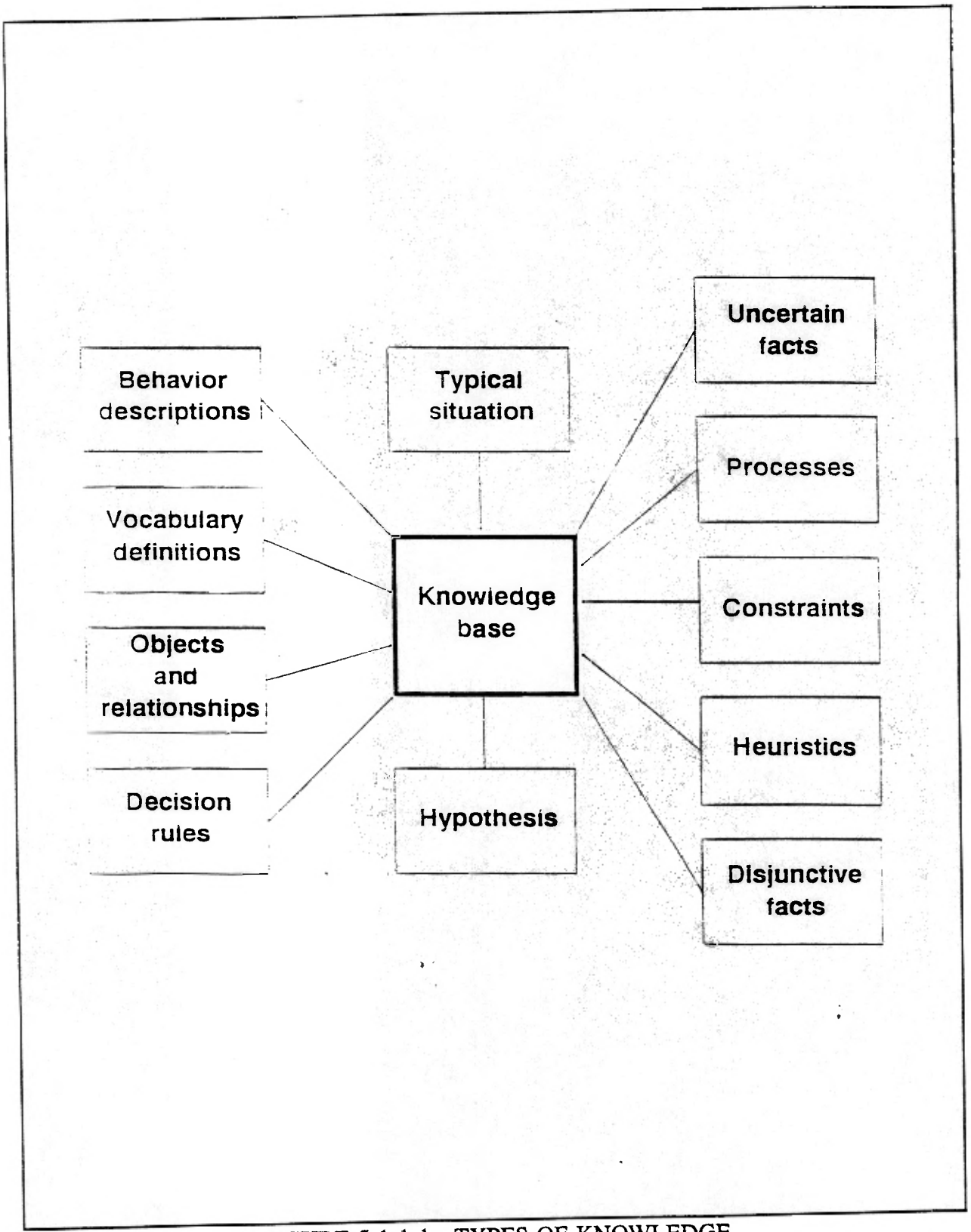

FIGURE 5.1.1-1. TYPES OF KNOWLEDGE

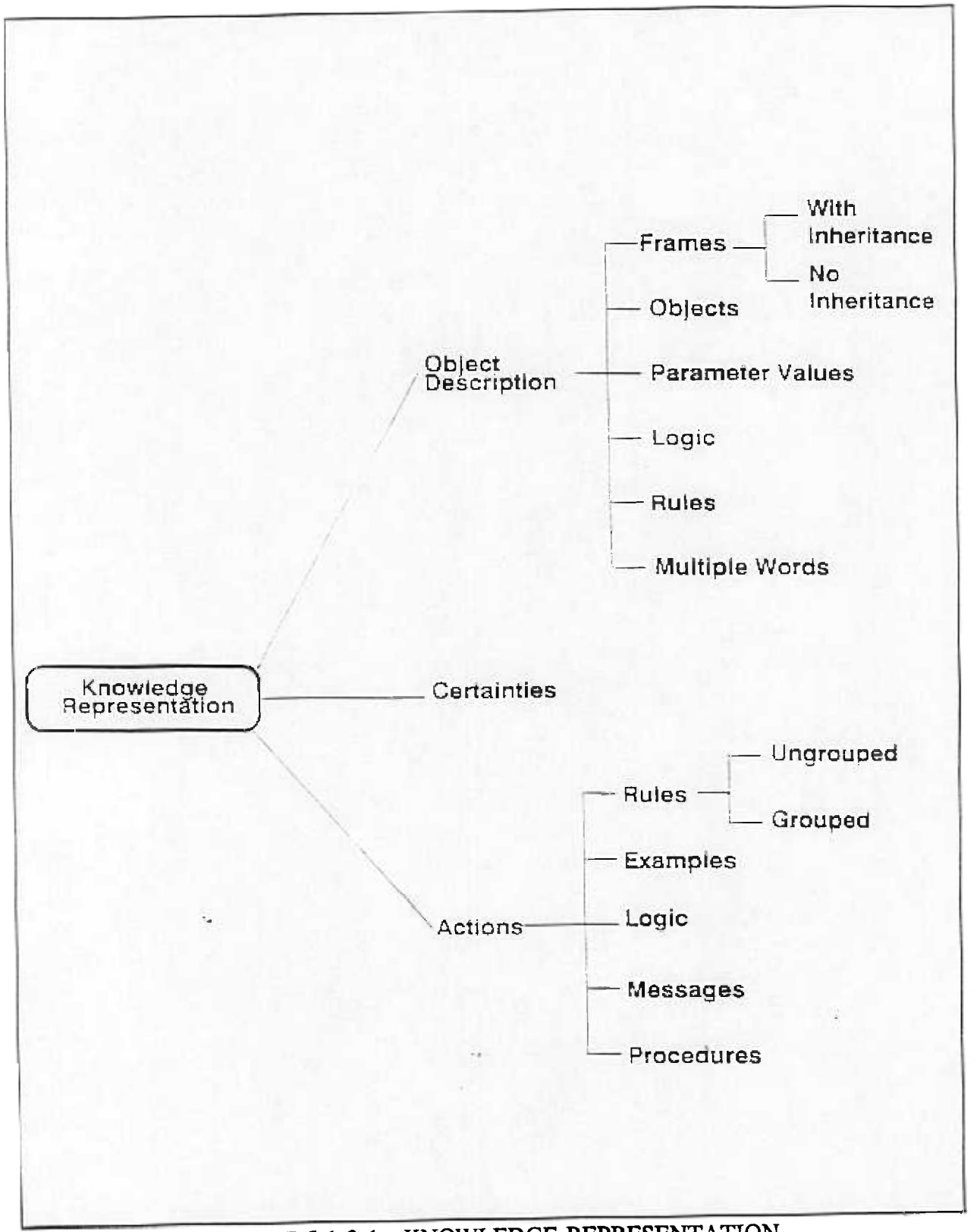

FIGURE 5.1.2-1. KNOWLEDGE REPRESENTATION

a. Mental models. Technicians maintain a mental model of the equipment configuration, operating systems, software, and hardware. For example, each piece of hardware could be described with the following facts:

1. Name
2. Number
3. Location
4. Operating Systems
5. Software
6. Data Communication Lines
7. Interfaces
8. Common Problems
9. Repair Person
10. Others

b. Rules. Technicians have knowledge in the form of if-then rules. This knowledge is used in conjunction with the mental models to monitor, diagnose, debug, and repair the systems.

The mental models and technician rules can be formalized, using the knowledge representation techniques of frames and rules. Both techniques can be easily applied to the knowledge of technicians. The rule to rule transformation is apparent. The mental models of the technicians may be represented in the form of a frame. The ASR-8, communication lines, hardware, software, and operating systems will each have generic frame representations. The slots or attributes of each frame will uniquely describe the frame by holding information about particular objects. For example, the frame describing a communication line may be organized in this way:

FRAME COMMUNICATIONS LINE

ATTRIBUTES

NUMBER: 116
DESTINATION: Honolulu
LINE STATUS: up
LINE USAGE: in-use
HARDWARE USED: IBM 3083
OPERATING SYSTEMS USED: MVS, Guardian
SOFTWARE USED: X.25
DATA FLOW DIRECTION: R
DATA TYPE:
LINE USAGE SCHEDULE:
OTHER:

For this example, the frame type is a communications line that has 11 descriptive attributes. The values of these attributes uniquely describe line number 116, the X.25 line that receives data from Honolulu.

The knowledge representation techniques described in this section can formalize and capture the knowledge of technicians. To use this knowledge, an ES must utilize and apply inferencing techniques to the knowledge.

5.1.3 Inferencing.

To produce valid conclusions, the CM2 system must employ the proper inferencing techniques. Two basic types of inference methods are used: goal driven and data driven. These two techniques may be used separately, or in conjunction with each other, a method called a hybrid approach. Figure 5.1.3-1 shows other inferencing techniques that can also be used. Goal driven, or backward chaining, inference mechanisms are applicable in situations in which one particular fact must be determined. For example, if the user wants to know if the system is functioning normally, he or she will process only those rules that conclude that the particular system is functioning normally.

Data-driven, or forward chaining, inference mechanisms are used when data are present, and conclusions must be drawn. For example, when a sequence of system messages is present, the user will process rules that have satisfied condition statements. The application of these rules will allow the user to draw conclusions from the present sequence of system messages.

The hybrid approach will probably be necessary for the CM2 ES. Both goal driven and data driven inferencing techniques may be used. However, further knowledge, engineering, and analysis are necessary before firm conclusions can be drawn.

5.1.4 Interfaces.

In addition to knowledge representation techniques and inference mechanisms, a review of interface requirements is necessary to plan implementation. Two types of interfaces are examined: the UI, and an interface between the ES and the system messages from the system itself.

a. UI. The UI is an important aspect of any ES. Figure 5.1.4-1 shows some of the capabilities offered by ES UIs.

Techniques such as NLP, graphics, touch screens, icons, and menus can be used to create an efficient, user-friendly interface. However, for an initial implementation, extensive UIs are not necessary. The ES will probably support a combination of menus, simple graphics, descriptive icons, and low-level NLP.

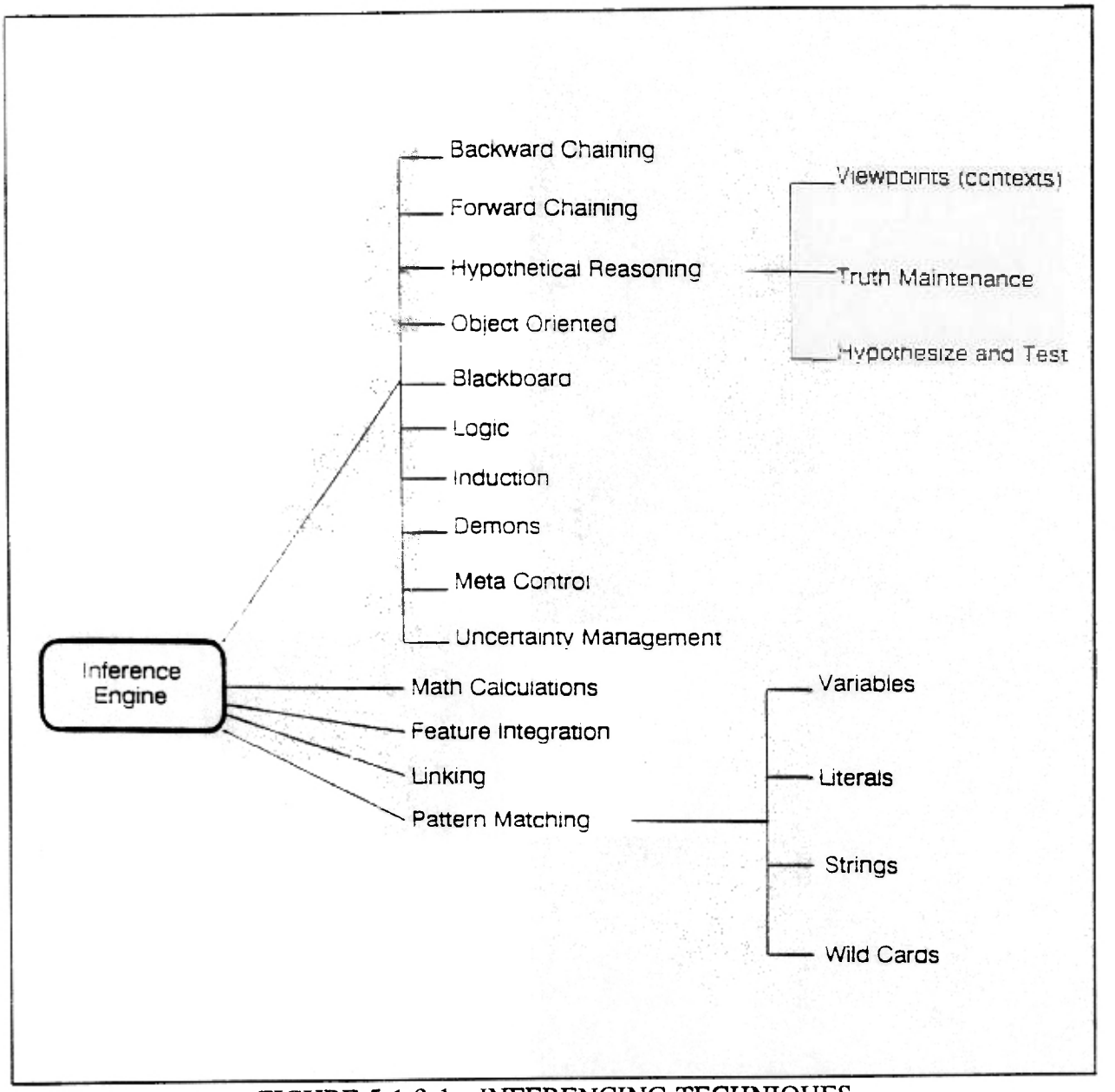

FIGURE 5.1.3-1 INFERENCING TECHNIQUES

b. System Message Interface. The ES is expected to monitor the system messages. This requires a special interface between the ES and the mainframe operating system. This interface can be divided into three parts: mainframe software, micro-to-mainframe communication, and workstation software. Each part of this interface will require special capabilities and efforts.

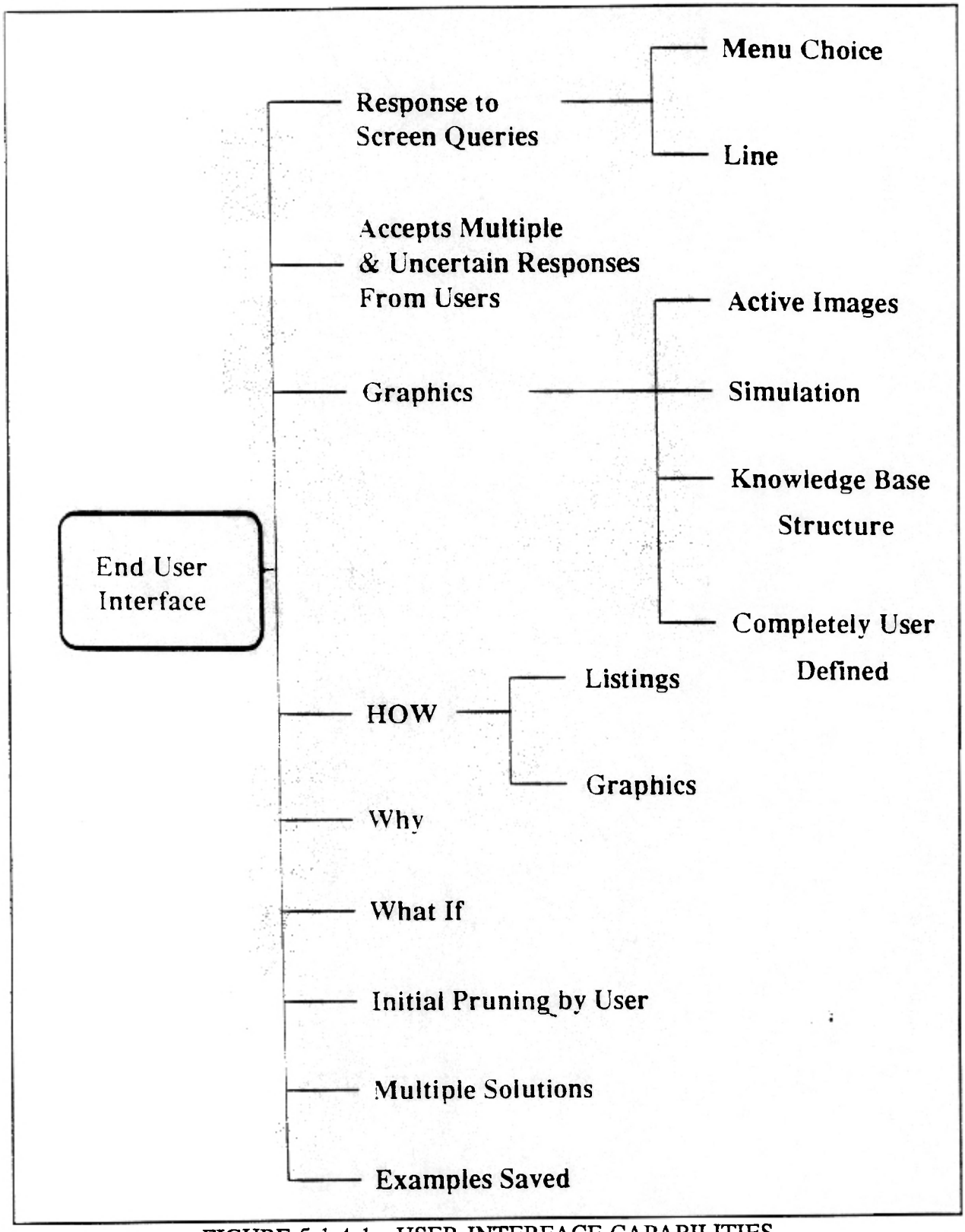

FIGURE 5.1.4-1. USER INTERFACE CAPABILITIES

5.2 TECHNOLOGY ISSUES.

The technology issues involved in building an ES include, primarily, software and hardware choices. Now that the general issues of knowledge, inferencing, and interfaces have been addressed, the actual hardware and software are chosen that will be used for implementation.

5.2.1 Software.

The software options for building an ES range from simple and flexible, to complex and unbending. Four basic types of software tools exist. Each of these will be discussed along with their advantages and disadvantages in the areas of knowledge representation, inferencing, and interfaces.

5.2.1.1 Standard Programming Languages.

Standard programming languages, such as C, Pascal, C++, Lisp, and Prolog provide the most flexible means of building an ES. However, because of the ground up development that is necessary when using a programming language, the development time is greatly increased relative to other techniques.

a. Knowledge Representation. A basic programming language gives the developer a full range of choices for knowledge representation. However, the programmer must know how to implement the knowledge structure using the selected programming language.

b. Inferencing. Any inferencing mechanism can be developed, but the programmer must implement it from scratch.

c. Interfaces. A standard programming language does not restrict the interfaces that can be used in the ES

5.2.1.2 ES Development Environments (ESE).

ESE, such as ADS, ART, GoldWorks, Nexpert Object, Level5, KEE, and MUSE, are powerful tools for ES applications development. These environments have been designed, from concept through implementation, to provide a comprehensive set of capabilities to the ES developer.

a. Knowledge Representation. ESE knowledge representations are based on the frame, and include rules, semantic nets, and other representation techniques. These tools allow great flexibility for knowledge representation, and provide assistance with knowledge organization.

b. Inferencing. ESE contain several inferencing mechanisms, including forward chaining, backward chaining, hybrid methods, nonmonotonic reasoning, and other techniques. Most environments allow for several independent inference paths to be followed simultaneously.

c. Interfaces. ESE provide a variety of tools for developing a UI. Most provide options for using menus, graphics, icons, active images, and natural language. External interfaces are possible either by integrating programs written in other languages, or by embedding the ES in other applications.

5.2.1.3 Specialized Tools.

Certain ESs can be built from specialized tools. Specialized tools are highly structured systems built for a specific application. For instance, PICON is a specialized tool designed for developing process control ESs.

a. Knowledge Representation. Knowledge representation in specialized tools is limited to those techniques that are appropriate for the intended domain. Little flexibility exists for creating new or unique representations.

b. Inferencing. Specialized tools contain only those inferencing techniques needed in the domain.

c. Interfaces. Interfaces are restricted to those required by the application.

5.2.1.4 ES Shells.

ES shells are generic tools developed for use with general types of problems. Shells may contain only one type of knowledge representation or one type of inference mechanism. Examples of ES shells are Personal Consultant Plus, Intelligence Compiler, and KES.

a. Knowledge Representation. Most shells use rules as the basis of knowledge representation. Some shells have added frame-like structuring mechanisms. Shells do not have great flexibility for developing powerful knowledge representations.

b. Inferencing. Shells offer a limited number of inferencing methods. Some may offer only backward or forward chaining. Few allow for multiple inference paths.

c. Interfaces. UIs in shells are usually restricted to either menus or text. Graphics, icons, and natural language interfaces can be used with very few. External interfaces are treated as a function call from the shell. The amount of external information that can be imported by a shell is restricted.

5.2.2 Hardware

As figure 5.2.2-1 indicates, hardware available for developing and running ESs falls into four general categories:

Mini and mainframe computers can be used to run large ESs. Cost: over $20,000.

b. Conventional workstations, such as Sun, Apollo, MicroVax, IBM RISC-6000, and AT, have the memory and speed to effectively run medium-sized applications. These range in price from $5,000 to $30,000.

c. Dedicated AI machines, such as Symbolics, TI Explorer, and Xerox, are optimized to run Lisp programs, and can handle large applications. These range in price from $50,000 to $100,000.

d. PCs, including IBM PC/XT/AT, 486AT, IBM PS/2, and Apple Macintosh, have been used for small applications, but by increasing memory and improving microprocessor speeds, these machines can be used for medium-sized applications. These range in price from $2,000 to $15,000.

5.2.3 Technology Selection

Given the options, categories of hardware and software are selected. Hardware and software decisions are based on several factors. Contributing factors include the ES's scope, knowledge representation, knowledge inferencing techniques, and interface requirements. The following two sections describe the hardware and software issues, and suggest categories of tools for implementation.

5.2.3.1 Computer Hardware

The following issues and criteria contribute to the suggestion that a workstation or PC would best fulfill the ES hardware requirements:

a The computer should not restrict the choice or functionality of ES tools.

b. The ES has the potential to be a real-time system, so processing speed is important.

The computer must have the capability to interface with a mainframe.

d. The computer must have a large memory because ESs are memory intensive.

A flexible UI must be provided.

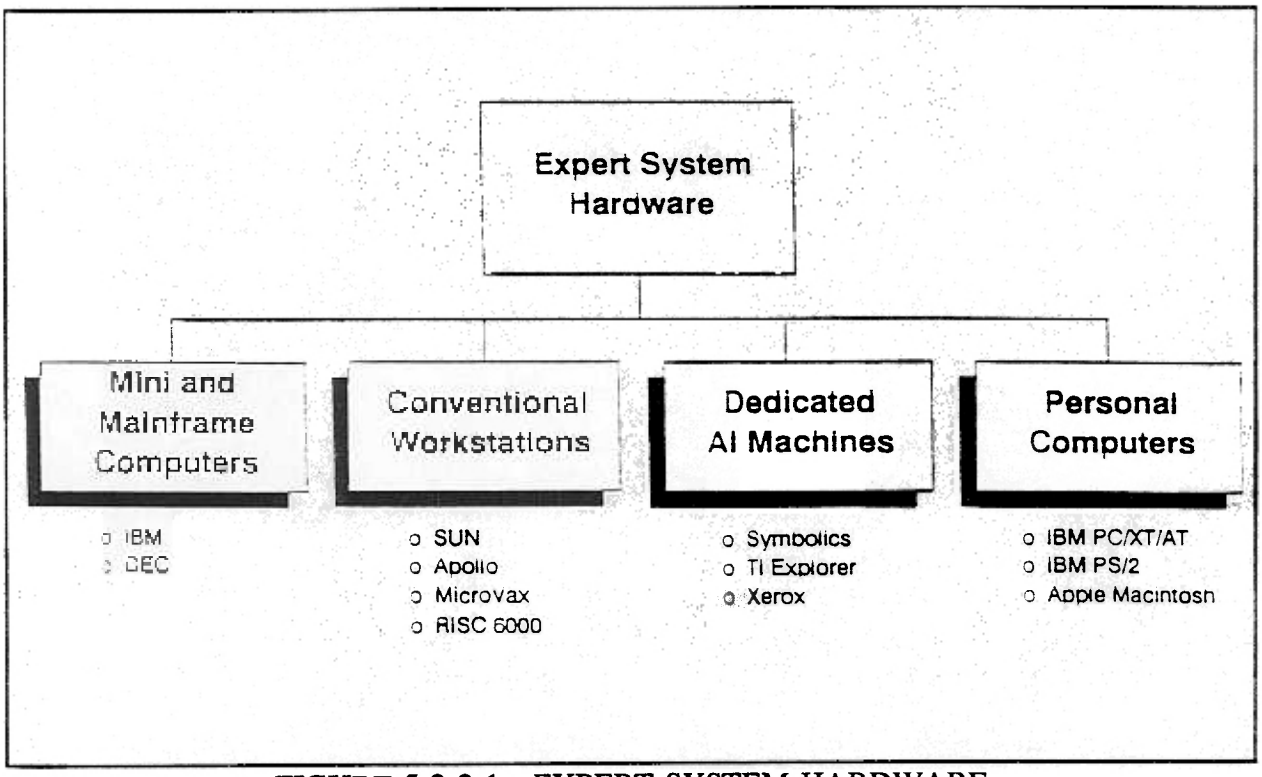

FIGURE 5.2.2-1. EXPERT SYSTEM HARDWARE

f. Although the main purpose of the computer will be to support the ES, it should have multi-purpose capabilities.

g. Cost should be as low as possible.

Based on an analysis of these requirements and the available hardware, workstations or PCs are deemed the best alternative for the pilot implementation. Workstations, especially Sun and MicroVAX, and microcomputers, such as IBM PS/2, 486 PC/AT machines, RISC 6000, and the Apple Macintosh, are viable candidates for hosting the CM2 ES application.

5.2.3.2 ES Software Tool Selection.

To select a class of tools for implementing the ES, the requirements, in terms of knowledge representation, inferencing techniques, and interface requirements, are analyzed. Figure 5.2.3.2-1 shows many of the factors that must be considered.

For the CM2 ES, the ES tool attributes of interest have already been stated. Knowledge representation capabilities must include both rules and frames. Interface capabilities must include a menu, a text UI, and an external interface that can access the CM2 system

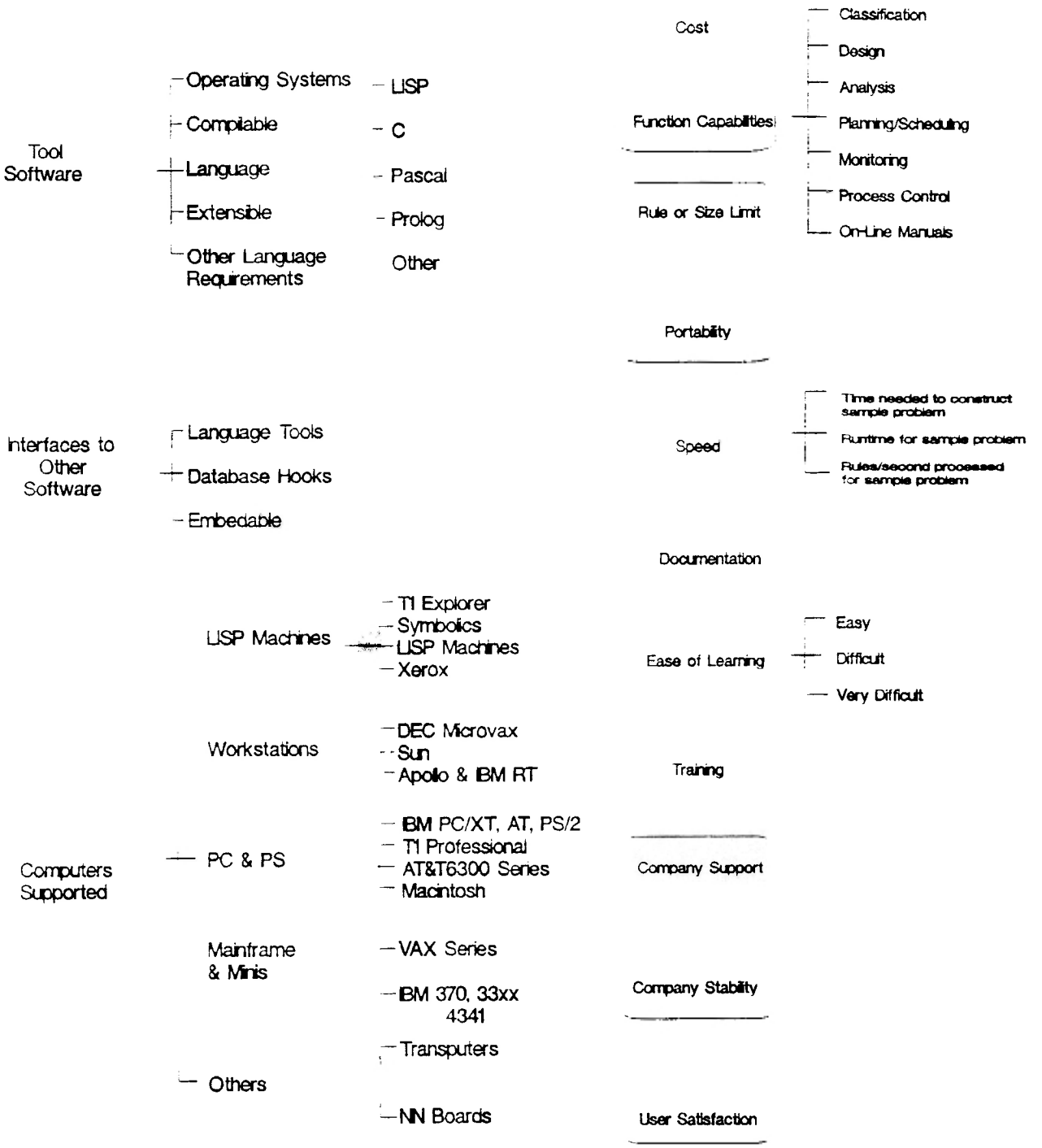

FIGURE 5.2.3.2-1. FACTORS FOR EXPERT SYSTEM TOOL SELECTION

messages. Hardware support must include microcomputers or workstations, and portability to minicomputers and mainframes would be an extra advantage. The developer's interface should include many of the features shown in figure 5.2.3.2-2.

Based on these requirements, a survey and analysis of current ES tools was performed (see figure 5.2.3.2-3). The results suggest a set of implementation tools, including the following:

a. ADS, AION, Inc.
b. ART, Inference Corporation
c. Goldworks II, Gold Hill Computers, Inc.
d. KEE, IntelliCorp, Level5 Object, Nexpert Object, Neuron Data

5.2.3.2.1 Specialized Tools.

AI application development and deployment is facilitated by the appropriate choice of a development tool and platform. Sometimes the platform on which the application is developed is not the same as the one on which it is fielded. The following is a summary of some platforms and tools that have potential for AI applications for AF.

a. Vendor: AI Squared, Inc.
139 Billerica Road
Chelmsford, MA 01824
(508) 250-4000

Product: Intelligent Diagnostic Expert Assistant (IDEA):

a) IDEA is a PC-based software diagnostic tool-kit to assist technicians in identifying component failures in electro-mechanical devices. IDEA has a model-based architecture, i.e., the system is built so that it knows how each component behaves. Advantage of the model-based approach is that the resulting ES can solve problems it has never encountered before. The IDEA PC Development Environment guides developers through the process of creating and editing diagnostic applications. The IDEA PC delivery environment allows a technician to execute the developed applications.

Information from the schematics and block diagrams is transferred to the system using DESCRIBE, a specially designed modelling language. An on-line debugger is included to help the developer test and correct problems within the initial model. An easy to use interface that stresses high resolution graphics guides the user through a diagnostic session. IDEA supports graphics files created with PCX standard format in either EGA or VGA resolution. This format allows a user to create graphics from paint and draw programs, as well as many desk top scanners and video digitizer programs.

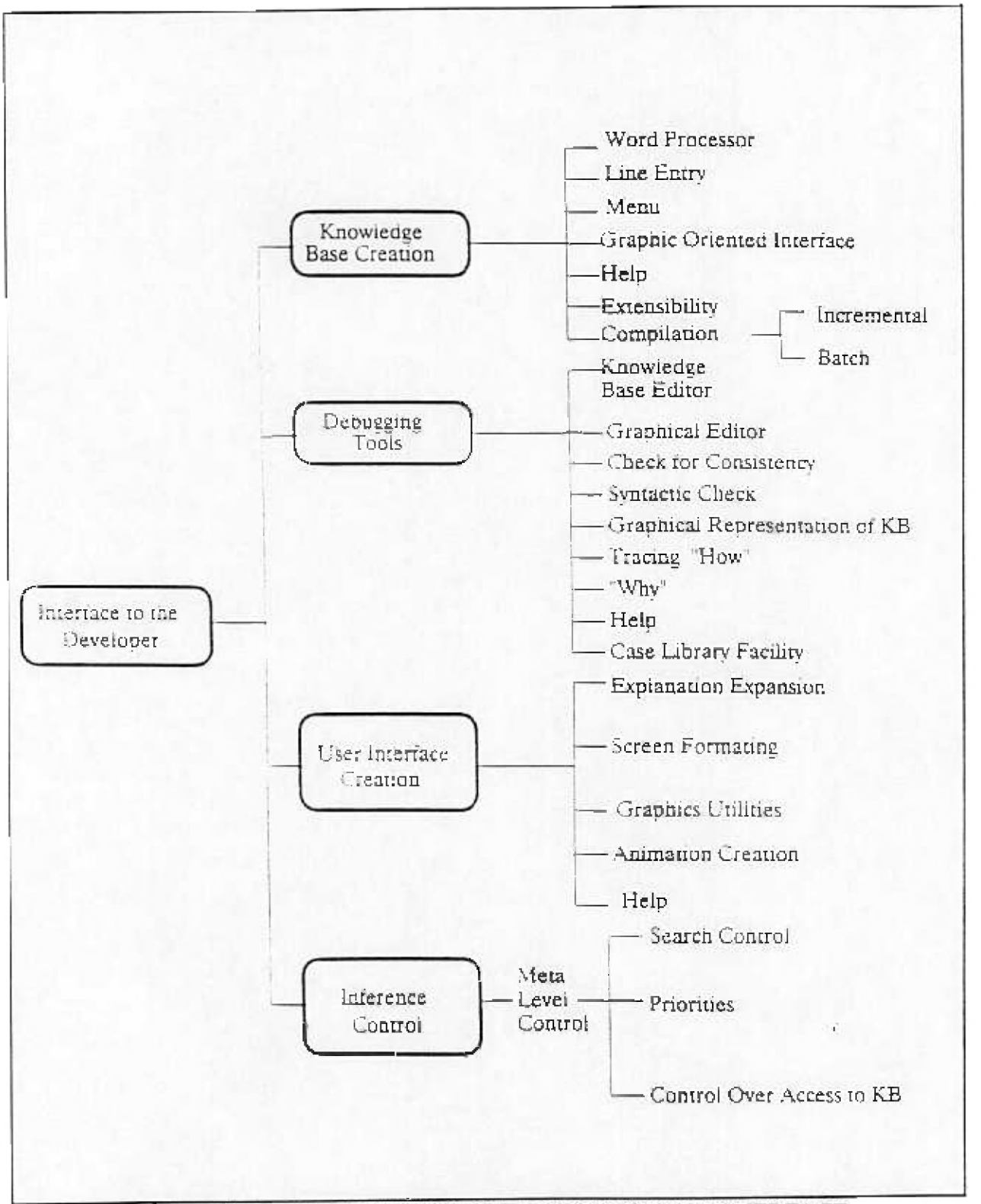

FIGURE 5.2.3.2-2. FEATURES OF A DEVELOPER'S INTERFACE TO AN EXPERT SYSTEM TOOL

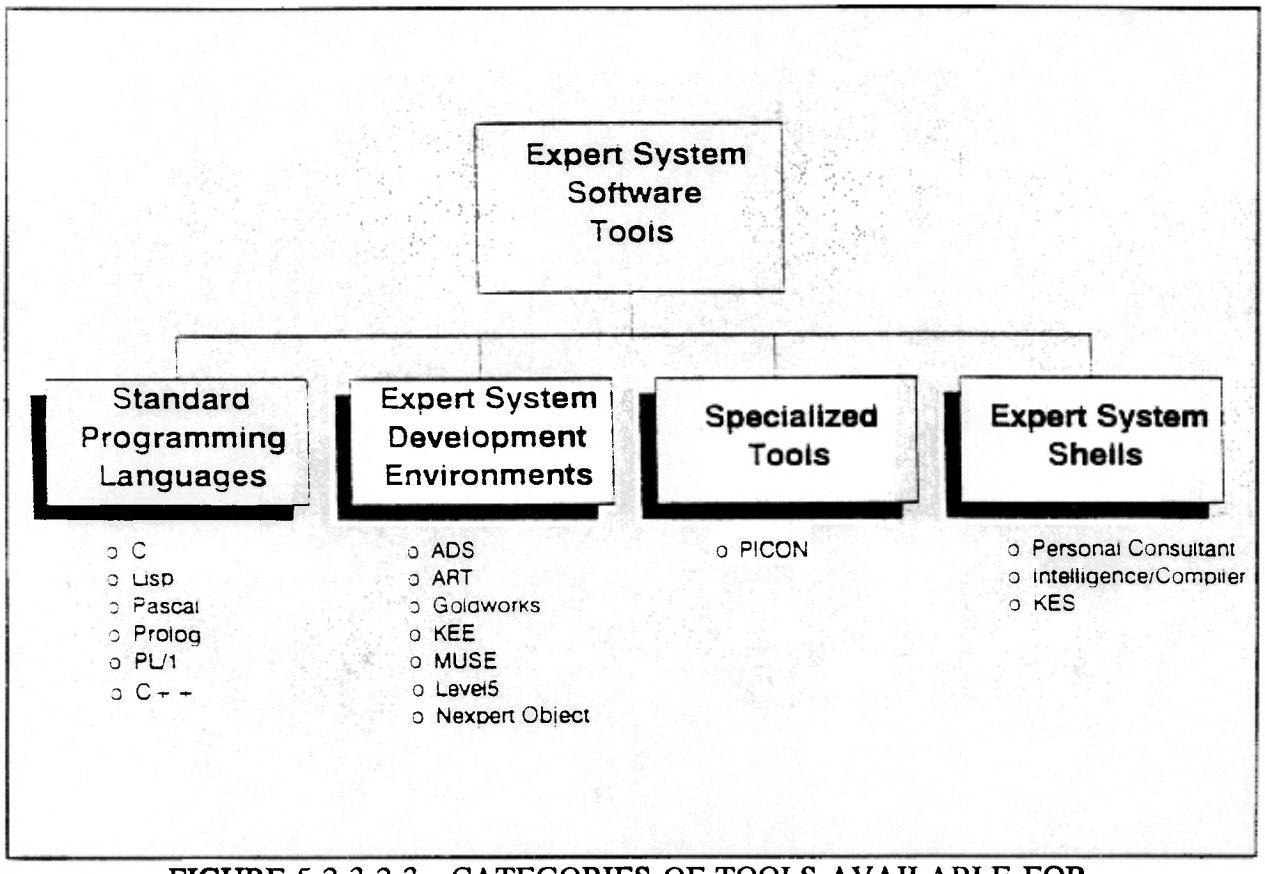

FIGURE 5.2.3.2-3. CATEGORIES OF TOOLS AVAILABLE FOR BUILDING EXPERT SYSTEMS

A technician executes an IDEA application by selecting problem class and symptoms. IDEA requests measurements or tests. When enough information has been collected, a diagnosis is invoked and a Diagnosis Status screen appears. Each field-replaceable item is displayed in the Pass or Fail window. The components in the Fail window become suspect candidates for the failure of the device. Measurements, tests and observations are requested until the number of potential candidates cannot be reduced further. Multiple points of failure are also detected during the diagnosis. The current version of IDEA incorporates hypertext and comes with the Diagnostic Control Mechanism (DCM). DCM allows the developer to control the flow, direction and options available in a completed application. IDEA also comes with a Graphics Development Environment and an explanation facility.

For large systems, model-based diagnostics can be a problem in that the system has to take into account many components that could give rise to the observed symptom. These possibilities can increase exponentially, and thus render the application too slow to use.

b. Vendor: Emerald Intelligence
3915-A1 Research Park Drive
Ann Arbor, MI 48108
(313) 663-8757

1. Products: Diagnostic Advisor, Mahogany Help-Desk, and Mahogany Expert System Development Tool.

a) Diagnostic Advisor. This tool is designed for detecting and fixing faults on the manufacturing or processing plant floor rather than diagnosing electro-mechanical equipment.

b) Mahogany Help-Desk. This tool was designed to simplify the creation of problem solving Help-Desk applications for technical support. This tool creates trees. The tree is traversed from top to bottom by answering questions asked by the system. There does not seem to be a provision to enter symptoms and other information in order to zero in on the fault. In other words, for a given type of fault such as 'a printer problem' the system goes through a set of predefined questions in an order defined by one of the branches of the tree. The Mahogany Help-Desk system has the capability to build large systems very quickly.

c) The Mahogany Expert System Development Tool. Features of this tool include object-oriented and rule-based systems, multiple object inheritance, forward and backward chaining, explanation facilities, and external function interfaces.

c. Vendor: Rosh Intelligent Systems
One Needham Place
50 Cabot St.
Needham, MA 02194
(617) 449-0049

1. Products: This company offers three products of interest for maintenance applications. They are Knowledge-CAIS, Central-CAIS, and Brief-CAIS.

a) Knowledge-CAIS runs on a UNIX-based workstation. This allows product specialists to build knowledge bases. It has graphics editors from which to enter block-diagram representations of a product's physical and functional structures. It has utilities for refining knowledge bases. Its modular knowledge acquisition structure allows several product specialists to work simultaneously. The Doc-CAIS document system automatically generates complete hard-copy documentation from product knowledge bases.

The resulting service manuals contain such information as troubleshooting trees, diagrams, lists of parts, tests, and symptoms. It also has a learning module that enables the ES to learn from diagnostic experience. This diagnostic experience can either be simulated in a controlled environment, or drawn directly from actual service calls.

b) Central-CAIS is also run on a UNIX-based workstation. Its primary functions are collecting and distributing service history information, real-time monitoring of all current service activities, and interactive support of brief-CAIS sites. Central-CAIS can automatically distribute troubleshooting knowledge to Brief-CAIS at remote sites. It can electronically answer queries to its session history database and can deliver expert diagnostic guidance whenever and wherever needed. Currently part of the capabilities of Central-CAIS are present in the Tandem system via the MMS. If the Tandem system should be phased out, this system may be considered as its replacement as it provides additional services such as electronic documentation and paperwork automation.

c) Brief-CAIS runs on IBM compatible PC laptops or desktops. Brief-CAIS provides the service engineer with expert diagnostic guidance, electronic documentation, automatic logging and reporting capabilities, as well as access to the collective service history database. Brief-CAIS provides the service engineer with diagnostic expertise, as in the ADVISOR ES. The ES evaluates the symptoms and tests results, and recommends tests to be executed. After identifying the fault, it provides repair instructions to the service engineer. If the appropriate interface is provided on the equipment, Brief-CAIS can drive diagnostic routines through an RS-232 connection with the system under test.

d. Vendor: Gold Hill Inc.
26 Landsdowne Street
Cambridge, MA 02139
(617) 621-3300

1. Product: GoldWorks III

a) GoldWorks III is a powerful ES tool for the development of advanced applications. It is a general purpose tool integrated with a Windows 3 interface. It has dynamic graphics, a graphics layout tool, a foreign function interface, device independent bitmaps, and dynamic data exchange. It is integrated with Golden Common Lisp and also has interfaces to dBase and Lotus 1-2-3. To assist rapid prototyping of an application, it has a browser, a rule editor, debugging tools, and tutorials. The object-oriented development is supported by frames, multiple inheritance, goal-directed forward chaining, and rule sets. In its inference engine there is provision for certainty factors, an explanation facility, dependency network agendas and rule priorities. The advantage of such a general purpose tool is that it is possible for the developer to incorporate his/her strategy into the program without being constrained by the limitations of special purpose tools.

e. Vendor: Carnegie Group
Five PPG Place
Pittsburgh, PA 15222
(412) 642-6900

1. Products: Knowledge Craft, TestBench, and Service Maintenance Planner (SMP).

a) Knowledge Craft is an integrated knowledge representation and problem solving environment for constructing robust ESs.

b) TestBench is advanced software for developing and delivering a cost effective expert troubleshooting system for field and customer service support.

c) SMP is a decision support system designed to resolve conflicts between service and maintenance schedules. Carnegie group's Diagnostic Division develops systems that assist in diagnosing and repairing complex equipment to aid field service technicians, shop floor maintenance crews, and technical assistance operators.

f. Vendor: Gensym
1801 Robert Fulton Drive
Suite 400
Reston, VA 22091
(703) 758-3571

1. Product: Gensym's Real Time ES G2

a) G2 allows the user to develop, test, and deploy real-time applications better, faster, and more productively. G2 is an ES development and delivery environment that combines powerful software features such as real-time execution, and procedural reasoning, dynamic simulation, UI and database interface capabilities. After an application is completed, G2 maintains an uninterrupted watch over all data sources, looking for irregularities and taking measures to correct potential problems at their early stages. This capability to use expert knowledge to directly monitor and control dynamically changing variables, with thousands of objects and rules, distinguishes G2 from conventional ES tools. G2 Diagnostic Assistant has been used for real-time fault diagnosis. The principle component of G2 Diagnostic Assistant is a graphical language for diagnostics called GDL, which is used for representing diagnostic knowledge. GDL contains tools for common diagnostic problems such as malfunction detection, alarm filtering, intelligent information display, and fault recovery. It incorporates discrete logic, FL, and evidence combination mechanisms during the inference process.

The cost of these AI application development environments, when based on a workstation or PC, falls in the range of $2,000 to $20,000.

Each of these tools meets the initial requirements for the CM2 ES. However, the final tool selection should not be made until a more detailed analysis of capabilities and requirements is completed.

5.3 IMPLEMENTATION PLAN.

Now that specific categories of hardware and software have been selected, and other general implementation issues have been addressed, a plan for the implementation of an ES can be developed.

This section presents an implementation plan for an ES. Included in this plan are the three major phases of ES development, implementation milestones, personnel, and time estimates.

5.3.1 Development Phases.

Before an ES is produced, knowledge is acquired from various sources, such as experts, books, log reports, or Standard Operating Procedures (SOP). The knowledge engineer proceeds through several stages. These stages may be characterized as requirements engineering, knowledge engineering, and knowledge management and maintenance, as shown in figure 5.3.1-1. However, the process is not as neat and well-defined as the figure suggests. These stages are simply a rough characterization of the complex and ill-structured activity that takes place during knowledge acquisition. They will vary from one individual situation to another, and the acquisition process is not understood well enough to outline a standard sequence of steps that will optimize the ES building process. Nevertheless, a significant body of experience has been gained by various groups designing knowledge bases for diverse domains.

5.3.1.1 Phase 1: Requirements Engineering.

Requirements engineering typically consists of three stages:

a. Identification
b. Conceptualization
c. Formalization Stage

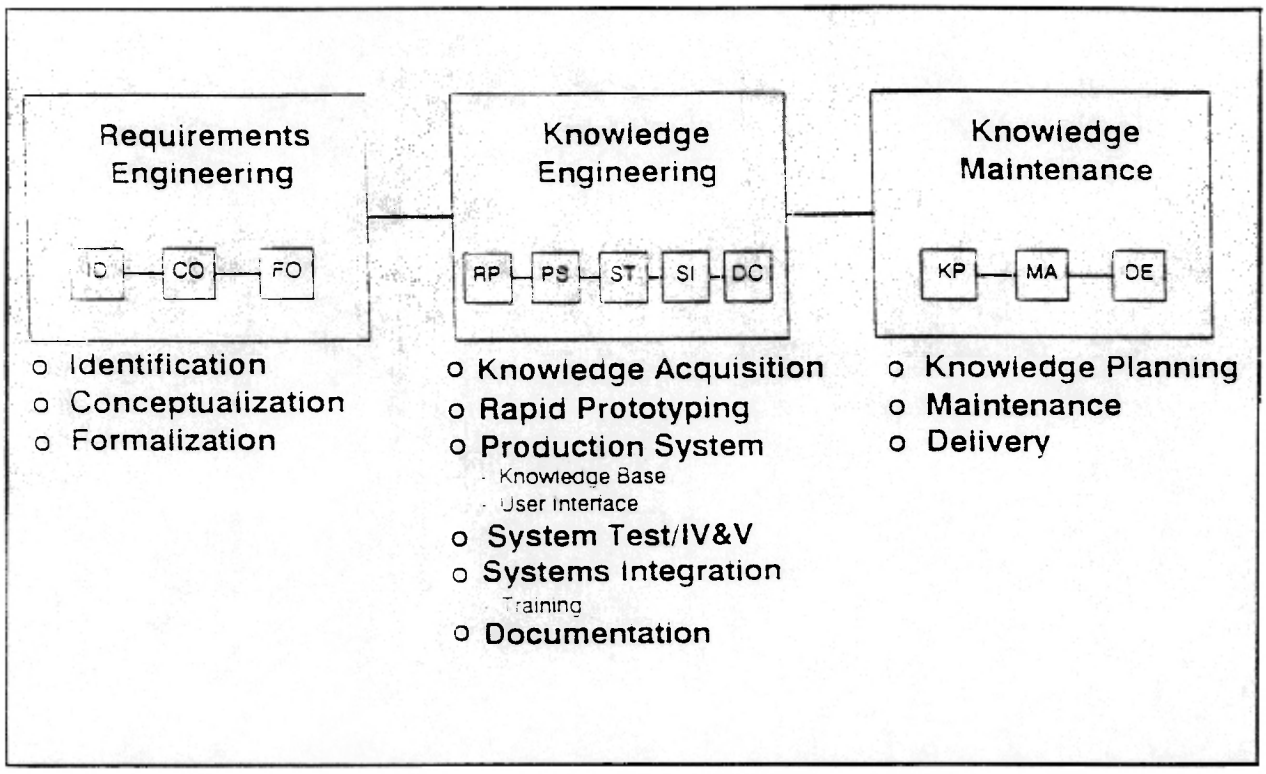

FIGURE 5.3.1-1 THREE MAJOR PHASES OF EXPERT SYSTEM DEVELOPMENT

Each stage is described below:

a. Identification Stage. The first step in acquiring knowledge for an ES is to characterize the most important aspects of the problem. This involves identifying the participants, problem characteristics, resources, and goals. The entire team of knowledge engineers and domain experts is involved.

b. Conceptualization Stage. The key concepts and relationships, already identified during the identification stage, are made explicit during the conceptualization stage. The knowledge engineer may find it useful to diagram these concepts and relationships to cement the conceptual base for the prototype system. The team of knowledge engineers and domain experts is involved.

c. Formalization Stage. The formalization process involves mapping the key concepts, sub-problems, and information flow characteristics isolated during conceptualization into a more formal representation based on various knowledge engineering tools or frameworks. The knowledge engineer plays a more active role in this stage, telling the domain expert about the existing tools, representations, and problem types that seem to

match the problem at hand. The output of this stage is a set of partial specifications describing how the problem can be represented within the chosen tool or framework. Most of the work and functions at this stage are performed by knowledge engineers. It is assumed that domain experts will be available continuously during this phase.

5.3.1.2 Phase II: Knowledge Engineering.

This phase consists of the following stages, and are described below:

a. Knowledge Acquisition
b. Rapid Prototyping (Proof of Concept)
c. Production System Development
d. Testing and Independent Verification and Validation
e. Documentation
f. Systems Integration

a. Knowledge Acquisition Stage. This is the most time consuming process. Automatic knowledge acquisition techniques help the process. However, such techniques are rare. This stage involves acquiring knowledge using several methods including interview protocols, books, SOPs, and log books. The team of knowledge engineers and domain experts is heavily involved.

b. Rapid Prototyping Stage. A small version of an ES is developed to demonstrate the overall feasibility of the proposed system. This stage establishes concepts for representing knowledge by describing the key concepts of the problem domain, the interrelationships with the problem domain, and the flow of information needed to describe the problem solving process (i.e., forward, backward, or hybrid chaining). This stage also provides the opportunity to make decisions regarding the appropriate hardware and software for the target application. Additionally, the formats used for knowledge representation are selected (semantic networks, production rules, frames, or logic techniques). To perform this task, knowledge engineers develop a representation of the key problem concepts of the system, any sub-problems, and required information flow for the knowledge base given various knowledge engineering tools and shells.

Major constraints, hardware and software requirements, documentation of the reasoning process, explanation information, and other modeling are finalized at this stage. After a prototype is up and running in an abbreviated form, it becomes the model of the planned complete ES. Some adjustments to the performance and capabilities are made at this point. Knowledge engineers perform most of the functions and tasks, and confer with the domain expert.

c. Production System Development Stage. The great majority of knowledge is added to the system in this stage. Information is added in bulk following consultation with the domain experts. The UI is tailored and the system's working performance is monitored and compared to the established benchmarks.

During this stage, the rules that embody the domain experts' knowledge are refined by combining and reorganizing the knowledge contained in the knowledge base. Not only is the knowledge base dramatically expanded, but the UIs are carefully designed. These interfaces include the actual UI and the front end interface. The front end interface concerns the input, modification, and maintenance capabilities of the system itself. It is the way the information is entered into the system. The UI concerns the methods the end user needs to interact with the system. These interfaces usually include some type of menu-driven control featuring help screens. This stage is generally completed by the knowledge engineers.

d. System Testing and Independent Verification and Validation Stage. The system must be tested in the user environment, again comparing its operation against established benchmarks, to modify and polish the system until it performs as desired. The UI, reasoning techniques, data structure, assignments and combinations of certainty factors, and the feasibility study of benchmarks are all fine-tuned at this point. The problem areas and software errors are also handled at this point. Any major modification suggested during this stage requires redoing of the prototype development, production system development, and system testing. The development-testing loop continues until the ES performs as expected, meeting the benchmarks. The knowledge engineers and programmers perform most of the predefined tasks and functions.

This is one of the most difficult stages since it involves testing, verification, and validation. It is difficult because system testing includes unit, stress, and functional testing of the developed software. This study assumes that the tool and shell selected have gone through the system testing phase. An expensive ES environment tool is supposed to have been system tested. Verification and validation criteria for an ES have not yet been established. This is usually done using a number of domain experts and experienced users.

e. Documentation Stage. The documentation stage involves preparing various documents needed by the end user. Usually this stage starts during the knowledge acquisition stage and continues through system integration. A team of knowledge engineers, a technical writer, and other support personnel are involved.

f. System Integration Stage. This stage involves fielding the ES in a real-world user environment. This may involve porting the system to different hardware, and it certainly should include training users, and helping them understand the system. This is an important phase since user acceptance can dictate success or failure. The difficulties are organizational and psychological rather than technical. During this phase, the payoff of all briefings,

demonstrations, and organizational politics the project manager engaged in while the knowledge engineer worked at extracting and encoding the experts' knowledge, becomes evident. The user receives full training, support, and documentation during this stage. This stage requires the efforts of management, project team personnel, and the knowledge engineers.

5.3.1.3 Phase III: Knowledge Maintenance.

This phase involves all the steps of the knowledge engineering phase, knowledge management, knowledge planning and evolution, final delivery of the product, and system maintenance. This is the final phase and is never complete; it continues as long as the system is used. The system must continually be revised and updated as necessary, against benchmarks that dictate new applications or performance improvements. The development team provides a document to the users containing the knowledge planning and knowledge management information. During this phase, users get heavily involved with support from the developer team.

5.3.2 Milestones.

The three phases of ES development have four major milestones. Each milestone represents a major event during development. This section describes the milestones that are completed during the ES implementation.

a. Milestone 1 - Requirements Engineering. The first milestone is a report containing the detailed analysis of system requirements. This report includes specifications of system inputs, outputs, hardware, and software. The knowledge sources are identified, and schedules for interviewing experts are arranged. Test plans are developed and test cases are generated.

b. Milestone 2 - Demonstration Prototype. The demonstration prototype is developed using rapid prototyping techniques. The prototype is a proof-of-concept system, which proves whether or not the approach is viable. A small knowledge base is implemented to allow for the evaluation of the knowledge engineering and representation techniques, inferencing methods, and UI.

c. Milestone 3 - Production System. The production system is the final implementation of the ES. The production system contains the full knowledge base, which covers all of the defined domain tasks. An interface between the ES and the system messages is developed. System testing, IV&V, and documentation are also finished at this time.

d. Milestone 4 - Knowledge Maintenance. After the production system has been developed and integrated, the ES must undergo a period of knowledge maintenance to ensure proper performance in the real-time environment.

5.3.3 Personnel and Time Estimates.

This section suggests categories of personnel for the CM2 application, and estimates the personnel requirements for each milestone in terms of man-weeks of effort. These estimates are based on the size and complexity of the knowledge domain, the projected difficulties of integration, the class of tools selected, and the delivery hardware.

The following categories of development personnel are required for the development of the ES:

a. Project Leader
b. System Expert (SE)
c. Senior Knowledge Engineer
d. Knowledge Engineer
e. Programmer
f. Technical Writer

Figure 5.3.3-1 provides a schedule for the implementation The following are detailed estimates of the effort required to meet each milestone:

a. Milestone Requirements Engineering

		Weeks	Man weeks
	Duration:	1-17	(17)
2.	Project Leader		3
3.	SE	15	
4.	Sr. Knowledge Engineer		17
5.	Knowledge Engineer		17
6.	Programmer		2
7	Technical Writer		4

b Milestone 2 - Demonstration Prototype (using Rapid Prototyping)

		Weeks	Man weeks
1.	Duration:	18-26	(8)
2.	Project Leader		
3.	SE	8	
4.	Sr. Knowledge Engineer		8
5.	Knowledge Engineer		8
6.	Programmer		4

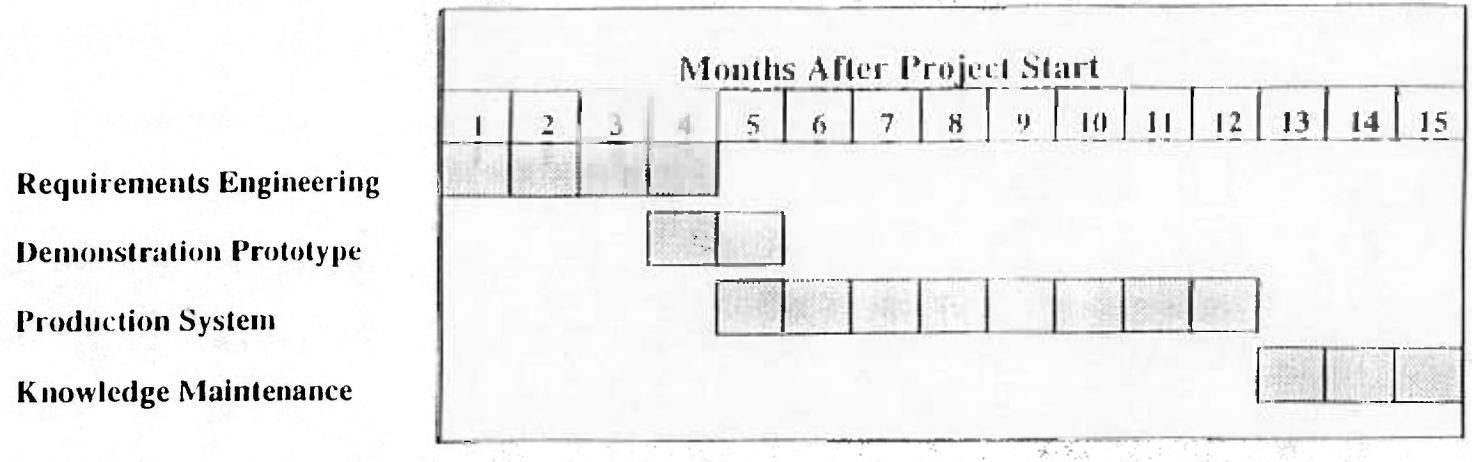

FIGURE 5.3.3-1. OVERALL VIEW OF TIME AND SCHEDULE

c. Milestone 3 Production System

		Weeks	Man weeks
1.	Duration:	27-60	(34)
2.	Project Leader		5
3.	SE	16	
4.	Sr. Knowledge Engineer		20
5.	Knowledge Engineer		34
6.	Programmer		34
7.	Technical Writer		13

d. Milestone 4 - Knowledge Maintenance

		Weeks	Man weeks
1.	Duration:	61-74	(13)
2.	Project Lead		1
3.	SE	2	
4.	Sr. Knowledge Engineer		8
5.	Knowledge Engineer		13
6.	Programmer		8

Thus, the development of a full production system is estimated to take 60 weeks; 13 weeks are necessary for knowledge maintenance and user training.

6. DEVELOPMENT ISSUES FOR ANN SYSTEMS.

We have identified two NN applications just for alarm processing within AF maintenance. This section discusses the NNs development issues for the alarm processing system called a PRC. A PRC NN system tracks alarms and their associated resolutions. The purpose of this section is to develop a feasible implementation plan for the system. First, general implementation issues, such as knowledge representation, classification, network architecture, and interfaces, are addressed. Second, technology issues are examined, focusing on software and hardware. Finally, an implementation plan is generated, including milestones and time estimates.

6.1 GENERAL ISSUES.

To develop an implementation plan, several issues that will affect the choice of hardware, software, and NN tools must be addressed. These issues focus on the knowledge to be captured in the system, the classification techniques that will manipulate the knowledge, and the interfaces between the NN and the user.

6.1.1 Knowledge.

During the process of training, NNs acquire some knowledge about the problem. This knowledge is gained after several iterations of training. The knowledge gained by the network helps to make generalizations about the problem.

6.1.2 Knowledge Representation and Learning Laws.

An important part of NN implementation is the choice of knowledge representation techniques, and the learning laws to be used. There are two purposes in analyzing knowledge representation early in the development cycle. The first purpose is to determine if the domain knowledge held by experts can be captured and reflected in the weight and connection patterns. The second purpose is to determine the selection of tools and techniques that have the proper capabilities.

6.1.3 Interfaces.

In addition to knowledge representation techniques and learning methods, a review of interface requirements is necessary in order to plan implementation. The UI is an important aspect of any NN. A good UI will allow the user to execute the network training, debugging, and learning in a smooth manner.

6.2 TECHNOLOGY ISSUES.

The technology issues for building an NN are primarily software and hardware choices. Given that the general issues of knowledge representation, classification, and interfaces have been addressed, the actual hardware and software that will be used for implementation are chosen.

6.2.1 Software.

The options for software from which to build an NN range from simple and flexible, to complex and unbending. Each of these categories will be discussed in terms of their advantages and disadvantages in the areas of knowledge representation, classification, and interfaces.

6.2.1.1 Standard Programming Languages.

Standard programming languages, such as C, Pascal, C++, Lisp, and Prolog provide the most flexible means of building an NN. However, because of the ground up development that is necessary when using a programming language, the development time is greatly increased relative to other methods.

a. Knowledge Representation. A basic programming language gives the developer a full range of choices for knowledge representation and learning laws. However, the programmer must know how to implement the knowledge structure using the selected programming language.

b. Classification. Any classification mechanism can be developed, but the programmer must implement it from scratch.

c. Interfaces. A standard programming language does not restrict interfaces that can be used in the NN.

6.2.1.2 Neural Network Development Environment (NNE).

NNEs, such as Neuralware, Brainmaker, Axon, Nets, and Anita, are powerful tools for the NN developer. These environments have been designed, from concept through implementation, to provide a comprehensive set of capabilities for the NN developer.

a. Knowledge Representation. The knowledge and rules are contained not in the individual weights, but in the overall connection of weights and connections. By closely looking at the weight patterns, one can find out how the network makes its decisions. These environments offer a variety of ways to represent the network.

b. Classification. Most of the developing environments do the classification of the data based on a certain learning law. The methods used are back propagation, counterpropagation, adaptive resonance, kohonen feature map, and other learning techniques. These methods employ supervised or unsupervised learning.

c. Interfaces. NNEs provide a variety of tools for developing a UI. Most provide options for using menus, graphics, icons, active images, and natural languages. External interfaces are possible either by integrating programs written in other languages, or embedding the NN in other applications.

6.2.1.3 Specialized Tools.

Certain NNs can be built from specialized tools. Specialized tools are highly structured systems built for a specific application.

a. Knowledge Representation. Knowledge representation in specialized tools is limited to those techniques that are appropriate for the intended domain. Little flexibility exists for creating new or unique representations.

b. Classification. Specialized tools contain only those classification techniques needed in the domain.

c. Interfaces. Interfaces are restricted to those required by the application type.

6.2.2 Hardware.

As figure 6.2.2-1 indicates, the hardware available for developing and running NNs falls into four general categories:

a. Mini and mainframe computers can be used to run large NNs. The cost is over $20,000.

b. Conventional workstations, such as Sun, Apollo, MicroVax, and RISC-6000, have the memory and speed to effectively run medium-sized applications. These range in price from $5,000 to $30,000.

c. Dedicated AI machines, such as Transputers, DADO, and Think machines, are optimized to run NN programs, and can handle large applications. These range in price from $10,000 to $100,000.

d. PCs, including 486AT, IBM PS/2, and Apple Macintosh, have been used for small applications, but by increasing memory and improving microprocessor speeds, these machines can be used for medium-sized applications. These range in price from $3,000 to $15,000.

6.2.3 Technology Selection.

Hardware and software decisions are based on several factors, including the NN's scope, knowledge representation, classification techniques, and interface requirements. The following two sections describe the hardware and software issues, and suggest categories of tools for implementation.

6.2.3.1 Computer Hardware.

The following issues and criteria contribute to our suggestion that a workstation or PC would best fulfill the NN hardware requirements:

a. The computer should not restrict the choice or functionality of NN tools.

b. The NN has the potential to be a real-time system, so processing speed is important.

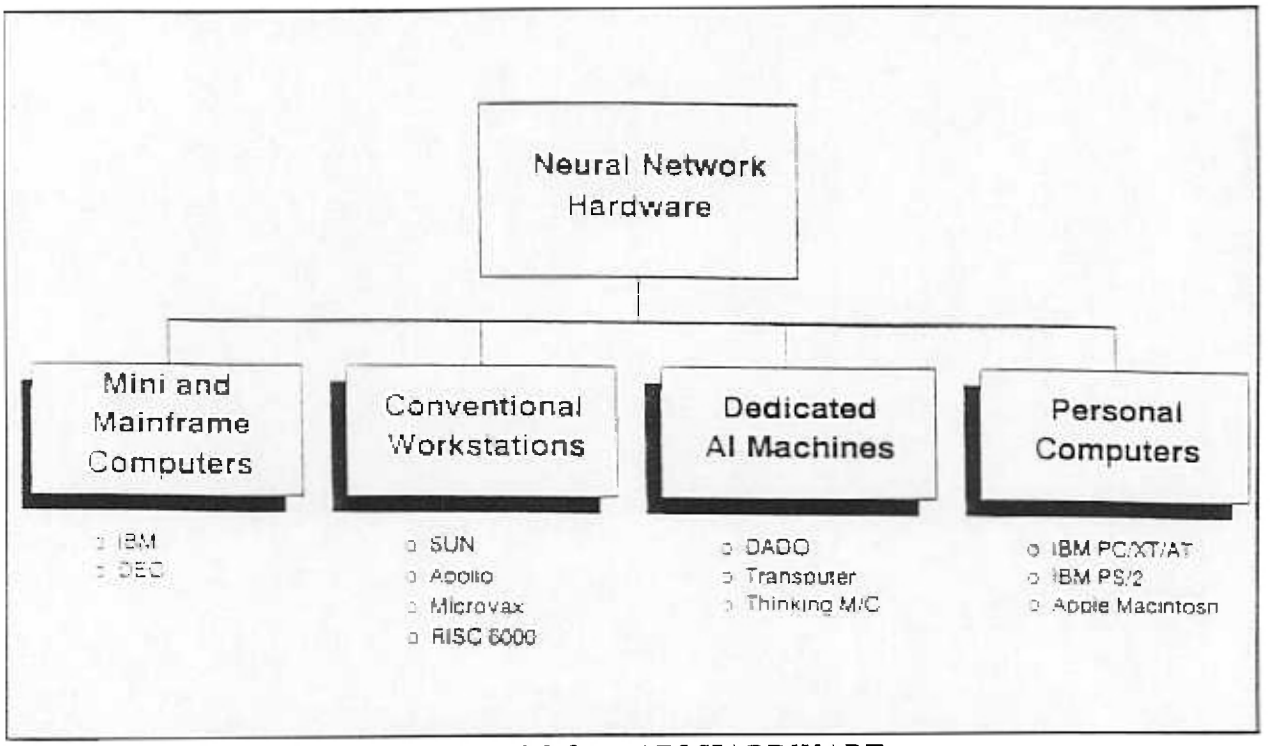

FIGURE 6.2.2- NN HARDWARE

c. The computer must have the capability to interface with the mainframe.

d. The computer must have a large memory capacity because NNs are memory intensive.

e. A flexible UI must be possible.

f. Although the main purpose of the computer will be to support the NN, it should have multi-purpose capabilities.

g. Cost should be as low as possible.

Based on an analysis of these requirements and available hardware, workstations or PCs are deemed the best alternative. Workstations, especially Sun, MicroVAX, RS6000, DEC 5000, and microcomputers, such as IBM PS/2, 386, 486 PC/AT machines, and the Apple Macintosh, are viable candidates for hosting the NN application.

6.2.3.2 NNs Software Tool Selection.

In order to select a class of NN tools for implementing the NN, the requirements of the NN, in terms of knowledge representation, classification techniques, and interface requirements, are analyzed.

Interface capabilities must include a menu and text UI, and an external interface. Hardware support must include microcomputers or workstations, and portability to minicomputers and mainframes would be an extra advantage. The developers' interface should include many of the features shown in figure 6.2.3.2-1.

Using these requirements, a survey and analysis of current NN tools was performed. results suggest a set of implementation tools, including the following:

a. Neuroshell, Ward Systems
b. Brainmaker, California Scientific
c. NeuralWorks, Neuroware
d. NNT, Shareware
e. ANITA™, CCG Associates, Inc.

The cost of these NN development environments, when based on a workstation or PC, falls in the range of $500-$15,000.

The final tool selection should not be made until a more detailed analysis of capabilities and requirements is completed.

6.2.3.2.1 Specialized Tools.

The following is a summary of some tools that are good candidates for ANN applications for AF:

g. Vendor: NeuralWare, Inc.
Penn Center West, Building IV, Suite 227
Pittsburgh, Pennsylvania 15276
(412) 787-8222

Product: NeuralWorks Professional II/PLUS (NeuralWorks)

a) NeuralWorks is available on various platforms such as 80286, 80386-387 based IBM PC compatibles, Intel i860 versions, Apple Macintosh IISE, SUN Sparc, SUN 4, or SUN 3 computers, IBM RS/6000, VAX Ultrix workstations, etc. NeuralWorks supports various NN architectures such as back propagation, learning-vector-quantization, self organization maps, ART1, cascade correlation, etc. Th

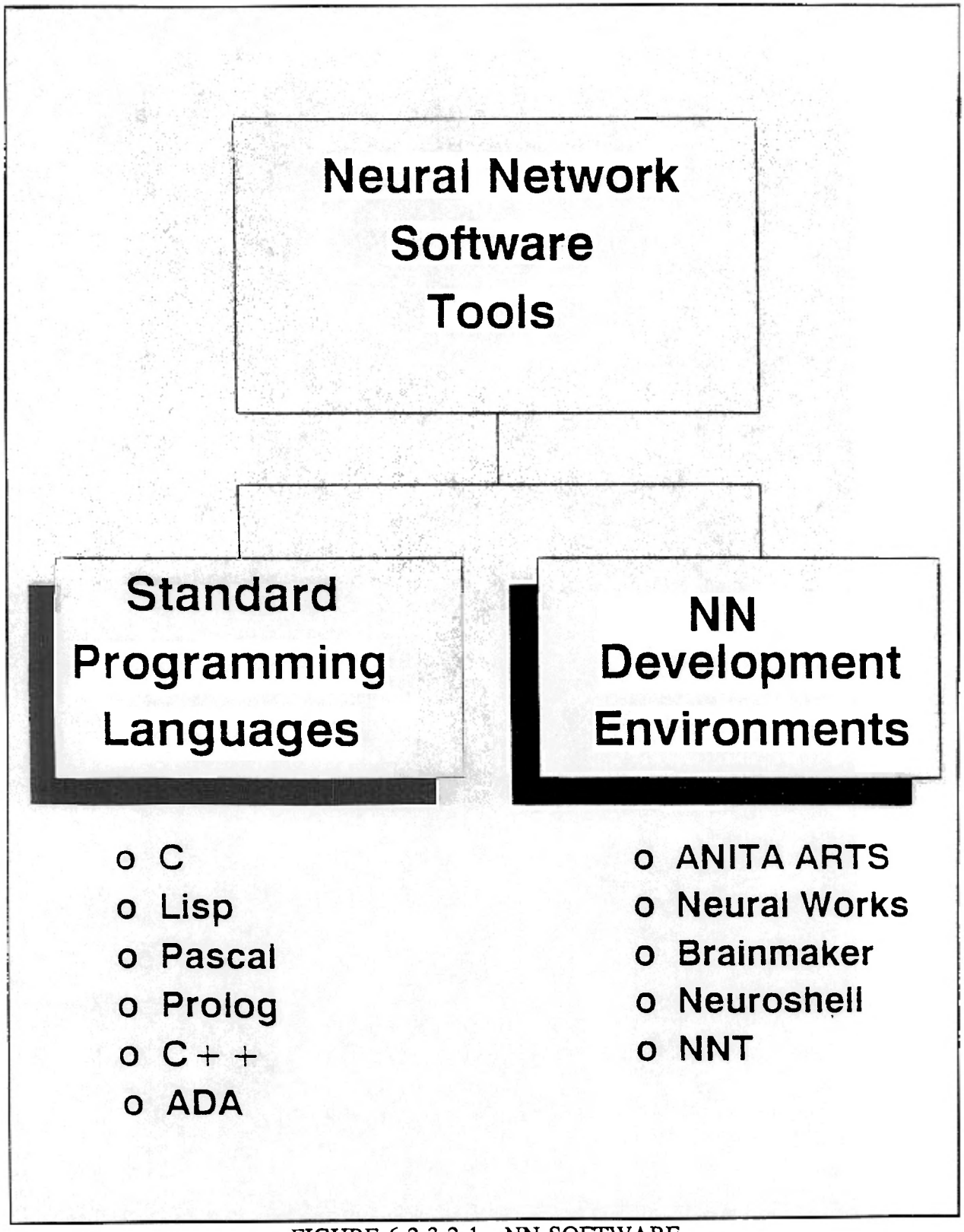

FIGURE 6.2.3.2-1 NN SOFTWARE

software allows users to build, train, refine and deploy NNs for a variety of applications. It generates a FlashCode to be used in other technologies like ESs. It also has a feature called ExplainNet, a facility that tells why a NN made a decision, as well as which information had the most effect on the NN output. It has a good graphical UI and a flexible architecture.

Vendor: CCG Associates, Inc.
8484 Georgia Ave. Suite 880
Silver Spring MD, 20910
(301)-587-6388

. Product: ANITA™:

a) ANITA is a tool built by CCG Associates, Inc. It has three training paradigms built into it; Back propagation, ART I, and ART II. It runs on IBM PC-compatible computers. It has a built in plotting package that can display information about how well the training has gone, and how inferences were made about the test data. ANITA has been successfully used in various applications such as Contract Laboratories Outliers Characteristics, Status Of Stocks (SOS), Financial Risk Analysis of Countries in the UN (RISK), etc.

6.3 IMPLEMENTATION PLAN.

6.3.1 Development Phases.

There are four phases to be discussed in this section (see figure 6.3. -1).

6.3.1.1 Phase I: Problem Selection.

NNs can be tried in areas in which there are already software solutions. Initially they can be used in areas in which speed of learning is not of vital importance.

For any problem to be solved by the NN approach, a statistically valid input data set, that will be mapped later on, is needed. The existing software solution can be algorithmic, statistical, or an ES. The existing solution can be viewed as a black box that can be replaced by an NN, if it offers better performance.

There are various reasons for choosing NNs rather than conventional methods. In certain cases, NNs are more accurate than conventional methods. Another important factor is the ability of the NN to train itself. For certain systems employing conventional methods, a minor change in the parameters of the system requires the system to be rewritten completely. However, if NNs are used, few changes are required. For example, in a vision system using NNs, if the data set is changed, only a few changes to the network are necessary; these are made interactively and do not require the use of a conventional programmer. NNs not only learn from human errors, but also its own past mistakes.

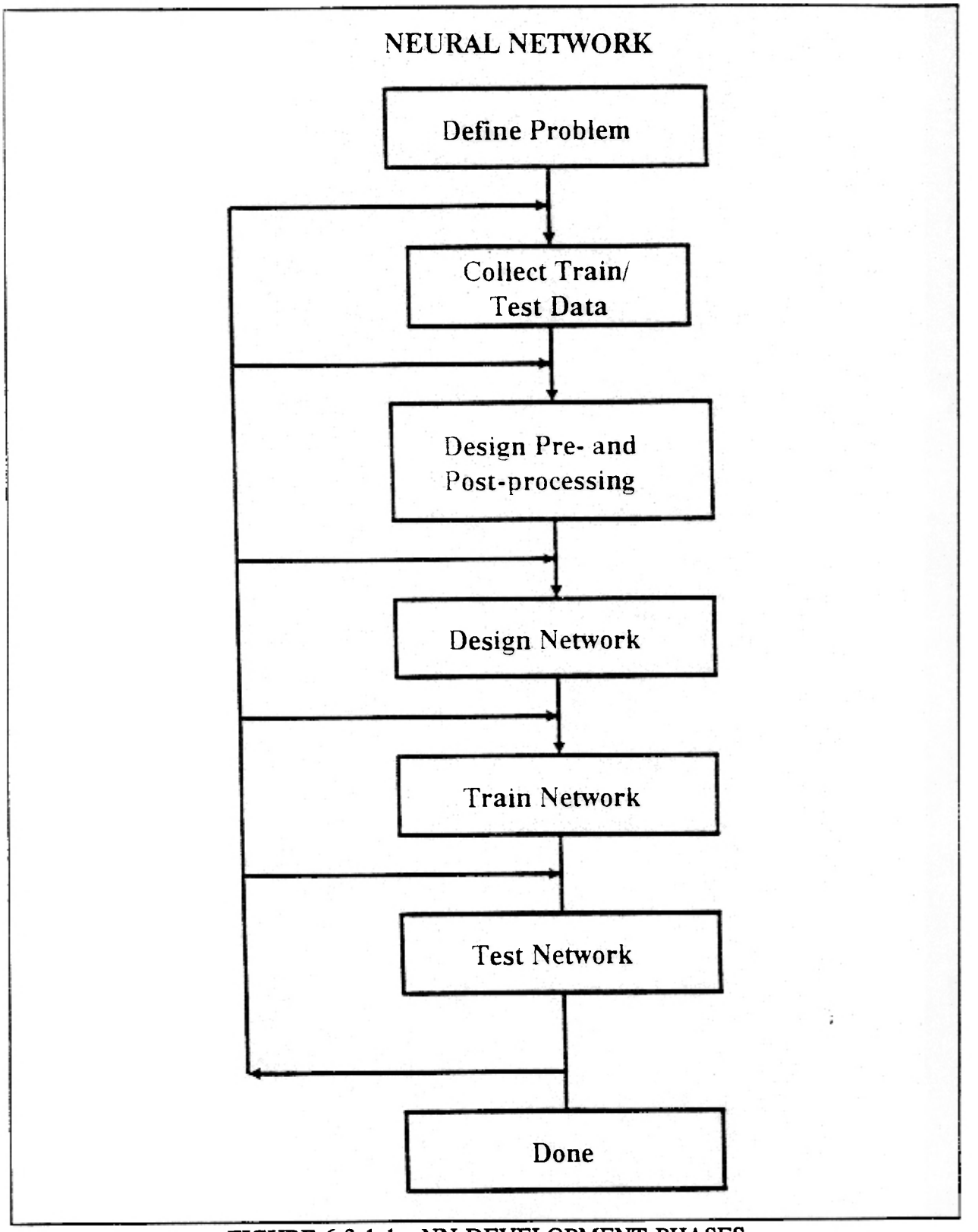

FIGURE 6.3.1-1. NN DEVELOPMENT PHASES

One important criterion used in the selection of an NN project is whether or not it can increase efficiency. Even a few percentage points of improvement in a big project are worth the effort.

Efficient data access must be ensured before the start of a project. The method of data access must be specified in an elaborate manner. The location of data access must be made known to the proper authorities. The formats should be selected in such a manner that the NN can read the data from the database.

Finally, one must ensure that the NN offers a significant amount of payback. All parameters contributing toward the cost must be thoroughly examined and justified.

6.3.1.2 Phase II: Selecting the Architecture and the Learning Law.

Following problem selection, the NN to be used must be selected. The two main components of any network are the learning law and the architecture. There are a number of NN architectures and learning laws described in the literature. Methods include back error propagation, counter-propagation, adaptive resonance theory, madaline rule III, adaptive bidirectional associative memory, and Nestors's Reduced Columb energy. The back propagation method is the most successfully tested and popular method. The merits and demerits of other methods are not fully known or understood.

The architecture of the NN depends on the learning law. After selecting the architecture, its efficiency can be improved by adding more processing elements. However, the disadvantage of this method is a reduction in the generalization ability of the NN. If additional processing elements are not added, then the network requires a long training time. There are two methods in use to prevent this problem. One is the use of a one pass learning system. The other is the use of Nestor's architecture that adds elements as it needs them.

There are some cases in which sufficient data are not available to train the NN. One of the ways to circumvent this problem is to add random noise of constrained value to the training data or the weights after the training. The noise values must be verified by domain experts.

6.3.1.3 Phase III: Prototyping

Prototyping is the most difficult stage of NN development. The attributes of the NN are established and subsequently coded. The data set could consist of analog values, binary vectors, or a range of vectors. Range scales could be linear or logarithmic in nature. Larger training sets are required for data sets that have large numbers of identifiable attributes. Data that are not useful in training should be filtered because irrelevant data can confuse the network.

For any NN to function well, a good NN preprocessor is an essential requirement. The network's performance will definitely improve with better preprocessing. Almost all problems require some form of preprocessing.

The only difficulty is in selecting the type of preprocessing needed for the problem. The type of preprocessing needed can be determined by the domain experts and through consideration of the conventional solutions for the problem. It is advantageous to preprocess the data numerically.

After training, validation of the results is necessary. As a rule of thumb, use 10 percent of the available cases for validation.

6.3.1.4 Phase IV: Deployment.

The prototype is finally converted into a product in this phase. If the project plan is carefully devised, there will not be any problems in the deployment phase. Specialized hardware makes the deployment harder. When a NN project is attempted for the first time, fancy hardware implementation should be avoided.

To minimize the problems in the deployment phase, one of the methods employed is to train the network off-line, and implement it in a programmable read only memory. This method is reliable and well known. On-line NN training should be done only after there has been enough experience with NN projects.

A software-only NN project is much easier to deploy. Experience from past software implementation projects can be of great value. With the recent advances in software engineering, code generators can produce code from the specifications. In addition, there are object modules that can be called from other programs, receive data, and return results.

The milestones for the NN project are shown in figure 6.3.1.4-1.

7. RECOMMENDATIONS.

This section contains the final conclusions and recommendations of the study. These recommendations constitute a concise summary of the items that have been discussed in detail in the previous sections of this report. The recommendations have been separated into short-term and long-term recommendations.

7.1 SHORT TERM.

The short term recommendations include those applications that are very important to FAA maintenance operations, and for which adequate technology is available to initiate the applications development immediately.

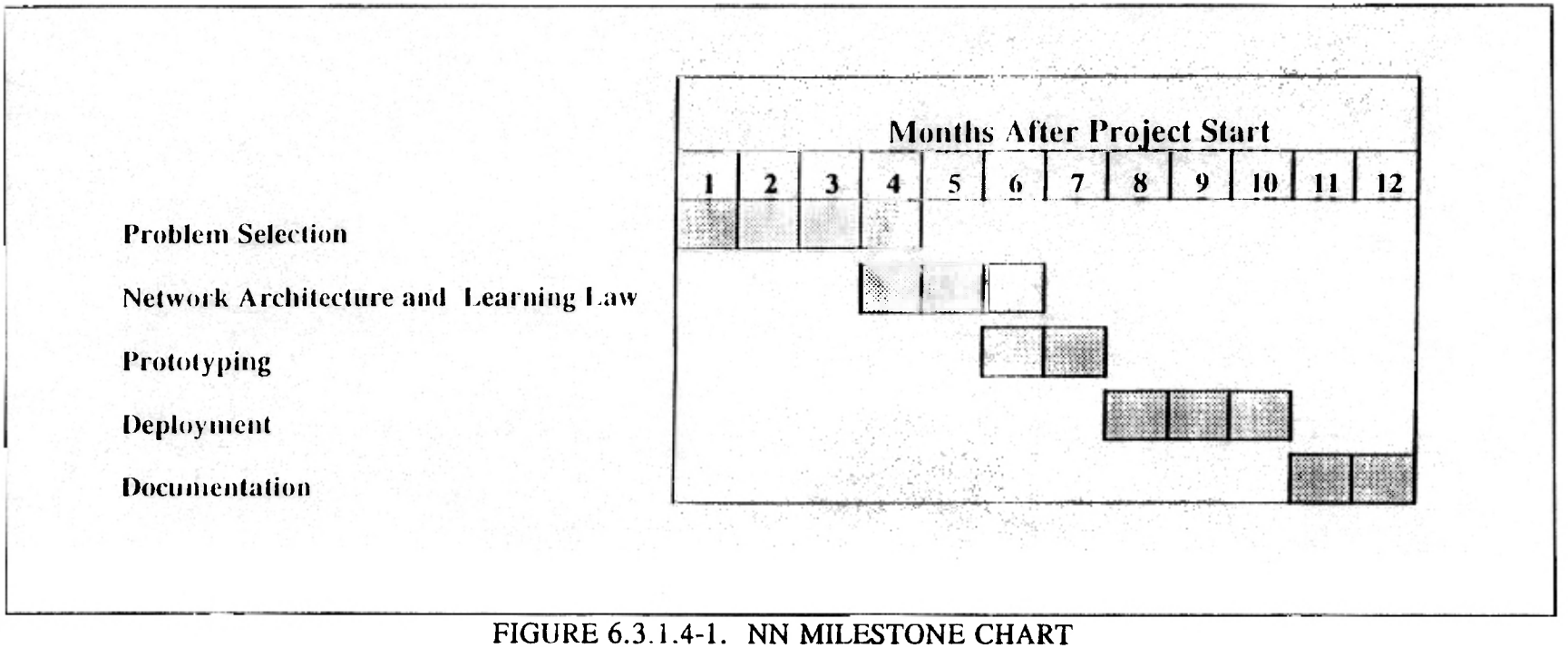

FIGURE 6.3.1.4-1. NN MILESTONE CHART

a. Problem Resolution Systems. The application most critical to FAA operations, because of the loss of expertise due to attrition, is to develop a problem resolution system. A PRF will consolidate nationwide expertise about various equipment that is maintained by Airway Facilities (AF) technicians. The application, although termed short term, is expected to have a long, useful life.

b. CM1 and CM2. The next application that might be implemented in the near future is that of the CM1 and CM2. This application is further divided into two applications:

1. The CM1 application is for new equipment. There is very little expertise available on this equipment in the field. A model-based approach to development is desired. This technology has not yet fully matured. Experience gained early in the implementation phase will play an important part in the development of a successful in-house application.

2. The CM2 application is a traditional rule-based application. The technology has matured and will be useful for all equipment that has been fielded for a while, and about which sufficient expertise is available in the maintenance work force. These applications, too, will have a long useful life, though the first one is expected to evolve over time.

c. Monitoring. Monitoring can also begin in the current hardware environment, and evolve to a centralized and more coherent application in the long term, with full implementation of the MCC concept. The monitoring application involves capturing the state of the system immediately prior to and during the fault conditions in the equipment. This is expected to assist the technicians in determining precisely what went wrong at the time of fault. The application is also expected to filter irrelevant data and decode relevant data into English-like phrases. It will use modern equipment such as Airport Surveillance Radar (ASR)-9 and Second Generation VORTAC in order to make better use of the available information.

7.2 LONG TERM.

Long term recommendations concern those applications for which either an appropriate setup is not available in the FAA, or the technology is not currently mature enough to handle the implementation of the application. The applications identified for long term development do not appear critical to present FAA operations.

a. The Alarm Processing application would receive alarms at a central location such as the MCC, prioritize them, and process them in order of priority. This application would be best developed after Remote Maintenance Monitoring (RMM) is sufficiently implemented. The application consists, primarily, of hardware and firmware enhancements rather than software implementations.

b. Certification is another application that is best implemented after an adequate number of facilities are RMMed. The certification programs would be run remotely from the MCC/work center, and the equipment would be certified. This would provide substantial convenience to the operators.

c. The Information Retrieval application involves paperless documentation. The current technology of hypertext and document imaging may not meet the demands of putting scores of manuals full of schematics and pictures into electronic media. Depending upon the diagnostics, Artificial Intelligence (AI) technology can, however, pinpoint the exact locations in the manuals. This application may be pursued on a piecemeal basis.

d. The Training application concerns improvement in technician training. It is not intended to be a substitute for academy training and on-the-job-training, but to supplement them. This application would be better undertaken when the CM1 or CM2 has been completed.

e. For PM , this report does not recommend any AI technology at the present time. However, it is recommended that a system be developed that will anticipate fault conditions in the equipment.

f. A framework for distributed maintenance based on DAI technology should be developed to provide effective diagnostics. Distributed maintenance employs diverse knowledge bases involving one or more kinds of equipment through DAI, a global interpretation of fault conditions and data is possible.

REFERENCES

Liepins, G. E., & Potter, W. D. A Genetic Algorithm Approach to Multiple-Fault Diagnosis. In L. Davis (Ed.), Handbook of Genetic Algorithms (pp. 237-250). New York: Van Nostrand Reinhold.

2. Goldberg, D. E. (1989). Genetic Algorithms in Search, Optimization and Machine Learning. Reading, MA: Addison-Wesley.

Davis, L. (Ed.). 1991 Handbook of Genetic Algorithms. New York: Van Nostrand Reinhold.

4. Liepins, G. E., Richardson , J., & Palmer, M. (1990). Genetic Algorithm Applications to Set Covering and Travelling Salesman Problem. In D. Brown (Ed.), OR/AI: The Integration of Problem Solving Strategies.

Liepins, G. E., & Potter, W. D. (1991). A Genetic Algorithm Approach to Multiple-Fault Diagnosis. In L. Davis (Ed.), Handbook of Genetic Algorithms (pp. 237-250). New York: Van Nostrand Reinhold.

6. Richardson, J. T., Palmer, M. R., Liepins, G. E., & Hilliard, M. R. (1989). Some Guidelines for Genetic Algorithms with Penalty Functions. In J. D. Schaffer (Ed.), Genetic Algorithms (pp. 191-197). San Mateo, CA: Morgan Kaufmann.

Belew, R. K., & Booker, L. B. (Eds.). (1991). Genetic Algorithms, Proceedings of the Fourth International Conference. San Mateo, CA: Morgan Kaufmann.

8. Grefenstette, J. J., & Baker, J. E. (1989). How Genetic Algorithms Work: A Critical Look at Implicit Parallelism. Proceedings for the Third International Conference on Genetic Algorithms (pp. 20-27). Fairfax, VA: Morgan Kaufmann.

9. Schraudolph, N. N., & Belew, R. K. (1991). Dynamic Parameter Encoding for Genetic Algorithms (Tech. Rep. No. CNLS, MS-B258). Los Alamos, NM: Los Alamos National Laboratory.

10. Laufmann, S. C., De Vaney, D. M., & Whiting, M. A. 1990, December). A Methodology for Evaluating Potential KBS Applications. IEEE Expert, pp. 43-61

Allred, D., Lichtenstein, Y., Preist, C., Bennet, M., & Gupta, A. (1991). AGATHA: An Integrated Expert System to Test and Diagnose Complex Personal Computer Boards. In R. Smith and C. Scott, (Eds.), Innovative Applications of Artificial Intelligence 3 (pp. 87-103). Menlo Park, CA: AAAI Press/MIT Press.

12. Kleer, J. D., Mackworth, A. K., & Reiter, R. (1990). Characterizing Diagnoses. Proceedings of the Eighth National Conference on Artificial Intelligence (AAAI-90) (pp. 324-330). Menlo Park, CA: AAA Press.

3 Muratore, J. F., Heindal, T. A., Murphy, T. B., Ramussen, A. N., & McFarland, R. Z. (1989). Space Shuttle Telemetry Monitoring by Expert Systems in Mission Control. In H. Schorr and A. Rappaport (Eds.), Innovative Applications of Artificial Intelligence (pp. 3-14). Menlo Park, CA: AAAI Press/MIT Press.

4 Silverman, S., Dinar, J., Fink, T., Kotas, P., Shoop, A., Ramesh, B., Klarh, P., & Abche, A. (1991). A Real-Time Alarm Analysis Advisor. In A. Rappaport and R. Smith (Eds.), Innovative Applications of Artificial Intelligence 2 (pp. 101-113). Menlo Park, CA: AAAI Press/Mit Press.

5 Crow, J., & Rushby, J. (1991). Model-Based Reconfiguration: Toward an Integration with Diagnosis. Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI-91) (pp. 836-841). Menlo Park, CA: AAA Press.

16 Caudill, M. (1991, October). Expert Networks. Byte, pp. 108-116.

BIBLIOGRAPHY

Allen, J 1987). Natural Language Understanding. Menlo Park, CA: Benjamin Cummings

Anand, T. S., & Lee, K. P. (1989). Extending CATS: Mixed-Initiative Inferencing. Proceedings of the Fifth Conference on Artificial Intelligence Applications (pp. 107-114) Miami, FL: IEEE.

Aubrey, J., & Nemes-Nemeth, Z. (1989). A Knowledge Based Emergency Control Advisory System for the Australian Coal Industry. In H. Schorr and A. Rappaport (Eds.), Innovative Applications of Artificial Intelligence (pp. 95-109). Menlo Park, CA: AAAI Press/MIT Press.

Bajpai, A., & Marczewski, R. (1989). Charley: An Expert System for Diagnostics of Manufacturing Equipment. In H. Schorr and A. Rappaport (Eds.), Innovative Applications of Artificial Intelligence (pp. 149-158). Menlo Park, CA: AAAI Press/MIT Press.

Carbonnel, J. (Ed.). 1990) Machine Learning, Paradigms and Methods. Cambridge, MA MIT Press.

Caudill, M. (1990, September). Using Neural Nets: Diagnostic Expert Nets. AI Expert, pp. 43-47.

Courtois, J. (1991). Teaching Diagnostic Skills Using AI: An Architecture Suitable for Students and Teachers. Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI-91) (pp. 55-60). Menlo Park, CA: AAA Press.

deKleer, J. (1991). Focusing on Probable Diagnosis. Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI-91) (pp. 842-848). Menlo Park, CA: AAA Press.

Evertsz, R. (1991). The Development of SYLLABUS - An Interactive, Constraint-Based Scheduler for Schools and Colleges. In R. Smith and C. Scott, (Eds.), Innovative Applications of Artificial Intelligence 3 (pp. 39-51). Menlo Park, CA: AAAI Press/MIT Press.

Friedrich, G., Gottlob, G., & Nejdl, W. Physical Impossibility Instead of Fault Models. Proceedings of the Eighth National Conference on Artificial Intelligence (AAAI-90) (pp. 331-336). Menlo Park, CA: AAA Press.

Goyal, S. K., & Worrest, R. W. (1988). Expert System Application to Network Management. In J. Liebowitz (Ed.), Expert System Applications to Telecommunications (pp. 3-44). New York: Wiley Interscience.

Hammond, K. J., & Hurwitz, N. (1988, May). Extracting Diagnostic Features from Explanations. Proceedings of Case Based Reasoning Workshop (pp. 169-178), Clear Water Beach, FL.

Harris, M. D. (1985). Introduction to Natural Language Processing. Reston, VA: Reston Publishing Company.

Hayes-Roth, F., Waterman, D. A., & Lenat, D. B. (1983). Building Expert Systems (pp. 3-29). Reading, MA: Addison-Wesley.

Kandel, A. (1986). Fuzzy Mathematical Techniques with Applications. Reading, MA: Addison-Wesley.

Kerschberg, L. (Ed.). (1986). Expert Database Systems. Proceedings from the First International Workshop. Menlo Park, CA: Benjamin Cummings.

Kerschberg, L. (Ed.). (1987). Expert Database Systems. Proceedings from the First International Conference. Menlo Park, CA: Benjamin Cummings.

Kodrotoff, Y., & Michalski, R. (Eds.). (1990). Machine Learning, An Artificial Intelligence Approach, Volume III. San Mateo, CA: Morgan Kaufmann.

Liebowitz, J. (Ed.). (1988). Expert System Applications to Telecommunications. New York: Wiley Interscience.

Mamdani, E. H., & Gaines, B. R. (Eds.). (1981). Fuzzy Reasoning and Its Applications. London, UK: Academic Press.

Michalski, R. S., Carbonell, J. G., & Mitchell, T. M. (Eds.). (1983). Machine Learning, An Artificial Intelligence Approach, Volume I. Palo Alto, CA: Tioga Press (Morgan Kaufmann).

Michalski, R. S., Carbonell, J. G., & Mitchell, T. M. (Eds.). (1986). Machine Learning, An Artificial Intelligence Approach, Volume II. Los Altos, CA: Morgan Kaufmann.

Mylopolus, J., & Brodie, M. L. (Eds.). (1989). Readings in Artificial Intelligence and Databases. San Mateo, CA: Morgan Kaufmann.

Negoita, C. V. (1985). Expert Systems and Fuzzy Systems. Reading, MA: Addison-Wesley.

Parsaye, K., Chignell, M., Khoshafiam, S., & Wong, H. (1989). Intelligent Databases, Object-Oriented, Deductive Hypermedia Technologies. New York: Wiley.

Pipitone, F., DeJong, K., Spears, W., & Marrone, M. (1988). The FIS Electronic Troubleshooting Project. In J. Liebowitz (Ed.), Expert System Applications to Telecommunications (pp. 73-101). New York: Wiley Interscience.

Pozesky, M. T. (1992, January). FAA Seminar on U. S. Air Traffic Control. McLean, VA.

Prerau, D. S. (1985). Selection of an Appropriate Domain for an Expert System. AI Magazine, 6(2), 26-30.

Raiman, O., Kleer, J. D., Saraswat, V., & Shirley, M. (1991). Characterizing Non-Intermittent Faults. Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI-91) (pp. 849-854). Menlo Park, CA: AAA Press.

Rajamoney, S. A., & Lee, H. Y. (1991). Prototype-Based Reasoning: An Integrated Approach to Solving Large Novel Problems. Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI-91) (pp. 34-39). Menlo Park, CA: AAA Press.

Rich, E. (1983). Artificial Intelligence. New York: McGraw-Hill.

Sager, N. (1981). Natural Language Information Processing, A Computer Grammar of English and Its Applications. Reading, MA: Addison-Wesley.

Shapiro, S. C. (Ed.). (1987). Encyclopedia of Artificial Intelligence: Vols. I and II. New York: Wiley Interscience.

Sleeman, D., & Brown, J. S. (Eds.). (1982). Intelligent Tutoring Systems. London, UK: Academic Press.

Smits, S., & Pracht, D. (1991). MOCA - A Knowledge Based System for Airline Maintenance Scheduling. In R. Smith and C. Scott (Eds.), Innovative Applications of Artificial Intelligence 3 (pp. 21-37). Menlo Park, CA: AAAI Press/MIT Press.

Wu, T. D. (1990). Efficient Diagnosis of Multiple Disorders Based on a Symptom Clustering Approach. Proceedings of the Eighth National Conference on Artificial Intelligence (AAAI-90) (pp. 357-364). Menlo Park, CA: AAA Press.

Wu, T. (1991). Domain Structure and the Complexity of Diagnostic Problem Solving. Proceedings of the Ninth National Conference on Artificial Intelligence (AAAI-91) (pp. 855-861). Menlo Park, CA: AAA Press.

APPENDIX A

DOCUMENTS REVIEWED

CTA INCORPORATED. (Prepared for FAA ACD-350) (7/10/89). Cost Study for Human Factors Program for Maintenance Automation System.

CTA INCORPORATED. (Prepared for FAA ACD-350). (7/2/91). Final Monitor and Control Software (MCS) User Interface Requirements Document and Design Model.

CTA INCORPORATED. (Appendix 1). (4/18/90). JTA of the System Engineer and Assistant System Engineer Position.

FAA Action Notice -ASM-1. (Not Dated). Maintenance Control Center Operations Concept and Implementation.

FAA. (Not Dated). The Electronics Technician in the FAA.

FAA - DRAFT. (8/1/86). Maintenance Automation Program Master Plan.

FAA NAS-MD-794. (3/15/86). Functions and Operational Requirements of the NAS Maintenance Control Center.

FAA Order 1100.124. (7/20/70). AT/AF Responsibilities at NAS Computer-equipped ARTCCs.

FAA Order 1100.127B. (9/23/81). Airway Facilities Sector Configuration Sign Criteria for Military Systems, Equipment and Facilities.

FAA Order 1380.40B. (Appendix 1) (1/17/86). Facility Types Contractions and Definitions.

FAA Order 6000.10. (6/3/82). Airway Facilities Service Maintenance Program.

FAA Order 6000.15B. (8/15/91). General Maintenance Handbook for Airway Facilities.

FAA Order 6000.26A. (5/14/82). Reliability and Maintainability Policy.

FAA Order 6000.27A. (1984 Update). Transmittal of Maintenance Philosophy Steering Group (MPSG) Report.

FAA Order 6000.30. (Appendix 1). (4/26/82). Airway Facilities Service Policy for the Maintenance Program of the 1980's.

FAA Order 6000.30A. (1/5/87) Policy for Maintenance of the National Airspace System (NAS).

FAA Order 6100.1B. (2/22/90) Maintenance of NAS En Route Stage A-Air Traffic Control System.

FAA Order 6310.19. (7/24/91). Maintenance of the Airport Surveillance Radar-9 (ASR-9).

FAA Order 6480.6B. (6/20/90). Maintenance of Terminal Air-to-Ground (A-G) Communication Facilities.

FAA Order 6820.7A. (10/5/88). Maintenance of Navigational Aids Facilities and Equipment VOR, VOR/DME, VORTAC.

FAA Order 6850.5A. (5/6/81). Maintenance of Lighted Navigational Aids.

Federal Aviation Administration. (1/91). The National Plan for Aviation Human Factors. (Draft). Washington, DC: Author.

Maintenance Automation Tiger Team (MATT). (4/12/89). End State MCC Questions and Answers from Annapolis, MD.

MITRE Working Paper No. WP-89W00073. (4/25/89). Evaluation of Maintenance Control Center (MCC) Operational Concepts.

MITRE Working Paper No. WP-89W00320. (12/8/88). Simulation of Operations at a Maintenance Control Center.

Native American Consultants Inc. (Not Dated). Maintenance Management System (MMS) Phase 1 Instruction Manual for Regional Office Users.

Philips, Robert O. (9/89). Concept for Maintenance of the National Airspace System. (Report No. WP-59-FA915-2). Cambridge, MA: Transportation System Center, Operations Assessment Division.

Stephens Engineering Company, Inc. (Prepared for FAA ASM-240) (3/24/88). National Airspace System End State Maintenance Support Systems Description.

APPENDIX B

DOCUMENT SUMMARIES

Maintenance of NAS En Route Stage A- Air Traffic Control System - Feb. 22, 1990

Provides guidance and prescribes technical standards, tolerances, and procedures that apply to the maintenance and inspection of the NAS En Route ATC System.

Provides information on special methods and techniques that will enable the technician to achieve optimum performance from the equipment.

Major changes in this document from the previous version consist of the following:

a. Removal of the IBM 9020A and 9020D Central Computer Complex (CCC) equipment except for the Peripheral Adapter Module (PAM), that was moved to the CCCH.

b. Movement of the IBM 9020E tasks to the Display Channel Complex system from the CCC.

This document does the following:

a. Identifies the NAS En Route Stage A Model 4 technical characteristics.
b. Identifies the standards and the tolerances.
c. Describes the periodic maintenance activities that are required.
d. Describes the system maintenance procedures.
e. Describes the certification requirements.

The Electronics Technician in the FAA (TETI)

This document acquaints the incoming electronics technician with the history and organizational structure of the FAA. This document also explains the general duties and career opportunities for the electronics technician within the FAA.

The National Plan for Aviation Human Factors Vol. I.

Volume one is a draft document that presents an overview of the National Plan and a summary of the Technical Agenda.

The airway facilities research projects in the plan are separated into four domains:

a. Manpower, Personnel, and Training (MP&T).
b. Organizational Design and Management (ODAM).
c. Maintenance Automation (MA).
d. Human Performance (HP).

Within these four domains are twelve research projects:

a. Manpower requirements for AF maintenance.
b. Selection system for AF maintenance.
c. An integrated personnel system for the AF work force.
d. Integrated training system for AF personnel.
e. Increasing organizational effectiveness.
f. Maintainer considerations in the acquisition of new systems.
g. The human-machine interface in AF systems.
h. Applications of Intelligent Systems (IS) in AF maintenance.
i. Information transfer/operational communications in AF maintenance.
j. Development of a task analytic database for AF.
k. Effects of adverse environmental conditions on AF maintenance job performance.
l. Control of errors in AF maintenance job performance.

Concept for Maintenance of the NAS 9/89

This document provides a comprehensive description of the maintenance concept of the FAA NAS for:

a. Air Traffic Control.
b. Navigation and communication facilities and equipment.

The NAS maintenance concept encompasses the following three broad subject areas:

a. Provision of services to users.
b. Airway facilities organizational issues.
c. Resource management.

The National Plan for Aviation Human Factors Vol. II. 12/90

Volume two of the National Plan for Aviation Human Factors is a detailed description of the technical plan for human factors research and development.

The plan is separated into five major aviation environments:

a. Aircraft flightdeck.
b. Air traffic control.
c. Aircraft maintenance.
d. Airway facilities maintenance.
e. Flightdeck/ATC integration.

These plans are separated into research domains, projects within each domain, and task-by-task components within each project.

Maintenance Management System (MMS) Phase I. Instruction Manual for Regional Office Users

MMS is a computerized national system for managing the maintenance of the NAS facilities and equipment. The MMS contains information on facility inventory, equipment status and performance, and resources available for maintenance. MMS provides reports on facility operations in a region, reduces on-site time for technical inspections, assists in troubleshooting, and provides an inventory of facilities and equipment. This manual is for the training of FAA regional office personnel in the use of the Phase I MMS software.

The main focus of the document is the following:

a. How to use MMS to generate reports.

1. How to retrieve information from MMS and produce printed reports or computer terminal reports.

b. How to enter data.
c. How the data is used to support regional office operations.

Job Task Analysis of the NAS Operations Manager (NOM) Position

This document identifies thirteen major duties assigned to a NOM:

a. Performing NAS system configuration.
b. Performing NAS system restoration.
c. Certifying services.
d. Coordinating NAS systems maintenance activities.
e. Examining NAS systems integrity.
f. Analyzing NAS systems availability and reliability.
g. Supporting NAS systems testing.

h. Performing CFAD, CRAD, and DRAD shutdown startup activities.
Directing aircraft accident/incident activity.
j. Implementing new NAS systems.
k. Analyzing administrative activities.
l. Administering personnel policy.
m. Conducting/receiving training.

Each of these duties is subdivided into tasks, subtasks, elements and sub-elements.

Order 6310.19 Maintenance of the Airport Surveillance Radar-9 (ASR-9)

This handbook provides the technical standards, tolerances, and procedures for the maintenance and inspection of the ASR-9 system. It also provides information on special methods and techniques to be used by maintenance personnel to achieve optimum performance from the equipment.

Order 6480.6B Maintenance of Terminal Air-to-Ground (A-G) Communications Facilities

This handbook provides technical standards, tolerances, and procedures that apply to the maintenance and inspection of terminal air-to-ground communications facilities. As with other handbooks, this handbook also provides information on special methods and techniques that will help maintenance personnel to keep the equipment operating at an optimum level.

Order 6820.7A Maintenance of Navigational Aids Facilities and Equipment - VOR, VOR/DME, VORTAC

This document provides technical tolerances and standards, procedures, and general guidance for the maintenance and inspection of the VHF OmniRange (VOR/DOPPLER VOR), Distance Measuring Equipment (DME), and Tactical Air Navigation system (TACAN) facilities and equipment.

Functions and Operational Requirements of the NAS Maintenance Control Center NAS-MD-794

This document describes in depth the functions and operational requirements of the NAS maintenance control center.

The MCC concept focuses on the remote monitoring and control of facilities and equipment from a central location, at a node of the Remote Maintenance Monitoring System (RMMS) network. RMMS will provide the primary interface between the MCC and the unstaffed facilities and equipment to be monitored. The MCC will be equipped with a variety of voice and data communications that will be linked to AF and AT.

Order 6000.15B General Maintenance Handbook for Airway Facilities

This handbook provides the complete maintenance procedures and requirements necessary for the administration and maintenance of NAS facilities and equipment.

This document is separated into the following chapters:

a. General information.
b. Administrative management issues.
c. General technical maintenance procedures and criteria.
d. Field repair of equipment.
e. Service interruption, restoration, and certification.
f. Protection of agency property and personnel.

Order 6850.5A Maintenance of Lighted Navigational Aids

This handbook provides the technician with guidance and prescribes technical standards and tolerances, and procedures for the maintenance and inspection of lighted navigational aids systems.

APPENDIX C

QUESTIONS FOR SITE VISITS

I. Introduction

1. Briefly describe your job.
2. What are your primary responsibilities?
3. What are your secondary responsibilities?
4. What kinds of systems are you responsible for?

II. Routine Maintenance

1. Do you have step by step procedures (Road maps) to perform routine maintenance?
2. For each type of system that you maintain briefly describe the routine maintenance procedure.
3. How much do you depend on the maintenance manuals for the procedures?
4. What type of routine maintenance is the most frequent?
5. Briefly describe the diagnostic and test equipment you use.
6. How much of this test equipment is specialized?
7. Currently where are the maintenance tests initiated?
8. Are the tests currently conducted on-site amenable to remote maintenance if the appropriate system is constructed?
9. What maintenance procedures are difficult to perform?
10. Why are these procedures difficult to perform?
11. Does the system have self-diagnostics?

III. Certification

1. What type of equipment can you certify by performing built in diagnostics alone?
2. What kind of equipment needs manual procedures before being certified?
3. How often does equipment need to be certified?
4. What kinds of problems are encountered in the process of certifying equipment?
5. In your opinion, in what way can the certification procedure be simplified or improved?

IV. Alarm Processing

Briefly describe different types of alarms you receive.
2. How are these alarms generated?
3. Briefly describe the process of resolving an alarm.

4. What is the total number of different types of alarms?
5. Do you have to add to the list of alarms with the introduction of new types of equipment?
6. How many alarms do you expect after everything is under RMM?
7. What types of alarms do you get most often?
8. What constitutes high priority alarms?
9. How do you respond to high priority alarms?
10. What is the average response time for restoring a facility so that conditions for high priority alarms no longer exist?
11. What kind of alarms are difficult to resolve?
12. Why are they difficult to resolve?
13. Do they occur frequently compared to other alarms or are they very rare?
14. Do you get multiple alarms?
15. If yes, how do you deal with this situation?
16. Do you reconfigure the system in response to an alarm?
17. Do you reconfigure the system in response to other situations?
18. Briefly describe those situations.
19. Who makes the decision to reconfigure the system?
20. Are there guidelines for reconfiguring the system or is the reconfiguration done solely based on the judgement and experience of the operator?
21. How difficult is the process of optimally reconfiguring the system?
22. How is maintenance scheduled in response to alarms?
23. Is maintenance scheduled in response to other situations? Give some examples.

V. CM

1. Describe the decision making process involved in isolating a faulty LRU in a system.
2. What percentage of CM involves tuning of parameters (such as frequency, voltage)?
3. Are these procedures predominantly manual requiring special calibration instruments or are they performed by executing commands from a console?
4. Is the information about what parameters need to be tuned evident from the alarms alone?
5. What other indications or conditions prompt you to suspect that some parameters may be out of their normal safe operating range?
6. What percentage of CM involves replacement of parts?
7. To what level of system assembly (e.g., system level, module level, box level, LRU level, component level) can you locate a fault based on alarm information alone?
8. What problems are most troublesome (intermittent faults, analog test circuits, etc.)?
9. Why are they troublesome?
10. How often do you get multiple fault situations?
11. How do you deal with these situations?

12. How many times do you have to change your hypothesis?
13. How does your accuracy of fault determination improve with experience?
14. Have you ever had a situation in which you replaced a part and the replacement failed due to a previously unidentified fault?

VI. Equipment

1. Does modern equipment have better self-diagnostics?
2. Has self-diagnosis made the maintenance of the modern equipment easier?
3. Is the time needed to detect and find faults less than that for the older equipment?
4. Is the modern equipment more complex?
5. How would you feel if the maintenance manuals or the test procedures were made available on a terminal?

VII. Administrative Functions

1. How much time is currently spent filling out maintenance Form 6030?
2. Do you do any additional paperwork?
3. Do you keep maintenance histories for individual equipment?
4. Do they include performance data on key parameters?
5. Are the histories of a particular type of equipment consolidated to generate a report regarding common failures or problems for that type of equipment?
6. Is the performance history of equipment (critical parameters) taken into account for scheduling maintenance?
7. Who decides the scheduling of maintenance personnel?
8. How many times do personnel scheduling problems occur when fewer technicians are available than needed?
9. What are the factors that are taken into consideration while deciding the schedules?
10. How is the perceived complexity of a problem matched with the capabilities of a technician?
11. What preparation do you do before going to a site?
12. Do you have a check list?
13. What documentation do you use on site?
14. Is the documentation readily available?

VIII. Training

1. Do you think on-the-job training can contribute to your proficiency?
2. Do you feel a need to be trained to process alarms that occur rarely?
3. How do you keep your knowledge current about equipment that fails rarely?

IX. Experts

1. Are there recognized experts at the system level?
2. How many experts are available for a particular system nationwide?
3. Do the experts spend part of their time educating other technicians?
4. How often do you get help from more experienced technicians?

X. General

1. Are you required to make decisions under pressure?
2. Can you identify areas in your job where some degree of automation or change in maintenance methods will assist you in your functions?
3. What changes do you think can help you improve system performance?

APPENDIX D

INTERVIEWS SUMMARY

NOTE: This document is a consolidated summary of all the information gathered during the interviews that were conducted. The examples and detailed information that were received from the interviews were all used during the analysis and advanced analysis phases of the study. More detailed transcripts can be supplied to the FAA if requested.

I. Introduction

The supervisors are in charge of maintaining systems in one or more specialty areas, such as environmental, navigational aids, computers, communications, or radars. They have several technicians reporting to them. The job of supervisors consists of administrative duties such as scheduling periodic maintenance (PM). The MMS reports provide a listing of equipment due for PM along with the acceptable window. The supervisors determine the availability of the technicians and equipment, and schedule maintenance.

Maintenance scheduling: Supervisors may currently be spending up to 50 percent of their time in coordination activities. These activities may include:

a. Daily assignment of technicians to various jobs on equipment located at different sites including remote ones.

b. Annual vacation planning.

c. OJT planning.

The technicians perform all PMs and look for signs that may indicate degradation of services in the near future. In some cases the maintenance schedule is obtained from MMS; in other cases the maintenance schedule is prepared by the technicians; and in some cases it is done by the supervisors.

II. Routine Maintenance

1) Do you have step by step procedures (road maps) by which to perform routine maintenance?

The FAA technical documents provide step by step procedures by which to perform routine maintenance. The technical documents consist of maintenance handbooks and technical instructions. These documents mandate PM and certification intervals. They also specify allowable tolerances for key parameters. The TIs contain schematics of assemblies and subassemblies that are useful in troubleshooting and parts replacement.

2) For each type of system that you maintain, briefly describe the routine maintenance procedure.

Routine maintenance procedures comprise the following, depending on the type of system:

a. Physical inspections - check for worn parts, corrosion, etc.

b. Cleaning, lubrication - maintain equipment in good operating condition and appearance.

c. Take readings of various key parameters. If any parameters are found to be out of tolerance, tune them back into tolerance.

d. Run self-diagnostics on the system, if any exist. For example, CCH, DARC, CDC, ARTS IIA, ARTS IIIA, etc., all have self-diagnostics.

e. Perform a status light check. For example, error indications for the Paradyne modem are provided by status lights on the control panel.

3) How much do you depend on the maintenance manuals for the procedures?

Most of the maintenance procedures are done by following the maintenance manual. After considerable experience, the daily, weekly, and even the monthly, PMs may be done without consultation of the TIs. The quarterly, semi-annual and annual PMs are, however, done by looking into the TIs since there is usually less familiarity with those procedures.

With experience, the technicians may prepare simplified "cribbage" sheets that help them to complete the maintenance procedures more easily.

4) What type of routine maintenance is the most frequent?

This question relates to the comparison of PM activities such as cleaning and lubrication, vs. running diagnostic tests and measuring key performance parameters, tuning parameters, etc. The answers varied depending on the type of equipment.

5) Briefly describe the diagnostic and test equipment you use.

The diagnostic and test equipment ranged from standard volt OHM meters (VOMs) and oscilloscopes, to more specialized test equipment.

6) How much of this test equipment is specialized?

Test equipment specialization depends on the type of system maintained. For example, new equipment such as the ASR-9 has a large number of specialized test equipment, whereas the CCCH does not have much specialized equipment even though it has a set of diagnostic tests. Localizers and glide slopes have some specialized equipment that is carried to sites by the technicians.

7) Currently where are the maintenance tests initiated?

The maintenance tests are initiated at the site or from remote locations such as workcenters or the MCC. At the current stage of MCC implementation, a limited number of diagnostic tests can be initiated from the MCC. The MCC receives several alarms that are processed by clearing them or taking some other action such as dispatching a technician to the site.

8) Are the tests currently conducted on-site amenable to remote maintenance if the appropriate system is constructed?

Some equipment do not have automated self-diagnostic tests, including the long range radars, common digitizers, and glide slopes. For equipment like this, the question of how many tests can be initiated remotely is difficult to answer. The Localizer in Nashville has remote monitoring. It is not clear, however, what level of diagnostics can be performed remotely (for that matter, locally), without actually having to probe test points. In the case of equipment such as the CCCH, CDC, and the DARC, tests are initiated at the site. These facilities are in close proximity (same building) to the maintenance console (MCC or SMMC). New designs are required to take remote test initiation into consideration.

9) What maintenance procedures are difficult to perform?

10) Why are these procedures difficult to perform?

These questions were posed to identify the source of difficulties in performing some maintenance procedures. Maintenance procedures requiring two people for coordination, such as flight inspections (for radar and navigational aid facilities), are considered difficult. Adjusting the power supply voltage in the CDC to achieve load balancing are also considered difficult because the setting is highly critical and unstable. Some tasks requiring cleaning and lubrication are difficult because of the inaccessibility of the equipment. Tasks such as servicing overhead display screens are difficult because they involve lifting of heavy weights.

11) Does the system have self-diagnostics?

Some systems, such as the CCCH, CDC, DARC, ASR-9, ARTS IIA, ARTS IIIA, and the ARSR-3 have adequate self-diagnostics. Some PCSs and communication equipment, such as the Paradynes, have limited self-diagnostics.

III. Certification

The certification procedures reflect acknowledgement by a technician that the equipment is functioning within preset tolerances and specifications.

1) What type of equipment can you certify by performing built in diagnostics alone?

Only the CCCH and similar types of equipment are certified by running diagnostic tests alone. Certification of other equipment often involves PM procedures, reading of key performance parameters, physical inspections, etc.

2) What kinds of equipment require manual procedures before being certified?

Physical inspection procedures, such as checking of battery fluid levels and specific gravity for PCSs, are necessary prior to certification.

3) How often does equipment need to be certified?

Typically equipment/service is certified monthly. However, some equipment/services are certified daily (every shift). The equipment definitely must be certified when any CM is done which adjusts the certification parameters, prior to placing equipment back on-line.

4) What kinds of problems are encountered in the process of certifying equipment?

The certification procedure in the maintenance handbooks is followed and no specific difficulties are experienced.

5) In your opinion, in what way can the certification procedure be simplified or improved?

This opinion question was asked in order to determine if there was any room for improvement from the technician's perspective. The general consensus was that there was no way to improve or simplify the certification procedure, unless it could be done remotely from either a workcenter or the MCC.

IV. Alarm Processing

There are several obstacles to designing an alarm processing application in the current environment. The alarms are not received at a single site but at various locations depending on the equipment generating the alarms. Also an alarm may indicate a possible malfunction in a piece of equipment without going into detail concerning the cause of the alarm. With the centralization of alarms at the MCC, the RMMed equipment will allow more specific alarms to be generated/transmitted enabling a better initial assessment of problem situations,

leading to improved prognosis and site visit preparation. The proposed AI alarm processing application will have additional complexity due to a variety of equipment models performing the same function at different locations. For example, there are a number of vendors for the PCSs. These PCSs will generate different alarms that will have different diagnostic information content. Alarm processing applications will be of value, if they result in a reduction of reportable outages and/or down time of services.

1) Briefly describe the different types of alarms you receive.

There are four types of alarms that are received. These are hard alarms, soft alarms, state change alarms, and intermittent alarms. These alarms are received at different places. For example, the SMMC receives alarms (lights) regarding abnormal status in the CDC, DARC, Communications, etc. At the CCCH the alarms are generated on the console printout, automatic reconfiguration takes place, and a core dump is initiated. Several alarms, such as facility intrusion alarms and abnormal function alarms for the Second Generation VORTAC, are wired into the MCC.

2) How are these alarms generated?

Alarms are generated when a facility's performance parameters are out of acceptable operating tolerances.

3) Briefly describe the process of resolving an alarm.

The process of resolving alarms is usually simple because, in most cases, it requires reconfiguration of the system. In the case of single alarms, services are restored via alternate provisions. In the case of multiple alarms, the alarms are resolved in decreasing order of user impact. Alarms concerning critical facilities/services are resolved first.

4) What is the total number of different types of alarms?

The intention of this question was to extract categories of alarms from the technicians. No total number of alarms could be given, but the alarms are grouped into four categories, namely, hard, soft, state changes, and intermittent alarms.

5) Do you have to add to the list of alarms with the introduction of new types of equipment?

The alarms are generated at the equipment level and some high level information regarding the functional status is evident in the alarms. However, in general there is no fixed list of alarms to which additions would be made for each new type of equipment.

6) How many alarms do you expect after everything is under RMM?

Many of the technicians felt that either there would be the same number of alarms or fewer alarms.

7) What type of alarms do you get most often?

This question was posed to determine if, for a particular facility or a group of facilities, there are certain common problems. The technicians did not feel that they had any specific type of alarms that occurred more often than others.

8) What constitutes high priority alarms?

Any alarms that indicate disruption in facility services are high priority alarms. Within these services the criticality may vary intrinsically or depending on external conditions such as weather. AT and AF make the decision as to the priority/criticality of alarms and services.

9) How do you respond to high priority alarms?

The alarms/malfunctions can signal a reportable outage, which is a disruption in service for an interval greater than 59 seconds. For any facility, it is the goal to keep the unscheduled outages of any duration to an absolute minimum. In this sense, an immediate response to an alarm is to restore the service via an alternate route/channel and then schedule CM for the equipment causing the problems.

10) What is the average response time for restoring a facility so that conditions for high priority alarms no longer exist?

The average response time for restoring a facility depends on the faults. For most redundant systems, reconfiguration (automatic or manual) restores the status of services to 'normal'. The actual repair of equipment usually takes much longer. In the case of a remote facility, the outage condition may exist until a technician is dispatched to correct the situation.

1) What kinds of alarms are difficult to resolve?

12) Why are they difficult to resolve?

Intermittent alarms are difficult to resolve. These types of alarms are difficult to resolve because the condition that causes the fault does not exist at debugging time and there is no way to point a finger at something definite.

13) Do they occur frequently compared to other alarms, or are they very rare?

Intermittent alarms are relatively rare.

14) Do you get multiple alarms?

Occasionally multiple alarms are received. Frequently, these alarms are related. For example, a condition causing one alarm may also automatically cause another alarm.

15) If yes, then how do you deal with this situation?

Multiple alarms are typically resolved in perceived order of priority.

16) Do you reconfigure the system in response to an alarm?

Typically, you reconfigure the system in response to an alarm, but often this is done automatically. Sometimes a facility may need to be taken out of service, and a NOTAM is issued.

17) Do you reconfigure the system in response to other situations?

18) Briefly describe those situations.

Reconfiguration of one system may be done in order to schedule PMs on a different system or equipment.

19) Who makes the decision to reconfigure the system?

AT and AF make the decision to reconfigure the system. AT must be advised of all reconfigurations so that they are aware of any impact on their service.

20) Are there guidelines for reconfiguring the system or is the reconfiguration done solely based on the judgement and experience of the operator?

There are no firm guidelines for reconfiguring the systems. However, AT assesses the relative importance of services under the operating conditions, and AF performs the reconfigurations accordingly. Reconfigurations are done on the basis of the judgement and experience of AT and AF.

21) How difficult is the process of optimally reconfiguring the system?

Reconfiguration typically involves a small fraction of the equipment in use. Most reconfigurations consist of making the backup facilities primary. Neither the analytical nor the physical process of reconfiguration is difficult.

22) How is maintenance scheduled in response to alarms?

The alarms are received by the MCC specialist or the NOMs, or AT perceives a disruption in services. The first person to receive the alarm will try to resolve it. If the alarm cannot be resolved, the appropriate unit supervisor is then contacted if the alarm is received during administrative hours. If the situation occurs after administrative hours, the MCC has a call back list of the technicians who can be contacted.

23) Is maintenance scheduled in response to other situations? Give some examples.

If, during normal inspections and PM, a technician notices any abnormal trends in the key performance parameters or other conditions that may result in disruption of service in the near future, he may request the facility to be taken out of service for an extended period during which he may perform extensive PM procedures.

V. CM

CM occurs in response to three types of situations.

1) Malfunctioning equipment is causing a degradation/disruption of services.

2) Malfunctioning equipment has been taken off-line and has been substituted with standby equipment, thus providing full services.

3) The equipment performance is deteriorating and is expected to fail.

The first case is the most critical to the operations of the FAA.

1) Describe the decision making process involved in isolating a faulty LRU in a system.

An AT, MCC specialist, or NOM describes perceived problems to the extent possible. The alarm and some indicators on the equipment may provide additional clues as to the cause of the problem. A hypothesis is made regarding the cause of the problem. Additional tests are conducted to confirm the hypothesis or to narrow it down further in order to locate the fault at the LRU level. The sequence of hypotheses and tests depends on the symptoms, equipment design, diagnostic tests design, and technician experience and understanding of the system.

2) What percentage of CM involves tuning of parameters (such as frequency, voltage)?

The percentage of CM that involves tuning of parameters depends on the system. Usually, once tuned, the parameters are stable except in circuitry employing vacuum tubes. Tuning of parameters is often required when some parts are replaced.

3) Are these procedures predominantly manual, requiring special calibration instruments, or are they performed by executing commands from a console?

Some parameters can be tuned from the console, such as glide slopes, VORs, and localizers for which parameters are set from the terminal, either locally or remotely. Calibration procedures are performed by using various instruments, either digital readout or analog meters. These meters may be standard or specially designed for the task.

4) Is the information about what parameters need to be tuned evident from the alarms alone?

Usually, the alarm condition does not get corrected by tuning some parameters alone. The parameters that need to be tuned are not necessarily evident from the alarms alone. In the Paradyne modems and the ASR-9, it is possible for some parameters, such as the signal to noise ratio the minimum discernible signal, to move outside their lower tolerance limits. These situations are not easily rectified just by tuning the parameters within the right range. The conditions that cause the key parameters to move out of tolerance need to be corrected.

5) What other indications or conditions prompt you to suspect that some parameters may be out of their normal safe operating range?

All of the equipment is kept in top condition through the performance of regular PMs. Some signs of performance degradation may be apparent during these rigorous PM procedures. Some indicator values may still be within operating tolerances, but the system may be providing a reduced quality of service, relative to optimum.

6) What percentage of CM involves replacement of parts?

Most CM involves replacement of parts. It is desirable to keep both the equipment down time and repair cost low. This means the lowest level faulty part (assembly) must be identified and replaced/repaired. Some circuit cards are repaired at the site, but most are returned to the depot that has better facilities for efficient card repair.

7) To what level of system assembly (e.g., system level, module level, box level, LRU level, component level) can you locate a fault based on alarm information alone?

Usually the alarm information is very general. Depending on the type of alarm information received faults can be located at all the levels of system assembly that are listed above. However, fault locations in areas other that those suggested by the alarms are difficult to detect because of the complex interconnections within the equipment.

8) What problems are most troublesome? (intermittent faults, analog test circuits, etc.)?

9) Why are they troublesome?

Intermittent faults are the most troublesome. For a fault to be located and repaired, it must be present (permanent) so that symptoms can be traced back to the fault location. An intermittent fault makes this process extremely difficult and subject to a trial and error strategy.

10) How often do you get multiple fault situations?

It is not common to get multiple fault situations. Occasionally a fault in one area may manifest as a problem in several areas.

1) How do you deal with these situations?

These problems are best handled by trying to identify the most likely problem, repairing it, and determining if other problems still persist.

12) How many times do you have to change your hypothesis?

Formulating and changing hypotheses regarding exact location of faults is an integral part of the decision making process in fault diagnosis. Often the hypothesis is refined in that the fault location is narrowed down from multiple probable locations to one or two locations. Occasionally, additional evidence may suggest pursuing a different line of reasoning previously abandoned or unexplored.

13) How does your accuracy of fault determination improve with experience?

With experience, the knowledge and understanding of the equipment grows and so does the accuracy of fault determination.

14) Have you ever had a situation in which you replaced a part and the replacement failed due to a previously unidentified fault?

Situations in which a replacement part failed due to a previously unidentified fault are rare, but do occur.

VI. Equipment

1) Does modern equipment have better self-diagnostics?

Usually, yes (e.g. ASR-9). All analog panel meters are eliminated. The readouts are presented on the console or printer. Modern equipment tends to be more complex in that more functions are combined in a single card, etc. The quality of the self-diagnostics provided depends on the individual equipment. Some are excellent, some are adequate, and some are inadequate.

2) Has self-diagnosis made the maintenance of modern equipment easier?

The answer to this question also depends on the quality of the diagnostics. If the diagnostics are well designed, the task of trouble shooting is simplified. Otherwise the tests are not of great help. In general the diagnostics have not reached a level of sophistication that they can indicate faulty cards (or circuitry) with a sufficient level of confidence.

3) Is the time needed to detect and find faults less than that for the older equipment?

The answer to this question depends on the equipment, and the level of circuitry at which the fault detection is sought. There is also less expertise for modern equipment causing more time to be spent in troubleshooting.

4) Is the modern equipment more complex?

Yes, the modern equipment is more complex.

5) How would you feel if the maintenance manuals or the test procedures were made available on a terminal?

Many technicians felt that having the maintenance manuals on the terminal would be beneficial, especially through a system that would provide figures (such as schematics), rapid skimming of pages, skipping pages, and rapid and easy updating.

VII. Administrative Functions

1) How much time is currently spent filling out maintenance Form 6030-1?

The 6030-1 form is relatively simple. It provides space for descriptions of the problem, symptom(s) observed, and action(s) taken. The entries are dated and initialed by the responsible technician. The logs are preserved for three years (yellow copy at site, white copy at the sector office/sector field office). The logs move with the facilities.

2) Do you do any additional paperwork?

There are other forms for noting values of the key performance parameters periodically as a part of the regular PM procedures. There is no additional paperwork apart from ordering required parts, updating the manuals, etc.

3) Do you keep maintenance histories for individual equipment?

The form 6030-1 and MMS log entries are kept for individual facilities. The MMS log entries and 6030-1 forms constitute the histories of the individual pieces of equipment. They are kept for a three year period after which they are destroyed unless required for a pending investigation. There is also data regarding the modification status of the equipment. This is present in the facility reference data file.

4) Do they include performance data on key parameters?

Performance data on key parameters are kept in the Technical Performance Records (TPRs).

5) Are the histories of a particular type of equipment consolidated to generate a report regarding common failures or problems for that type of equipment?

The entries in the Form 6030-1 are not manually entered and consolidated to generate nationwide reports for a system. However, MMS failure reports can be consolidated across the nation for an equipment type if desired.

6) Is the performance history of equipment (critical parameters) taken into account for the purpose of scheduling maintenance?

PMs and certifications are scheduled according to their due dates within the allowed windows. Additional maintenance may be scheduled at the discretion of the technician in consultation with the supervisor.

7) Who decides the scheduling of maintenance personnel?

This is primarily the unit supervisors' responsibility. It is done within the crew framework (wherever applicable) and in consultation with AT, whenever AT is affected.

8) How many times do personnel scheduling problems occur when fewer technicians are available than needed?

Generally, this does not happen. The Crew concept allows for overlapping coverage. This ensures a period of time during which PMs requiring two people may be scheduled. The situation may be different in the future given a shortage of experienced technicians due to retirement, promotions, etc.

9) What are the factors that are taken into consideration while deciding the schedules?

Generally, minimum impact to the users, meeting the PM schedule deadlines, maintaining equivalent workloads across technicians, and experience/capabilities of the technician are the factors taken into account while deciding the schedules.

10) How is the perceived complexity of the problem matched with the capabilities of a technician?

Technicians with journeyman level training are expected to deal with any problems. In the rare case of persistent problems, help may be sought from the sector, region or national field support divisions. Technicians with less experience are given responsibilities gradually, whenever possible.

11) What preparation do you do before going to a site?

Before going on a site visit, technicians study the symptoms, visualize the problem, and develop a strategy by which to troubleshoot the problem. The technicians gather the required equipment and spare parts that may be helpful in repairing the equipment.

12) Do you have a check list?

Usually not, but it would be nice to have a check list.

13) What documentation do you use on site?

Apart from the technical instructions (TIs) that describe the PM procedures and provide a functional description of the equipment, there are schematics for the equipment that are helpful in troubleshooting. Also used are the facility reference data files.

14) Is the documentation readily available?

Documentation is well maintained and current for each site.

VIII. Training

1) Do you think on-the-job training can contribute to your proficiency?

2) Do you feel a need to be trained to process alarms that occur rarely?

3) How do you keep your knowledge current about equipment that fails rarely?

The Academy training is good and cannot easily be replaced by other training. However, there are constraints such as low frequency of training opportunities for certain equipment, that make it difficult to schedule all the people from a sector to attend a course (there would not be enough people remaining to cover the normal workload). There are also several CBI courses available via hookup to the Academy computer. The students need to be authorized and registered and are evaluated on line. Most of these courses are preacademy courses. It may be desirable to produce courses/videos on procedures that are performed infrequently as well as problems that occur rarely. In a crew scenario, a technician may get to perform an annual PM once in five years or less. Also, with an awareness of the problems faced elsewhere and their solutions, the technicians will be motivated to learn why and how the solutions work and will be better prepared for unforeseen situations.

IX. Experts

1) Are there recognized experts at the system level?

2) How many experts are available for a particular system nationwide?

National level experts are available at the national field support divisions. They are located at the FAA Aeronautical Center and the FAA Technical Center.

3) Do the experts spend part of their time educating other technicians?

There are no direct training efforts; however, there is communication between the incoming and outgoing technicians during shift changes. There is a written log of observed problems as well as a sequential account of remedial steps taken or attempted. Additional information that cannot be logged, practically speaking, may be conveyed orally. Past experiences and solutions for similar problems may be discussed.

4) How often do you get help from more experienced technicians?

The experience levels of the technicians vary. Some are more experienced and expert than others. However, everybody has adequate knowledge and experience to perform any anticipated tasks without supervision or significant guidance.

X. General

1) Are you required to make decisions under pressure?

Yes, especially when a technician certifies or does CM on a piece of equipment that is going to be put back on-line.

2) Can you identify areas in your job where some degree of automation or change in maintenance methods would assist you in your functions?

3) What changes do you think can help you improve system performance?

Some areas where automation would be helpful are:

Load balancing in CDC power supplies
Hexadecimal decoding of CDC printouts
More Englishlike printouts (as in the case of SMMC outputs)
Vacuum tube circuit adjustments in the long range radar
Problem resolution file

APPENDIX E

ACRONYMS

AC	Alternating Current
AF	Airway Facilities
AI	Artificial Intelligence
ALS	Approach Lighting System
ALSF	Approach Lighting System with Flasher
ANITA™	Artificial Neural Information-processing Techniques and Analysis™
ANN	Artificial Neural Network
APES	Alarm Processor Expert System
ARSR	Air Route Surveillance Radar
ART	Adaptive Resonance Theory
ARTCC	Air Route Traffic Control Center
ARSR	Air Route Surveillance Radar
ARTS	Automated Radar Tracking System
ASDE	Airport Surface Detection Equipment
ASR	Airport Surveillance Radar
ASRS	Air Surveillance Radar Systems
AT	Air Traffic
ATC	Air Traffic Control
BUEC	BackUp Emergency Communications
CBI	Computer Based Instruction
CCCH	Central Computer Complex Host
CDC	Computer Display Channel
CERAP	CEnter Radar APproach
CM	Corrective Maintenance
CMOS	Complementary Metal Oxide Semiconductor
COTS	Commercial-Off-The-Shelf
DAI	Distributed Artificial Intelligence
DARC	Direct Access Radar Channel
DCM	Diagnostic Control Mechanism
DME	Distance Measuring Equipment
EHD	Expert Help Desk
EMS	Expert Monitoring System
ENS	Expert Neural System
ENN	Expert Neural Networks
ES	Expert System
ESE	Expert System Development Environments
FA	Fault Anticipator
FAA	Federal Aviation Administration

FL	Fuzzy Logic
GA	Genetic Algorithms
GL	Genetic Algorithm Learning
GMCC	GNAS Maintenance Control Center
GNAS	General National Airspace System
IDB	Intelligent Database
IDEA	Intelligent Diagnostic Expert Assistant
IDER	Intelligent Decoder for Equipment Readout
IF	Intelligent Filter
ILS	Instrument Landing Systems
IMCS	Interim Monitor and Control Software
I/O	Input/Output
IV&V	Independent Verification and Validation
KBES	Knowledge-Based Expert Systems
MAP	Multiple Alarm Processor
MCC	Maintenance Control Center
ML	Machine Learning
MMS	Maintenance Management System
MPSG	Maintenance Philosophy Steering Group
MOS	Metal Oxide Semiconductor
MPS	Maintenance Processor Subsystem
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NAS	National Airspace System
NAV/COMM	Navigational/Communications
NLP	Natural Language Processing
NN	Neural Network
NNE	Neural Network Development Environments
NOM	NAS Operations Manager
OJT	On-The-Job Training
PAR	Precision Approach Radar Systems
PCS	Power Conditioning System
PM	Periodic Maintenance
PRC	Problem Resolution Classifier
PRES	Problem Resolution Expert System
PRF	Problem Resolution File
PVD	Plan View Display
RAD/COMM	Radar/Communications
RCAG	Remote Center Air/Ground
RCO	Remote Communications Outlets
RES	Reconfigurer Expert System
RMM	Remote Maintenance Monitoring
RMMS	Remote Maintenance Monitoring System

RTR	Remote Transmitter/Receivers
SFO	Sector Field Office
SMMC	System Maintenance Monitor Console
SMP	Service Maintenance Planner
SOP	Standard Operating Procedures
TI	Technical Instructions
TTL	Transistor-Transistor-Logic
UI	User Interface
VASI	Visual Approach Slope Indicator
VHF	Very High Frequency