AD-A258 137

AFIT/GIR/LSY/92D-8

INTEGRATED DIAGNOSTIC EXPERT SYSTEM MODEL (IDESM): A MODEL FOR THE CONVERSION OF FAULT ISOLATION PROCEDURES INTO AN INTEGRATED DIAGNOSTIC EXPERT SYSTEM

THESIS

Mr. Robert J. Lacey, Australian DoD
Glen D. Steemson, Squadron Leader, RAAF

AFIT/GIR/LSY/92D-8

Approved for public release; distribution unlimited

The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

AFIT/GIR/LSY/92D-8

INTEGRATED DIAGNOSTIC EXPERT SYSTEM MODEL (IDESM): A MODEL FOR THE CONVERSION OF FAULT ISOLATION PROCEDURES INTO AN INTEGRATED DIAGNOSTIC EXPERT SYSTEM

THESIS

Presented to the Faculty of the

School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for Degrees of

Master of Science in Information Resource Management

Mr. Robert J Lacey, DipCoEng
Australian Department of Defence

Glen D. Steemson, BE
Squadron Leader, RAAF

December 1992

Approved for public release; distribution unlimited

Acknowledgements

We are indebted to the many people who have helped us during the research, testing, and preparation of this thesis. We sincerely thank our thesis committee, Professor Arthur A. Munguia and Capt Marsha Kwolek, who have encouraged and guided us throughout this demanding project. We express our gratitude to Lt Col James Holt for his technical assistance in the early part of the project.

We would like to thank Colonel Kadish, Commander of ASD/VF, for allowing us access to the information and staff within his organization. In particular, the assistance of Mr. Al Stringer and SMSgt Bernard McLoud has been invaluable and we thank them very much.

We are grateful for the assistance we have received from Mr. Paul Sutherland and Mr. James Kirk of National Cash Register (NCR) for providing the 3125 Notepad System and Mr. Brian Pioreck of Knowledge Garden for his help with KnowledgePro. We thank all the survey participants for their contribution and, in particular, thank Capt Terry Ryan (C-17 SPO), Lt Eric Carlson (Armstrong Laboratories), and SMSgt Joel Greenleaf (4950th Test Wing) for their co-ordination efforts.

Most importantly, for their patience, support, and understanding, we thank our wives and families: Ann, Matthew, and Cassandra Lacey and Barbara and Michael Steemson.

Robert J. Lacey　　　　Glen D. Steemson

Table of Contents

	Page
Acknowledgements	ii
List of Figures	vii
List of Tables	viii
Abstract	ix
I. Introduction	1
Background	2
Problem Statement	6
Research Objectives	6
Research Objective 1	6
Research Objective 2	7
Research Question 2.1	7
Research Objective 2.2	7
Research Objective 3	7
Research Question 3.1	7
Research Objective 3.2	7
Research Objective 4	7
Research Question 4.1	7
Research Objective 5	8
Scope/Limitation of Research	8
Definitions	8
Thesis Overview	10
II. Literature Review	11
Introduction	11
Organization of Technical Manual Fault Isolation Procedures	12
Hypermedia Definition	13
The Development of Management Information Systems	15
Expert System Definition and Structure	16
Knowledge Representation	17
Rule-Based Expert Systems	17
Deductive and Inductive Reasoning	18
Inference Mechanisms	18
Blackboard Architecture	19
Fact-Based Expert Systems	20

Page

Semantic Network Expert Systems 21
Frame-Based Expert Systems 21
Generic Categories of Expert System Applications 22
Problem Characteristics that Require Expert Systems . . . 22
Choosing a Tool for Building Expert Systems 23
Existing Fault Isolation Expert Systems 24
Fired Heater Advisor 24
An Expert Database System for Shipboard Maintenance . 24
Interactive Fault Diagnosis and Isolation System (IFDIS) . 25
Automotive Computer-based Expert (ACE) 26
Jet Engine Technical Advisor (JETA) 26
Integration of Navy Stock Points Expert System 27
Summary 27

III. Methodology 29

Overview 29
Explanation of Method and Research Design 29
Concept of Use 30
Model Design Methodology 31
Model Design 33
Principles of Software Design 38
Modularity and Partitioning 38
Coupling 38
Cohesion 38
Span of Control 39
Size 39
Shared Use 39
Generic Model Development 40
Development of Hypermedia Submodel 40
Storage 40
Chunking 41
Linking 42
Hypermedia Submodel Text 42
Hypermedia Submodel Graphics 44
General Aircraft Views 44
Detailed Diagrams 44
Schematic Diagrams 45
Special Tool Illustrations 45
Photographic Quality Illustrations 45
Hypermedia Submodel Audio/Video 45
Descriptive 45
Procedural 46

Page

Development of Expert System Submodel 47
Submodel Integration Shell 49
Prototype Development 49
Evaluation Plan 52
Description of Population and Sample 53
Instrument Development and Testing 54
Data Collection Plan 54
Statistical Tests 55
Summary 55

IV. Findings and Analysis 57

Overview 57
Survey Results 57
Ease of Use 59
Suitability of User Interface 61
User Level Adequacy 64
Correctness of Converted Procedure 65
Completeness of Converted Procedure 67
Efficiency 68
Reliability and Consistency of Results 69
Overall Usefulness of the System 69
IDESM Evaluation 71
Summary 72

V. Conclusions and Recommendations 73

Introduction 73
Conclusions 74
Recommendations for Further Research 77
Summary 79

Appendix A: Sample File Formats 81

Faultcode Module Template 81
Index File Format Sample 83
Text File Format Sample 83

Appendix B: Model Evaluation Questionnaire 84

Appendix C: Questionnaire Responses 93

Bibliography 113

Page

Vita 116

List of Figures

Figure — Page

1. Types of Hypermedia Links 14
2. Elements of an Expert System 17
3. Data Representation of Blackboard Architecture 20
4. IDESM Screen Presentation Format 35
5. IDES Components 41
6. Composition of Hypermedia Submodel 43
7. Expert System Submodel 48
8. Developed Prototype 51

List of Tables

Table	Page
1. Generic Categories of Expert Systems	22

AFIT/GIR/LSY/92D-8

Abstract

The purpose of this research was to develop a model to convert existing hardcopy maintenance manual fault isolation procedures into electronic format and to partially automate the fault isolation process. A comprehensive model was developed which comprised four major components: user interface, expert system submodel, hypermedia submodel, and submodel integration shell. Using this model, the F-15E nose landing gear fault isolation procedures were transformed into a rule-based expert system. An existing hypermedia information base was expanded and subsequently integrated with the expert system to form the prototype application.

The prototype was evaluated by engineering and maintenance personnel at Wright-Patterson Air Force Base. An analysis of the survey responses demonstrated favorable acceptance of the prototype and validated the Integrated Diagnostic Expert System Model (IDESM). Several conclusions from this project and recommendations for further research are presented.

INTEGRATED DIAGNOSTIC EXPERT SYSTEM MODEL (IDESM):

A MODEL FOR THE CONVERSION OF FAULT ISOLATION

PROCEDURES INTO AN INTEGRATED DIAGNOSTIC EXPERT SYSTEM

I. Introduction

The Australian Defence Force (ADF), as well as other western defense forces, has been directed to significantly reduce manpower levels. This directive is a result of the Australian government's recent decision to increase civilian contractor participation in support of the ADF, certain government economic factors, and the recent worldwide trend towards peace at the "superpower" level. As has been evident in past reductions, a consequence of this move towards a reduced force is a reduction in the availability and experience level of workforce personnel. Also, although the ADF is being reduced, it is not envisaged that the requirement for existing capabilities will be reduced proportionately. Therefore, all levels of the force will be required to find ways to improve their efficiency.

This investigation addressed the benefits of developing a model to convert existing hardcopy maintenance manual fault isolation procedures into electronic format and to partially automate the fault isolation process. The flexibility of the model to cope with other Service's publication formats may be a topic for further research. Because of their availability, United States Air Force maintenance manuals were used in this research.

Background

The Royal Australian Air Force (RAAF) has maintained a generalist training philosophy for its tradespeople. That is, a technician receives basic training in general trade practices and knowledge. Throughout his/her career, the technician tends to migrate from one equipment to another and from one technology level to another, rarely specializing in one particular type of equipment or system.

In the past, this philosophy has worked because there was considerable commonality among systems and the complexity was such that a technician could master many systems. However, with the sophistication of today's weapon systems, the technician spends a large proportion of his/her time in training and less time on the job. The current generation of weapon systems is technologically complex, with the majority of subsystems being integrated and interactive in some way. Newer equipment is even more complex. Although this higher technology has led to expanded capability and improved reliability of the equipment, it has introduced new problems.

The integrated nature of these new systems makes it difficult to specialize training to a particular subsystem in isolation. Also, because the total system is so large, it is impossible to fully train a technician on the total system during the normal posting cycle. In the past a technician achieved a basic level of competence through training, then developed his/her maintenance skills on the job through experience and repetitive maintenance situations, which reinforced the learning process. The trend of newer systems towards improved reliability and greater complexity has led to a decrease in the repetitive learning process, which has led to reduced efficiency. The technician forgets the knowledge gained from the symptoms and the repair of a particular fault before he/she again has a chance to work on a similar one.

A large number of the RAAF's publications are sourced through the United States (US) Foreign Military Sales (FMS) program. As such, these publications usually follow the specification and format of the parent weapon system's technical orders (TOs). Occasionally, there are some differences in those publications where fleet specific changes are made, but in the majority of cases these changes are only in the content, not the format. Therefore, it was considered appropriate to use United States Air Force publications as a basis for this research.

The quantity of publications for each new weapon system has grown in direct proportion to the increase in complexity of the weapon system. This growth in quantity has increased the cost of ownership for a full set of weapon system documentation. Even though the production process has been refined and improved, the dollar cost to acquire, reproduce, bind, distribute, and maintain these publications is enormous. In addition to this large monetary cost, the increase in complexity and volume also leads to inefficiencies in the use of a technician's valuable time in two ways: time is consumed as the technician navigates the documentation during the maintenance process, and technicians, because they are usually the last link in the chain, are often called upon to incorporate the publication amendments. In both cases, the technician's time is diverted away from the primary task of maintenance.

On all but the latest weapon systems, technicians use TOs to gain information regarding the system that they are to maintain. When a technician is relatively new to a system, he/she tends to rely more on the TO (in particular the fault isolation procedures) to assist in the logical approach to troubleshooting. Logical fault isolation relies on the use of several basic troubleshooting rules and deduction. The TO fault isolation procedures are an attempt to formalize these rules and reduce the amount of deduction required by the technicians.

An expert system also attempts to formalize these rules and automate the fault isolation process. An expert system, which is a software program and uses knowledge collected from diagnostic experts, is another tool that the technician can use to help locate a fault more accurately and with greater speed. By making the user interface simple to operate, minimal training is required to use the expert system. Although the technician may be required to perform measurements and tests of the weapon system under test, he/she usually only has to respond to questions from the expert system regarding the state of the system.

The introduction of expert systems throughout industry has led to savings in the technician's time for training (less time required to learn the system and less time required to develop deductive reasoning) and more effective fault isolation at a reduced experience level (18:1038). Comparisons by Chen between a human expert and the use of an expert system to isolate faults in an air-conditioner compressor resulted in the expert system being superior in both accuracy and speed (8:342-345). Therefore, the expected benefits of automation include less training, more consistent quality of maintenance, and increased productivity.

The pace of information processing development is such that the Australian Defence Force expects that, with the next major system acquisition, technical publications will be provided in electronic format, rather than hardcopy. In his thesis, FLTLT Peter Cassell (1991 AFIT Masters Graduate) developed a model for the conversion of technical maintenance publications into electronic (hypermedia) format (7). The Logistics Research Division of the Armstrong Laboratory at Wright-Patterson AFB is upgrading F-16 documentation to electronic format and is involved in the development of the electronic Integrated Maintenance Information System (IMIS) for the F-22 aircraft.

Several other organizations which are detailed in Chapter 2 are currently developing diagnostic expert systems that will integrate with electronic (hypermedia) publications. However, there are many existing fault isolation procedures which are not likely to be automated. Therefore, a model was developed to automate these existing fault isolation procedures and provide a similar capability to that expected to be delivered with future systems.

Problem Statement

The purpose of this research was to develop a generic model for the conversion of maintenance manual fault isolation procedures into corresponding expert systems and to integrate the expert system structure with a hypermedia technical publication information system.

Research Objectives

The research required to solve this particular problem was divided into several areas. Before a model could be developed that would convert maintenance manual fault isolation procedures into an expert system, the input to the model had to be defined. The input to the model was developed using information from the United States Air Force technical publication system. This approach was valid because the Australian Defence Force purchases the majority of its equipment from the United States and adopts the supplied equipment publications with little or no alteration to the content and no alteration to the format.

Research Objective 1. To determine the types (format/content) of maintenance manuals which the model would convert.

This objective involved a review of the existing military specifications which apply to the various maintenance manuals delivered to the USAF, and attempted to determine common data requirements that form the basis of these specifications. Because the objective of this research was to develop a generic model, it was important to determine input specifications that allowed the developed model to be widely applicable.

Research Objective 2. To develop the output specifications for the generic model.

Research Question 2.1. How should the expert system interface with the user to exchange fault isolation information?

Research Objective 2.2. To determine the structure of the existing information system.

The input and output of the generic model were defined with the completion of the first two objectives. The process of conversion was then identified and divided into a sequence of steps. Similar systems that had already been developed for military and civilian applications were reviewed, and the attributes of the various models were assessed against this application.

Research Objective 3. To select the most appropriate conversion model methods and criteria from existing automatic fault isolation systems.

Research Question 3.1. What models currently exist that convert fault isolation procedures into expert systems?

Research Objective 3.2. To identify existing model criteria and evaluate each criteria for suitability in this application.

Research Objective 4. To develop a generic model.

Research Question 4.1. How should the expert system be structured such that it can be interfaced with existing systems?

Research Objective 5. To prototype, test, and evaluate a sample system with the generic model.

The final stage of this research was to prototype the conversion of a fault isolation procedure based on the developed model and to evaluate the model for effectiveness. Effectiveness was defined as how well the model achieved the conversion objectives.

Scope/Limitation of Research

Time was the major limitation of this research. The prototype system had to be developed and tested within a timeframe of six months. Because of this timeframe, the research was limited to developing a model to convert fault isolation procedures, validating the model, and providing direction for further development.

Definitions

The term "technical orders" usually covers the full range of technical documentation for all USAF weapon systems and equipment. Technical orders differ according to which specification was used for their development. For example, the technical orders for the F-15 aircraft were produced in accordance with the Maintenance Integrated Data Access System (MIDAS) developed by the McDonnell Aircraft Company in response to MIL-M-83495. MIL-M-83495 is the military specification covering the Organizational Maintenance Manual Set.

Military specification MIL-M-83495A (13) requires that information be organized into a structured set of technical manuals, including general equipment (GE) manuals (referred to as general vehicle (GV) in TO 1F-15E-2-00GV-00-1 (14)), general system (GS) manuals, job guide (JG) manuals, fault isolation (FI) and fault reporting (FR) manuals, wiring data (WD) manuals, schematic diagram (SD) manuals, combining manuals, and related manuals (13:2-3).

To rectify a reported fault, the technician first needs to ascertain what is causing the problem, i.e., isolate the fault. Maintenance personnel use a fault reporting code which can be provided by the person making out the fault report or derived from a suitable checkout procedure. The particular fault reporting code is located in the fault isolation procedures contained in the fault isolation manual for that weapon system or equipment. This code indicates the starting point of a logical sequence of steps or tests that ultimately leads the technician to the component which most likely is the cause of the problem.

The information contained in these manuals can be converted into electronic format, such that the fault isolation procedures become an expert system. The storage, manipulation, and presentation of data in this management information system (MIS) is possible using a hypermedia system to link nodes of information which are presented to the user via a visual display unit in an associative user prescribed sequence. Overall, the converted manuals become a highly integrated MIS.

Thesis Overview

The management problem, research objectives and questions, the scope of the research, and definitions of terms were introduced in Chapter 1. Chapter 2 contains a literature review which was employed to research the field of expert systems and the tools available for expert system development. This review was also used to scope the range of specifications covering the fault isolation procedures covered in this thesis.

The methodology of the research is covered in Chapter 3. This chapter documents the development of a model for the conversion of hardcopy fault isolation procedures into an expert system and the construction of a prototype integrated expert system using that model. Chapter 3 also describes the testing methodology and evaluation plan for the prototype. Chapter 4 presents the survey findings and an analysis of the results. Chapter 5 contains the conclusions drawn from the research and provides recommendations for future research.

II. Literature Review

Introduction

This literature review summarizes existing knowledge relevant to the research problem. Specifically, the aims of this review are to determine input requirements to the model, identify any existing conversion models, and examine current trends in expert system development. Subjects covered include the organization of technical manual fault isolation procedures, the concept of hypermedia, the development of information systems, a general overview of expert systems and models, and specific expert systems developed to automate fault isolation procedures. Sources accessed include the Defense Technical Information Center reports, the Aerospace and ABI/Inform on-line databases, and Engineering Indexes.

An extensive amount of literature on expert systems exists. Consequently, the literature search was limited to expert systems literature concerning expert systems development and diagnostic, or fault isolation, types of expert systems. The review examines the approaches and tools used in constructing expert systems. In addition, existing diagnostic expert systems are discussed in terms of approach adopted, conversion models used, success of prototype, and any relevant research findings. However, very little literature was found regarding models used for converting existing fault isolation charts to expert systems.

Organization of Technical Manual Fault Isolation Procedures

In 1976 the Air Force Human Resources Laboratory (AFHRL) funded a study for the evaluation of three types of technical data for troubleshooting (25). From this study, Potter reported that conventional TOs of that era contained troubleshooting procedures that:

> will generally isolate the malfunction to a particular stage and then refer the technician to the appropriate diagram or illustration. The manuals are prepared assuming that the technician has experience and training in the use of test equipment, in locating most parts within the equipment, and in interpreting schematic diagrams. (25:25)

Logic Tree Troubleshooting Aids (LTTAs) were more proceduralized than the TOs of that time because they provided specific instructions both in the equipment checkout procedure and in the troubleshooting procedure.

> The troubleshooting logic trees give exact procedures to be performed and ask questions about results obtained ... The yes or no answer to these questions provides the logic in the fault isolation procedure. Each path ends with instructions to replace a faulty component. (25:25)

In comparison, Fully Proceduralized Troubleshooting Aids (FPTAs) provided a further level of troubleshooting information in that they gave:

> complete step-by-step instructions for both checkout and troubleshooting of the equipment. These aids are designed for use by both experienced and inexperienced technicians. A complete logical troubleshooting procedure is provided similar to the LTTAs. Here, however, all specific test equipment and tools are called out in each section as they are required. Each prime hardware item and the more complex test equipments and tools mentioned in the body of the text are accompanied by a callout number ... keyed to an illustration of items appearing on that same page. (25:32)

The study concluded that LTTAs and FPTAs were superior to the existing technical orders. As a result, military specifications now include the LTTA format for fault isolation procedures. Military Specification (MIL-M-83495A) (13) is the latest specification detailing the content and format of data which is required to be included in the organizational maintenance manual set. The requirements for the FI manual are included in Section 3.5 of this specification. The quantity of current USAF TOs which conform to the LTTA format as specified in military specifications since 1976 (including MIL-M-83495A) could not easily be ascertained. However, more manuals comply to the LTTA format than to MIL-M-83495A. Therefore, the LTTA format became the basis for developing the input specification for the Integrated Diagnostic Expert System Model (IDESM). The major benefit of selecting the LTTA format over a particular military specification is that the model's applicability is increased.

Hypermedia Definition

Hypertext and hypermedia are synonymous terms. Although there is no generally accepted definition for these systems, they are characterized by several features (2:820). The information stored within the hypermedia system is chunked into small units variously called notecards, frames, or nodes. Each individual unit may contain text, graphics, video, spreadsheets, sound, or animation. The information is displayed one unit at a time, with the units of information being interconnected by links. These links are displayed to the user to enable navigation through the hypermedia database for the required information. Figure 1 gives examples of the four different methods for structuring hypermedia information.

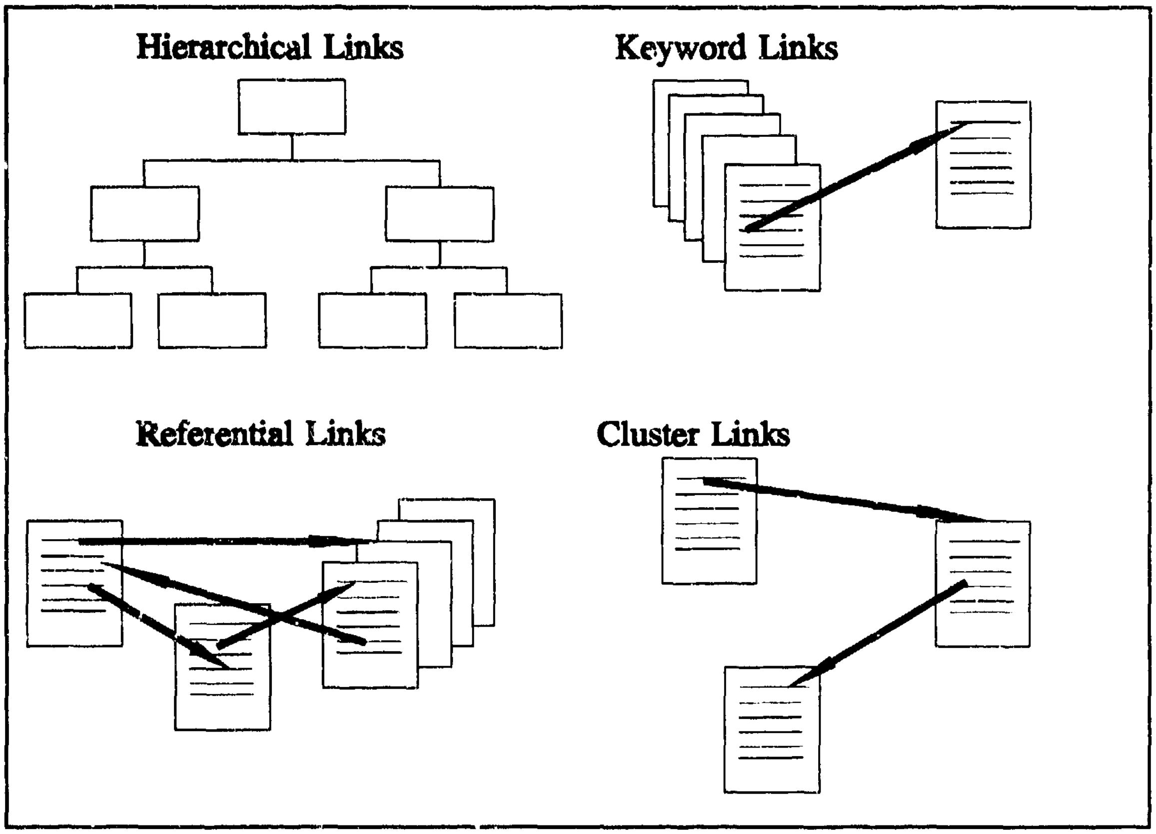

Figure 1. Types of Hypermedia Links (27:36)

Hierarchial linking establishes a structure in the information base that uses a menu to link to the next block of data to be accessed. Keyword linking identifies words that are embedded in the text as links to associated data. Usually the linked data does not provide access to further information. Referential linking, the preferred form of hypermedia, provides links from virtually any unit of information to all associated units. All of the information on a subject matter is completely interconnected. Cluster linking provides less capability than referential linking because it is usually limited to linking within a small cluster of units.

The Development of Management Information Systems

Nolan has categorized the development of management information systems within an organization into six stages (23:115-126). The first stage of system development occurs when several low-level operating systems are introduced into functional areas such as accounting and inventory control. When other functional areas see the success of these initial systems there is a rapid expansion of computing applications, which results in the second stage. The third stage of information system development occurs when management attempts to control the various computing resources. This stage is characterized by formalized planning, with the emphasis on rebuilding effective systems, professionalizing existing applications, and improving documentation. During the fourth stage previous applications are upgraded using database management systems. At this stage there is a change in orientation from management of individual computer assets to management of the company's data resources. In the fifth stage, data administration is introduced and the various applications are integrated. The final stage of information system growth occurs when all of the company's applications are integrated, and the system structure reflects both the organization structure and the information flows within the company.

Based on these stages of growth, the majority of information systems within the Australian Defence Force can be categorized as being in either stages four or five. However, the current emphasis is on developing integrated systems. The expert system developed during this study is an information system that is capable of integration with existing information systems to improve and expand the overall information management.

Expert System Definition and Structure

An expert system may be defined as a software application that represents the knowledge and judgement of a person who is a recognized expert in a particular field and uses this knowledge to solve problems or mimic human reasoning within that domain (17:131).

According to Waterman (30:22-24), the general structure of an expert system includes a knowledge base, an inference engine, and a user interface (see Figure 2). The knowledge base contains the formal representation of all of the knowledge provided by the expert(s). This base is termed the domain knowledge. The inference engine is a program responsible for interpreting the contents of the knowledge base in relation to a user-specified input or hypothesis in order to determine a goal or conclusion. The user interface is the mechanism which allows the user to communicate with the expert system.

The inference engine contains specific information on the current state of the problem/solution referred to as the context. This element can provide an explanation facility that informs the line of reasoning to the user. Because the process of drawing inferences from a knowledge base is essentially the same for similar problems, a single inference engine can function with a variety of expert systems manipulating different knowledge bases. Inference engines are usually available as part of the higher-level language or within the shell of an expert system development tool.

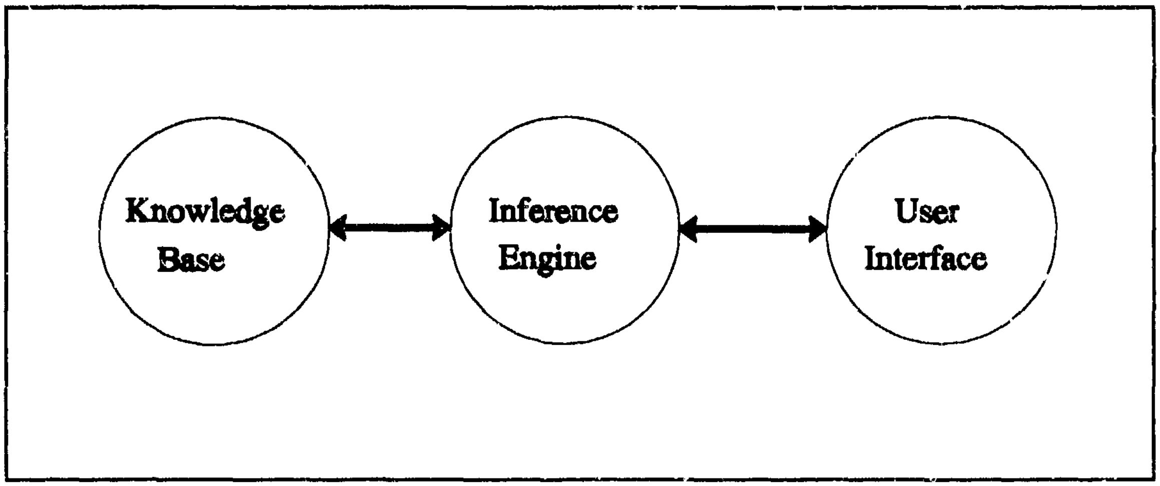

Figure 2. Elements of an Expert System

Knowledge Representation

The most common methods of representing knowledge are rules, facts and objects, semantic networks, and frames (3:29).

Rule-Based Expert Systems. In a rule-based expert system, the domain knowledge is represented as a set of rules (IF condition(s) exist, THEN action) that is checked against a collection of facts or knowledge known about the current situation (4:26). Each rule is given a certainty factor (usually a value between 0 and 1) which expresses the degree of confidence placed in the rule.

Deductive and Inductive Reasoning. The methodology for deriving expert system rules can be classified according to the two main types of scientific reasoning: deductive and inductive reasoning. Deductive rules are developed for expert systems when the expert can explain the logic behind the reasoning process in terms of which attributes of the problem were considered and the relative importance of each attribute. However, a problem arises in developing rules for the expert system when the expert cannot logically explain how or why a particular decision was made. This situation occurs because the expert uses the inductive reasoning process and his own experience and knowledge to make an inferential jump from the facts of the problem to the solution. Because of the difficulty that experts have in quantifying the inductive reasoning process, several systems have been developed from which valid and predictive rules are derived from a list of expert decisions. One of the most popular methods uses the Interactive Dichotomiser Mark 3 (ID3) algorithm. The ID3 algorithm, developed by J. Ross Quinlan, is a computer program designed to induce the most efficient set of rules from a set of example cases (22:379-383). This computer program analyzes all of the supplied decisions and attempts to develop a rule hierarchy that explains the decision making process.

Inference Mechanisms. In a rule-based expert system, there are several methods of inference. The two most common methods include backward chaining and forward chaining (4:28-34). In backward chaining, the inference mechanism works "backward" from the THEN part of the rule to the

IF part of the rule. The inference mechanism guesses at the conclusion. It then attempts to prove that its guess is correct by locating a rule whose THEN condition matches the guess and by establishing that all conditions contained in the IF part of that rule exist. In forward chaining, the inference mechanism first establishes facts and then deduces new facts by working forward through the rules (from the IF part to the THEN part). The decision to use forward chaining or backward chaining is normally based on the relative quantities of facts and conclusions in the rule base. Forward chaining is more appropriate if a problem involves significantly more conclusions than facts. Backward chaining is better suited to problems that involve significantly more facts than conclusions.

Blackboard Architecture. Blackboard architecture is used when either the domain knowledge or the control aspects of the problem become too complicated to be contained within a simple rule base (17:131-136). Consequently, independent groups of rules called knowledge sources are established, and the groups communicate through a central database called a blackboard (see Figure 3). The knowledge provided by each group consists primarily of intermediate results of problem solving. The structure of this system normally includes a monitoring expert system that continuously examines the input data and provides its interpretations to other expert systems which perform specific functions such as diagnosis or control. Because this architecture allows each system access to central data, the system can be developed incrementally, with each expert system being validated independently.

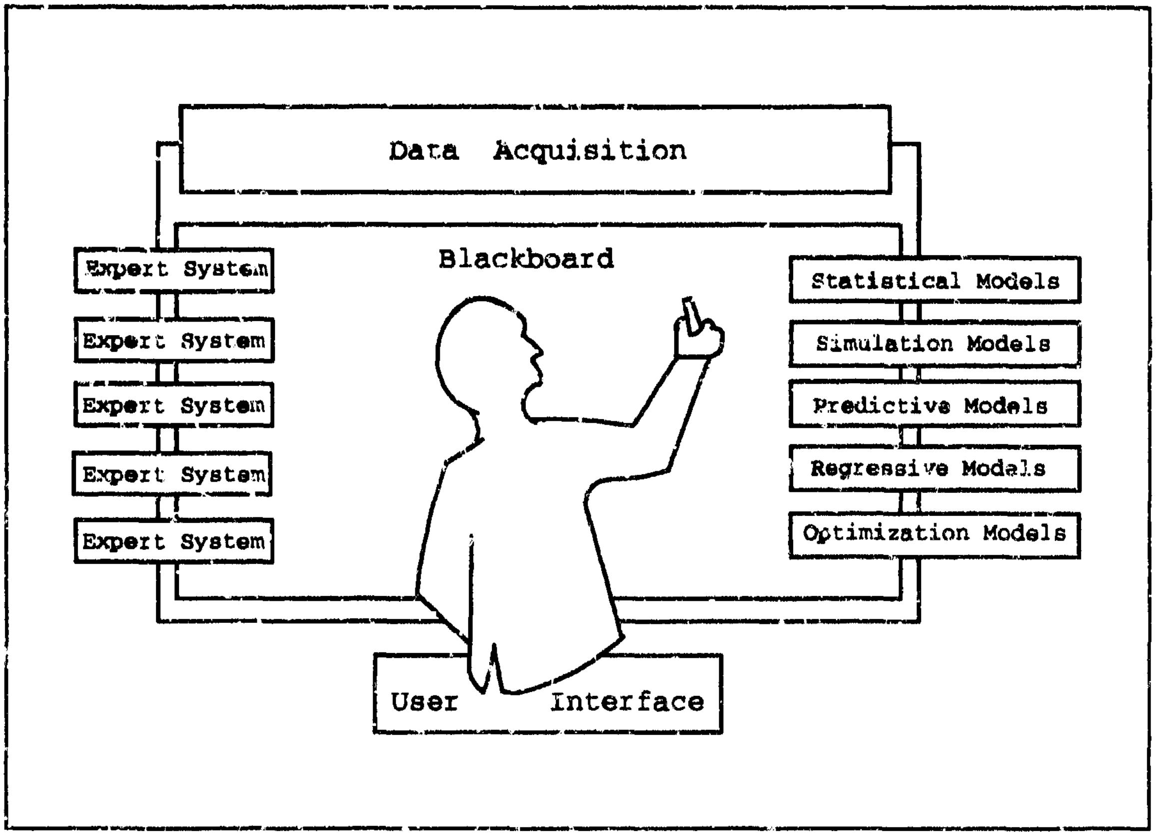

Figure 3. Data Representation of Blackboard Architecture

<u>Fact-Based Expert Systems</u>. The knowledge base for an expert system may also contain facts about the problem domain. Facts may be descriptions of objects and relationships between objects in the domain under consideration. By using the technique of propositional calculus and the knowledge of the existing facts, the system can then determine whether assertions about objects, concepts, or events are true or false (24:46-50).

Semantic Network Expert Systems. A semantic network is a method for representing the natural relationships that occur among objects. A semantic network is described by points (nodes) connected by a series of directed links (arcs or arrows) that show the hierarchical relations between two nodes. Nodes represent objects, concepts, or events. Arcs can be defined in a variety of ways depending on the type of knowledge that they represent. Pigford states that:

> One of the main advantages of the use of semantic nets is that almost any object, attribute (characteristic), or concept can be defined and relationships created. But there is a trade-off for this flexibility. There are no standard guidelines for forming semantic nets, so their form can vary from system to system. In contrast, prediction rules have a standard format. (24:43)

Frame-Based Expert Systems. Frame-based expert systems use a knowledge representation method that associates features with nodes representing concepts or objects. The nodes are connected into a network hierarchy by using links to describe the relationships between nodes. The topmost nodes represent general concepts and the lower nodes more specific instances. Nodes lower in the hierarchy automatically inherit properties of higher-level nodes. This method provides a natural, efficient way to categorize and structure a taxonomy such as medical diseases or speech recognition (30:73-79). The features of each node are described in terms of several attributes (slots) and their values. The idea is to represent data in a frame system with constraints between sets of values. The process of adding or removing values from the slots can violate the constraints and activate procedures attached to the slots. These procedures may then modify values in other slots, continuing the process until the desired goal is achieved (30:390).

Generic Categories of Expert System Applications

The generic categories of expert systems are listed in Table 1. Further review has been limited to expert systems that have been developed in the diagnosis category.

TABLE 1

GENERIC CATEGORIES OF EXPERT SYSTEMS (30:33)

Category	Problem Addressed
Interpretation	Inferring situation descriptions from sensor data
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observables
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Comparing observations to expected outcomes
Debugging	Prescribing remedies for malfunctions
Repair	Executing plans to administer prescribed remedies
Instruction	Diagnosing, debugging, and repairing student behavior
Control	Governing overall system behavior

Problem Characteristics that Require Expert Systems

To require an expert system solution, certain characteristics should exist in a maintenance fault isolation or diagnosis problem. First, the problem should be sufficiently complex to need an expert system, but the scope has to be narrow enough to allow all of the knowledge in the domain to be defined. Second, expertise in solving the problem must be scarce within the organization, but the problem must be capable of being solved by an expert within a few hours. Third, at least one recognized expert, who is willing to act as a source of information, must be available and able to adequately express his reasoning. Fourth, there must be a logical process involved in diagnosing the problem that does not require the novice to use large amounts of intuition. Finally, there must be a large benefit in resolving the problem quickly (6:459-460).

Choosing a Tool for Building Expert Systems

There are two software alternatives for developing expert systems - an expert system shell software package or a programming language. A variety of software shells are commercially available. Individual products vary according to the type of knowledge representation they support, the inference strategies employed, user and external interfaces, knowledge base size and performance limitations, machine availability, and cost (30:142-149).

The typical expert system shell is marketed as a package consisting of a compiler to translate the rule base from a software language into an internal representation and a run-time system to apply the compiled knowledge base to the user's problem. Shell systems are the most straightforward means of rapidly prototyping an expert system, as the developer does not have to provide the inference strategy or run-time support. Programming languages offer more flexibility than shells, but they also require the developer to design the knowledge base and implement the inference engine that accesses the knowledge (5:80-81).

Existing Fault Isolation Expert Systems

Several diagnostic expert systems that have been prototyped are now reviewed and their research findings presented. The methodologies which were used for representing knowledge include rules and frames. The systems discussed are a representative sample of the types of fault isolation expert systems that have been developed and reflect the developer's preference for rule-based systems.

Fired Heater Advisor. One example of the application of blackboard architecture is the Fired Heater Advisor, which is used to control a fired heater in the chemical industry. "A fired heater is a complex piece of equipment whose control demands close monitoring of the process parameters and fine judgement in reacting to subtle changes in them" (17:136). The Fired Heater Advisor monitors such parameters as temperature, fuel-gas composition, and control valves. The expert system continually checks the parameter values and, if any abnormal condition is detected, automatically invokes a diagnostic system. The expert system determines the pertinent rule base relevant to the problem, performs the diagnosis, and notifies the process controller of the conclusions.

An Expert Database System for Shipboard Maintenance. Lieutenant Commander Van Hook (29) developed a prototype for troubleshooting the NAXI

100-2 low pressure air compressor system. The objective of his research was to combine an expert system shell with a database management system. The troubleshooting guide from the technical manual was translated into a series of if-then rules for the expert system. The expert system identified a fault and then accessed a separate database to provide detailed procedures to correct the problem. The fact that the database for this prototype was limited to 254 character fields proved to be a major limitation. As a result, detailed maintenance procedures could not be accessed, and graphics could not be displayed.

Interactive Fault Diagnosis and Isolation System (IFDIS). Several versions of IFDIS have been developed for diagnosis of failures in jet aircraft engines. These include fault diagnosis of the TF-30 engine in the F-111 aircraft (19:15-16) and fault diagnosis of the F404 jet engine in the F/A-18 aircraft (20). The main aim of establishing these expert systems was to convert a large volume of technical documentation into a more accessible format and allow appropriate levels of access for different experience levels of technicians. The F404 IFDIS was established using the EMYCIN shell. EMYCIN is a backward chaining rule-based application package that is most suited to tasks that can be expressed as structured selection problems. Structured selection occurs when each successive question asked by the expert system reduces the list of failures that could have resulted in the observed problem. Solutions that are not excluded by the user's answers are presented at the end of the consultation in order of suspected causation. The knowledge base for IFDIS was created by converting the binary fault tree tables in the work package documentation into rules. Even though the prototype was successful, major conclusions from the research concerned the following: the poor performance of the expert system shell, a desire to express the knowledge base in a symptom-conclusion structure, and adequacy of the initial work package documentation.

Automotive Computer-based Expert (ACE) (21:189-191). ACE, developed through the Artificial Intelligence Laboratory at the University of Alabama, is a diagnostic expert system for the Altec D-900 Derrick vehicle operated by the Alabama Power Company. ACE's knowledge representation schemes, inference mechanisms, and explanation capability are all written in the programming language Microsoft C™. The system contains approximately 8000 lines of code and required one man-year of programming effort. The knowledge base contains approximately 200 IF-THEN rules and uses a conventional backward chaining inference mechanism. The unique feature of ACE is the graphic support provided to the troubleshooting program. This capability is made possible by the integration of digitized and edited 35mm photographs in the ACE knowledge base. Images are provided by the system in both mandatory (safety aspects, special procedures) and optional modes (user can request video information).

Jet Engine Technical Advisor (JETA) (1:154-157). JETA was developed using the strategy of viewing the diagnostic knowledge as a hierarchy of fault nodes. Each node represents a single fault or problem frame in the knowledge base. The hierarchy models the diagnostic knowledge from its most general to its most specific faults. Thus, the engine is considered to have several general faults (e.g., acceleration). Each of these faults becomes a branch in the hierarchy and is specialized until its descendent fault nodes point to specific faulty subsystems in the engine. Each rule frame provides the reasoning algorithm for alternatives to the current node or to its descendants given certain observations. At the time of publication of the article, there were approximately 120 frames in the knowledge structure, and the expert system was being field tested and evaluated by potential users.

Integration of Navy Stock Points Expert Systems (26:1-34). Students from the Naval Postgraduate School had previously developed three different expert systems to aid inventory managers at Navy Stock Points. The objective of Lieutenant Rouska's research was to convert these stand-alone systems into an integrated expert system. A major portion of Rouska's efforts involved the conversion of the existing knowledge bases, which were written in the programming languages M1™ and PROLOG™, into VP-Expert™ rule bases. A hierarchical system architecture was developed that used an integration module to control which of the three different systems were to be accessed. The prototype was successful and demonstrated that it is possible to integrate several different knowledge bases.

Summary

Although a plethora of information on experts systems exists, this literature review only covered the subject areas relevant to the research problem. The basic types of expert system were introduced, and the different methodologies for representing knowledge explained. The review of existing expert systems was restricted to systems that are within the diagnosis category. Because little information regarding models used to convert diagnostic procedures into an expert system knowledge base exists, the knowledge gained from previous work in the field was used to develop the outline for the generic model to be developed in the rest of the research task. This knowledge primarily included the organization of fault isolation procedures and the requirements of the relevant military specifications and was discussed at the beginning of the chapter. Finally, because the research objective for integrating this expert system with other information systems is part of an overall strategy to improve the development of information systems for the ADF, the stages in information system development were briefly reviewed.

III. Methodology

Overview

This chapter describes the methodology used to meet the objectives outlined in Chapter 1. The methodology includes an explanation of the research design, the processes used in developing the input and output specifications for the model, and an outline of the plan for model development. Existing knowledge determined through the literature review was aligned with the methodology.

Each research objective and its associated findings are reported. The model is then presented with an explanation of each element of the model. The chapter describes how a prototype system was developed from the model and details the stages of testing and evaluating the prototype. The chapter also outlines the development of the survey instrument, the data collection plan, and the method of analysis.

Explanation of Method and Research Design

There are typically five stages in the development of an expert system (30:139-140). The first stage, or demonstration prototype, is used to solve a portion of the problem being undertaken. This first stage is used to verify the problem definition, scope the task, determine adequacy of domain knowledge representation, and determine suitability of expert systems technology. Stage two occurs when the system is expanded into a research prototype which displays credible performance on the entire problem. These systems tend to be fragile because they lack sufficient testing and revision to meet all possible situations.

In the third stage, the system evolves into a field prototype which contains a medium-to-large-sized program that has been revised through extensive testing on real problems in the field environment. These systems have good performance with adequate reliability and user-friendly interfaces. The final stages of the production model and commercial system occur after the prototype systems have been extensively field-tested, obtained the necessary quality and performance criteria to meet the user's requirements, and are suitable for production. A typical system can take five years to be fully developed. Due to the time limitations imposed on this research project, the primary objective was to develop a prototype which combined the elements of stages one and two.

<u>Concept of Use</u>

The methodology utilized for the model design was based on a realistic concept of information usage within the next decade. The technical environment is foreseen as being almost paperfree. All of the information required by a technician to perform any task on any piece of equipment within the entire defense inventory could be stored and maintained in various on-line databases. A technician, tasked to repair an aircraft fault for example, would log on to a centralized computer and enter the details of the system that requires repair. The computer would download the required information to a portable computer that the technician would then take out to the aircraft to perform the maintenance task.

The technology to perform this level of information management is being developed and should be available within the next five years. Several civilian companies that manufacture notepad systems were contacted, with the intention of demonstrating the prototype on a notepad system to different organizations at Wright-Patterson Air Force Base. NCR company provided, on long-term loan, an NCR 3125 NotePad™ system. This NotePad is approximately A4 size (9.8" x 11.7" x 1"), weighs 3.95 pounds, uses Microsoft MSDOS™ and Windows for Pen Computing™ as operating systems, and utilizes a passive pen, instead of a computer keyboard, for input.

Model Design Methodology

In this research the following steps were utilized in developing the IDESM:

a. Discussions with local technical publication authorities working for the Air Force Material Command (AFMC) indicated that the latest military specification covering the requirements for Organizational Maintenance Manual Sets (OMMS) was MIL-M-83495A. In the time available, it was impossible to identify every specification or format that has been used in procurement/development of existing USAF publications and which publications conform to the LTTA format. However, the technical publication staff at AFMC confirmed that the majority did conform to the

LTTA format. Therefore, the model input specification was deliberately kept as broad as possible to cover the greatest range of existing hardcopy manuals.

b. Current USAF technical publication specifications and technical maintenance publications for the F-15E aircraft were analyzed to determine the basic structure of the knowledge used for fault isolation and the structure of any associated data.

c. Cassell's Structured Hypermedia Application Development Model (SHADM) prototype was dissected and analyzed to determine the basic format of the hypertext document, the linking arrangements, and any interface peculiarities.

d. Local experts were consulted regarding the impact of Computer-aided Acquisition and Logistics Support (CALS) and the direction other integrated applications such as IMIS were taking.

e. Local engineering and maintenance staff were consulted with regard to user interface requirements.

The results of these steps are outlined below in the next section. However, the intention of this approach was to provide the framework on which to build the model. The framework served as the basis for determining the knowledge representation methodology and the format of necessary text files, indices, and the user interface. It also provided the strategies for integrating the expert system, the hypermedia system, and the user interface.

Model Design

This section presents the results of the research into each of the objectives and discusses the impact of those results on the model design. The first research objective was to determine the types (format/content) of maintenance manuals which the model will convert. The objective in designing a generic model is to ensure that the model has wide application. Therefore, instead of selecting certain military specification(s) and possibly limiting the model's applicability to manuals that comply with those specifications, the decision was made to use the underlying concepts behind the development of these military specifications as the baseline. The literature review determined that most military specifications since 1976 have been developed using Logic Tree Troubleshooting Aids (LTTAs) in the fault isolation procedure.

LTTAs provide exact procedures to be followed during the equipment checkout and troubleshooting procedures and use Yes/No questions to provide the logic to isolate the fault. These Yes/No questions are ideal for conversion to knowledge base rules for an expert system. The minimum input requirement for the Integrated Diagnostic Expert System Model was therefore that the technical manual(s) being converted to an electronic form have LTTAs (or an equivalent method of data representation).

The second research objective was to develop the output specifications for the generic model. The output specification for the model was based on the concept of using a portable maintenance aid (PMA). The designers believe that the developed system must be capable of being used by the technician at the actual maintenance site, which means that the system must be suitable for use on an aircraft, in hangars/workshops, on a flightline, or on deployment. The designers' intent was to determine generic output specifications that could be refined during subsequent prototyping. As the system was designed as a PMA, the output specification consists primarily of the requirements for the format and display characteristics of the PMA screen output. Because a printer is not part of the foreseen system configuration, the format of any printed output was not pursued further.

In designing output screens, areas are required for headings and titles, the content of the display, and messages and instructions (27:408). Figure 4 shows the screen presentation format adopted for IDESM. Headings and titles are displayed at the top of the screen to inform the technician of his current position within the system. Messages and instructions are displayed at the bottom of the screen. The screen display area in the middle may be used for the display of text or graphic information or both. A split screen enables the text describing the fault isolation procedure to be displayed on the left side of the screen. Any additional information, such as graphics, can be displayed on the right side of the screen.

Two special features, scrolling and maximizing, are required to enhance the readability of the information displayed on the output screen. The detailed information provided in many hardcopy graphics (e.g., schematic and wiring diagrams that are presented on several foldout pages) is unable to be displayed on one display screen. Therefore, the user must have the capability to move (scroll) around the screen to the required part of the graphic and, if required, be able to maximize the graphic to provide a fullscreen view. Scrolling or paging can also be used if the user wishes to access a segment of text which exceeds one screen length. Therefore, the capability to scroll vertically and horizontally and the ability to maximize the graphics (transform to full screen view) were provided by the IDESM. These capabilities are consistent with the requirements of the draft military specification MIL-M-GCSFUI (9).

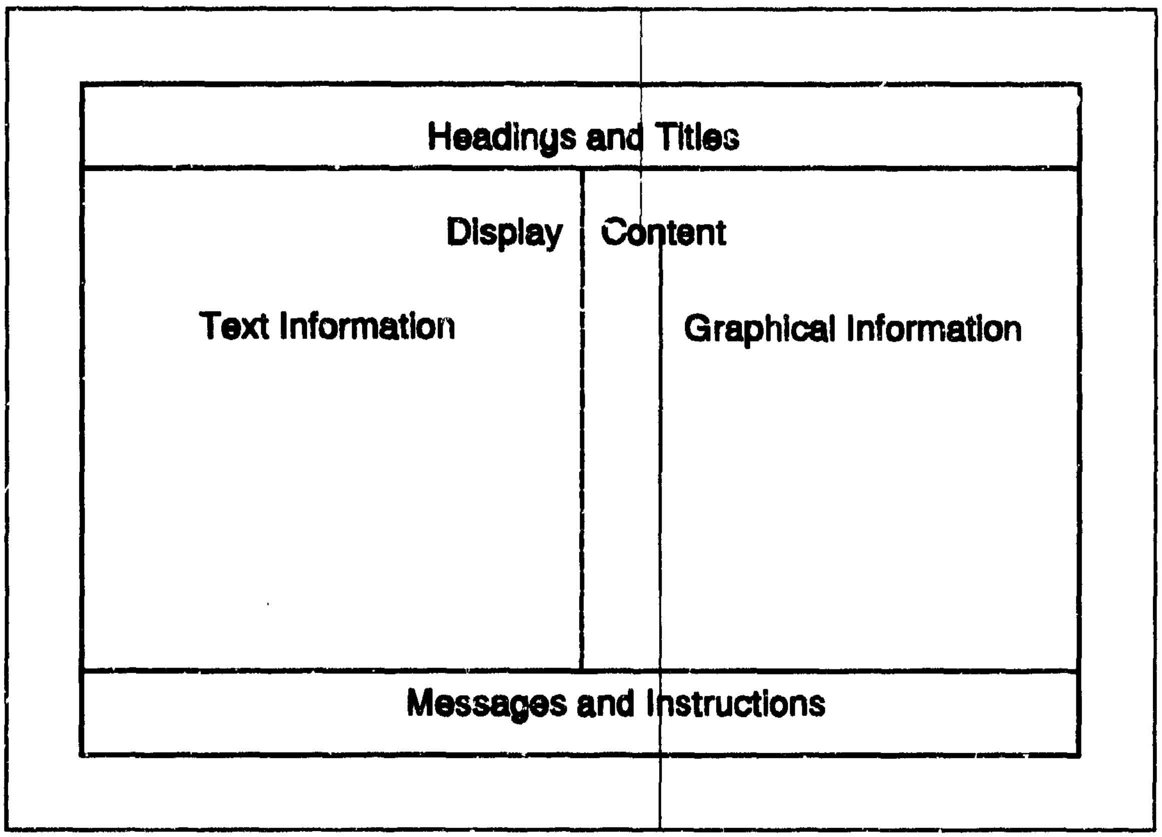

Figure 4. IDESM Screen Presentation Format

In addition, research objective two questioned the interfacing requirements of the user with the expert system. The PMA is likely to have either a limited keyboard or rely on input from the user via a pointing device (pen). The user interface should therefore be designed to minimize the data entry requirements from the technician. The user should be able to choose any function or option by selecting it from a displayed list. Because the system will be used by technicians with varying experience levels, the "system should be able to lead the newcomer by the hand without burdening the experienced user" (10:97). The user interface should also be capable of providing on-line assistance and be designed to minimize the chance of user error. The commands and instructions displayed to the user should be in everyday English and not use any specialized computer terminology. The method used for presentation of text and graphical information should be consistent throughout the information base and should conform to any normal technical stereotypes.

Research objective two also addressed the structure of the existing information system which was developed during the design and testing phases of the Structured Hypermedia Application Development Model (7). This system was based on CALS requirements as detailed in MIL-STD-1840A (11:11). The seven-bit ASCII-formatted information was stored in separate files by a vehicle system. Although the hypermedia links were created using the software package Hyperwriter®, minor modification to the linking information within the ASCII files allowed access to the data by other hypermedia systems and, in particular, the software shell used for development of the IDESM prototype.

The third research objective was to select the most appropriate conversion model methods and criteria from existing automatic fault isolation systems. The literature review discussed several existing expert systems and the various knowledge representation methodologies used for their development. The review essentially identified that there were four methods for representing knowledge within an expert system: production rules, facts and objects, semantic networks, and frames. The use of production rules is the most common method for representing knowledge, accounting for over ninety percent of developed expert systems. The reason for the popularity of this method is the ease of developing the associated logic and the large number of commercially available software packages that support rule-based systems.

An initial requirement of objective three was to determine the existence of any models that currently convert fault isolation procedures into expert systems. However, the literature did not reveal any models specifically developed for the conversion of fault isolation procedures into expert systems. The literature review revealed the following:

a. The major criterion for converting existing fault isolation procedures into an expert system consists of structuring the resulting knowledge base according to the requirements (syntax) specified by the software shell or programming language.

b. General guidelines for organizing rules or frames within the knowledge base do not exist.

In summary, the expert systems that have been previously developed have been constructed according to the programming language or software shell used.

A further research objective was to identify existing model criteria and evaluate each criterion for suitability in this application. As no models were found that specifically converted fault isolation procedures into an expert system structure, the authors decided to use the principles employed in structured programming and software design for development of the model.

Principles of Software Design (27:696-707)

A structured system is one that is developed from the top down and divided into manageable components or modules. Senn's principles of software design include:

Modularity and Partitioning. The design of the system should consist of a hierarchy of modules, with each module performing a specific function. Lower-level modules are generally smaller in scope and size compared to higher-level modules and serve to partition processes into separate functions.

Coupling. Coupling refers to the strength of relations between modules. Modules should be constructed with minimal dependence on other modules in the system.

Cohesion. Cohesion refers to the strength of relations within a module. Modules should contain all of the elements required to perform a single processing function.

Span of Control. Span of control refers to the number of subordinate modules controlled by the calling module. Modules should interact with and manage the functions of a limited number of lower-level modules.

Size. The number of instructions contained in a module should be limited so that module size is generally small.

Shared Use. Functions should not be duplicated in separate modules but should be established in a single module that can be used by any other module when needed.

This structured system methodology was chosen primarily because of the advantages gained from using the concepts of modularity and shared use. Modularity allows the system to be developed in stages. More importantly, any required maintenance during the life of the system can be controlled at the module level without requiring a complete rewrite of the software. Also, modules at the same hierarchical level can be designed according to a common structure, thus producing a more controlled design and thereby increasing maintainability.

Shared use of modules provides several additional advantages, including reducing the amount of software that must be designed and written, minimizing the number of changes required during system maintenance, and decreasing the chance of software errors. With shared use of modules, information normally duplicated throughout hardcopy maintenance manuals (e.g., the safety warning that precedes every maintenance action) needs to be stored only once in an electronic system and the appropriate connections established for its shared use. This approach reduces the amount of storage space required for aircraft documentation.

Generic Model Development

The Integrated Diagnostic Expert System Model (IDESM), developed to fulfill the requirements of research objective four, contains four major elements - the user interface, the hypermedia submodel, the expert system submodel, and the submodel integration shell (see Figure 5). The research findings from the first three objectives were incorporated into the design of the model.

The major design considerations of the user interface have been detailed previously in this chapter under research objective 2. Therefore, the design considerations of the hypermedia submodel, the expert system submodel, and the submodel integration shell will be presented in the following sections.

Development of the Hypermedia Submodel

The implementation of hypermedia within the model requires the definition of several control strategies - storage, chunking, and linking.

Storage. Discussions with several experts on technical documentation suggested that the storage requirements for an entire set of aircraft publications on electronic media would require between 700 and 1000 Megabytes of storage. Because large amounts of data are being accessed, the processing time required to locate and extract the required unit of information from storage must be minimized. The major element of processing time is the time required to access a hard disk. Therefore, the stored data must be structured such that a minimal number of disk accesses are required to extract the required data. Because of the slow response time generated, a sequential read of a database of this size searching for the required data would produce an unusable system. Therefore, the most efficient method for data storage is to use an index file as a pointer to the actual location of the required data. Extraction of the required data then requires a read of the index file and direct access to the data.

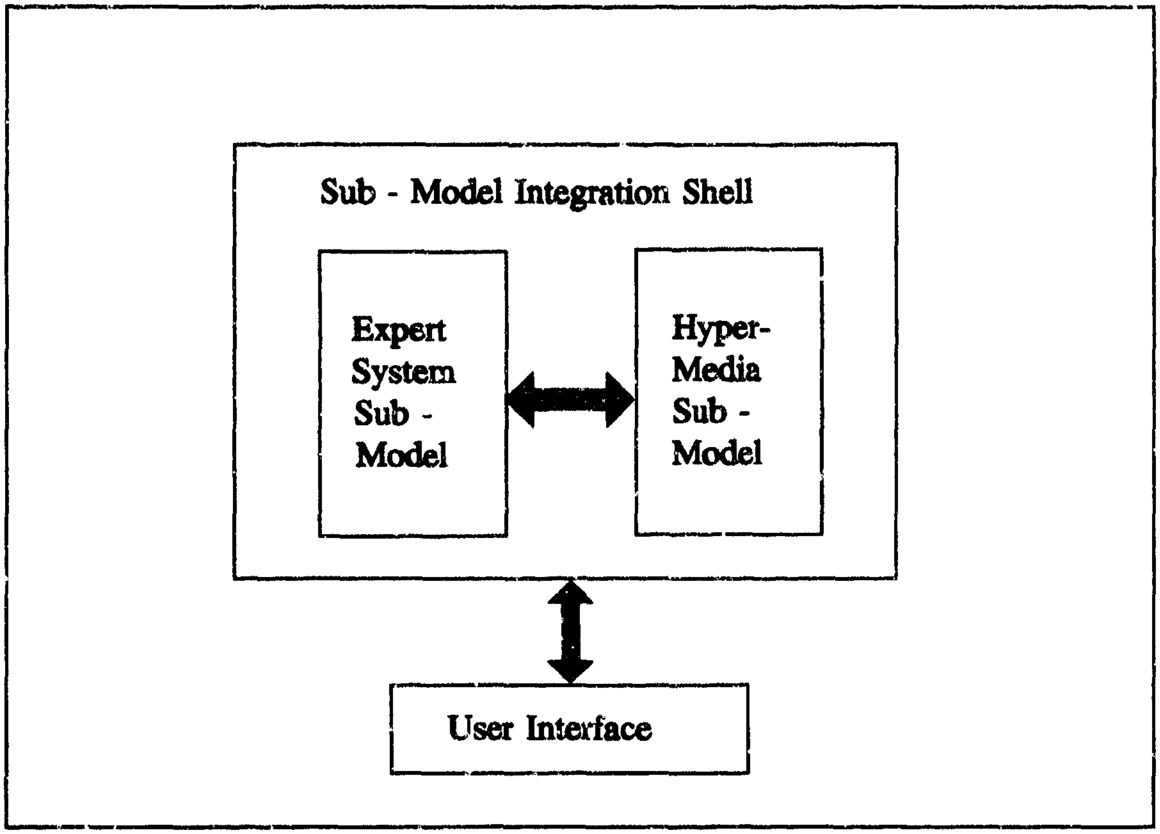

Figure 5. IDES Components

Chunking. The information stored in each unit or node should be segmented into logical chunks and should not be limited to the amount of data that can be displayed on one computer screen. If the unit of information exceeds one computer screen, then the user should be provided with the ability to access the entire unit of information.

Linking. Linking is the process whereby units of information are connected together by a software pointer. Referential linking, as described in Chapter 2, should be implemented within the hypermedia information base, and an unlimited number of links should be possible from any one unit of information. There are two software methods for implementing links within hypermedia documents. The first method requires the developer to identify both ends of the link and the actual interconnection path. Using this method, the developer must re-establish the link every time the information within the database is changed. This method is obviously unsuitable for large databases with dynamic data. The second approach is to create a virtual link using a keyword or phrase. In virtual linking, a keyword (e.g., safety) identifies a link to further information on safety procedures. The indexed database is then searched to locate the keyword and its linking information and a virtual pointer to the relevant information is established. Because the link is only established as needed and maintenance of only the keywords and the index is required, this approach is quite flexible.

Hypermedia Submodel Text. The structure of the hypermedia submodel is illustrated in Figure 6. The logical hierarchical format of the OMMS produces the following major groupings of information: aircraft, system, subsystem, sub-subsystem, and line replaceable unit (LRU). The system, subsystem, sub-subsystem groups can be further subdivided into general (description/overview) or specific (principles of operation, special maintenance requirements, test equipment, etc.) information. This subdivision generates eight types of text information, each of which requires different linking capabilities.

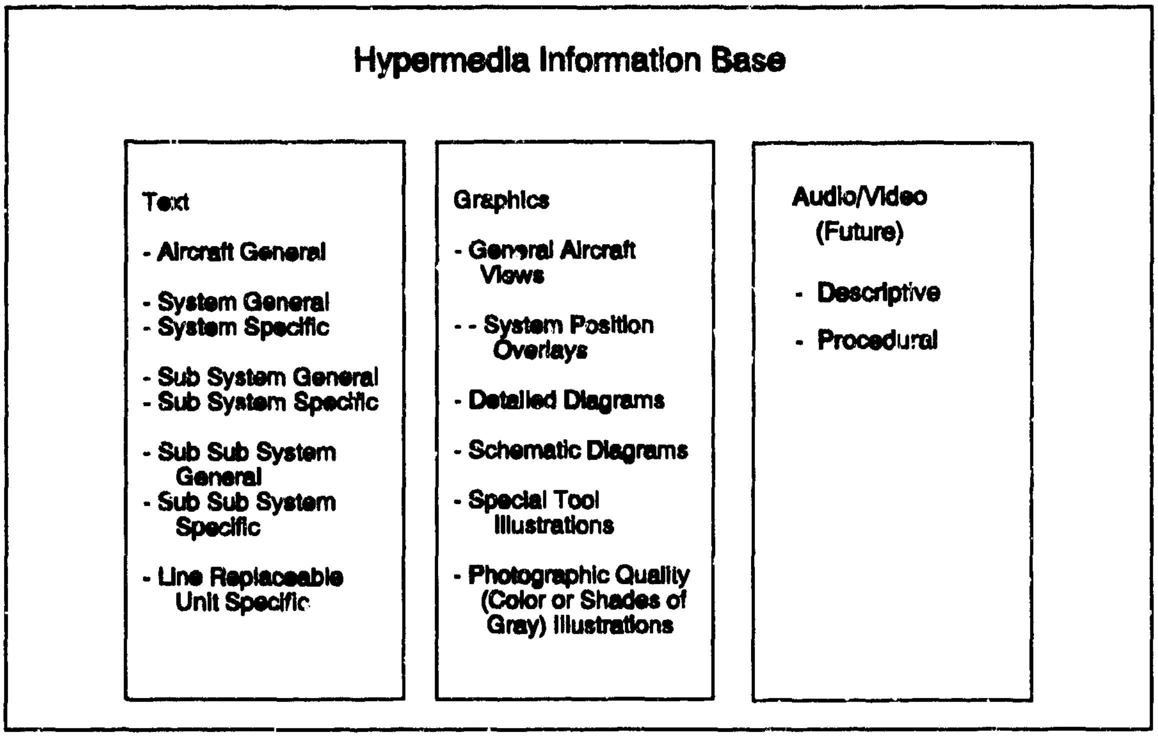

Figure 6. Composition of Hypermedia Submodel

The GV manual contains general aircraft and system general information which should be available for global access within the hypermedia information base. Information within the GV manual includes:

> a short description of each system, general maintenance procedure information; danger areas and precautions; dimensions and areas; information relating to lifting and jacking, levelling, towing, parking and

> mooring; and information relating to aircraft servicing. Consolidated lists of supplies, test equipment, and special tools, complete with part numbers ... all abbreviations and electrical, electronic, and mechanical symbols. (14:1-1)

The information describing the lower six levels is distributed throughout the general system manuals, the fault isolation manuals, and the job guides. System specific and subsystem general information is contained in the General System manuals. More detailed information, regarding the subsystem specific, sub-subsystem (general and specific), and LRU specific can be found in the GS manuals, FI manuals, and JGs. This information should be available for access depending on the task being performed and the needs of the user.

Hypermedia Submodel Graphics. Five different types of graphic information have been identified.

General Aircraft Views. These illustrations are simplified graphic drawings of the aircraft that identify locations of subsystems/LRUs. Typically, the same foundation drawing is reproduced with an overlayed identifying pointer and text each time a different location is illustrated. To minimize the storage of graphic information in electronic format, the designers propose the use of common aircraft base drawings and specific overlays to identify the required item. This approach is consistent with paragraph 3.3.3.2 of (draft) MIL-M-GCSFUI (9).

Detailed Diagrams. These diagrams provide the user with a detailed illustration of the subsystem/LRUs supported by numbered call-outs to a tabular component list.

Schematic Diagrams. These diagrams provide specific electrical and hydraulic schematics for the subsystem/sub-subsystem/LRUs.

Special Tool Illustrations. These illustrations provide information on special tools that are required for task performance.

Photographic Quality Illustrations. Photographic quality illustrations (black and white or color) are photographs that can be utilized to provide information that cannot be displayed adequately in drawings. Photographs are expensive and difficult to reproduce in hardcopy publications at the resolution needed to transfer information. However, for use in a hypermedia application, the photographs can be inexpensively digitized and stored electronically. Once digitized and stored, the photographs can be manipulated the same as any other digital data. The only limitations associated with the hypermedia use of photographic quality data are the memory needed to store and manipulate the data and the speed penalties incurred by the application in processing the larger amounts of data.

Hypermedia Submodel Audio/Video. The hypermedia model includes the capability for integrating audio/video into the system. The two types of audio/video presentations identified are:

Descriptive. Descriptive audio/video presentations can be used instead of text for several topics, including principles of operation and system description.

Procedural. Procedural audio/video presentation can be used to guide the technician through general maintenance and fault isolation procedures.

The information stored within the model's knowledge base should conform to several other standards. The use of standardized System/Subsystem/Subject Number (S/S/SN) assignment throughout the technical manuals, is in accordance with MIL-STD-1808, provides maximum cross referencing, and reduces the search time required to locate data.

The information stored in electronic format should comply with any CALS requirements. CALS specifications, which include MIL-M-28001A, MIL-M-28002, and MIL-M-28003, establish:

> the requirements for the digital data form of page orientated technical publications. Data prepared in conformance to these requirements will facilitate the automated storage, retrieval, interchange, and processing of technical documents from heterogeneous data sources. (12:1)

The format for data storage within the model should therefore follow the guidelines associated with the use of the Standard Generalized Markup Language (SGML).

In summary, the hypermedia submodel has partitioned the data within the information base into text, graphics, and audio/video. Each of these areas has then been further partitioned into functional and logical access areas. The submodel has also considered the methods of storage, chunking, and linking the necessary information to facilitate an integrated system.

Development of Expert System Submodel

Research objective four also questioned how the expert system should be structured so that it could be interfaced with existing systems. Because the LTTA structure was suitable for direct conversion into a series of IF/THEN rules, the method of knowledge representation chosen for the expert system was rules. The estimation of the number of rules that would be required in a knowledge base for all the fault isolation procedures associated with a particular aircraft is extremely difficult. The designers believe that literally thousands of rules would be necessary. Consequently, a modular structure was developed, as shown in Figure 7. This structure follows the principles of top-down design and was based on the standardized S/S/SN assignment. The highest level of knowledge base which relates to the aircraft or general vehicle (e.g., F-15E) was designed as a control module that would allow the user the option of either selecting a lower level system for fault analysis or directly accessing the hypermedia information base.

The next level which relates to the aircraft system (e.g., landing gear) was also designed as a control module. The user should be able to either select a subsystem for fault analysis or access the hypermedia information base at that level or a higher level. The knowledge base at the subsystem level (e.g., extension and retraction system) includes the rule base for the fault analysis checkout procedure. This module provides guidance to the technician through the checkout procedure and links directly to the relevant faultcode information when a failure is identified at a procedural step.

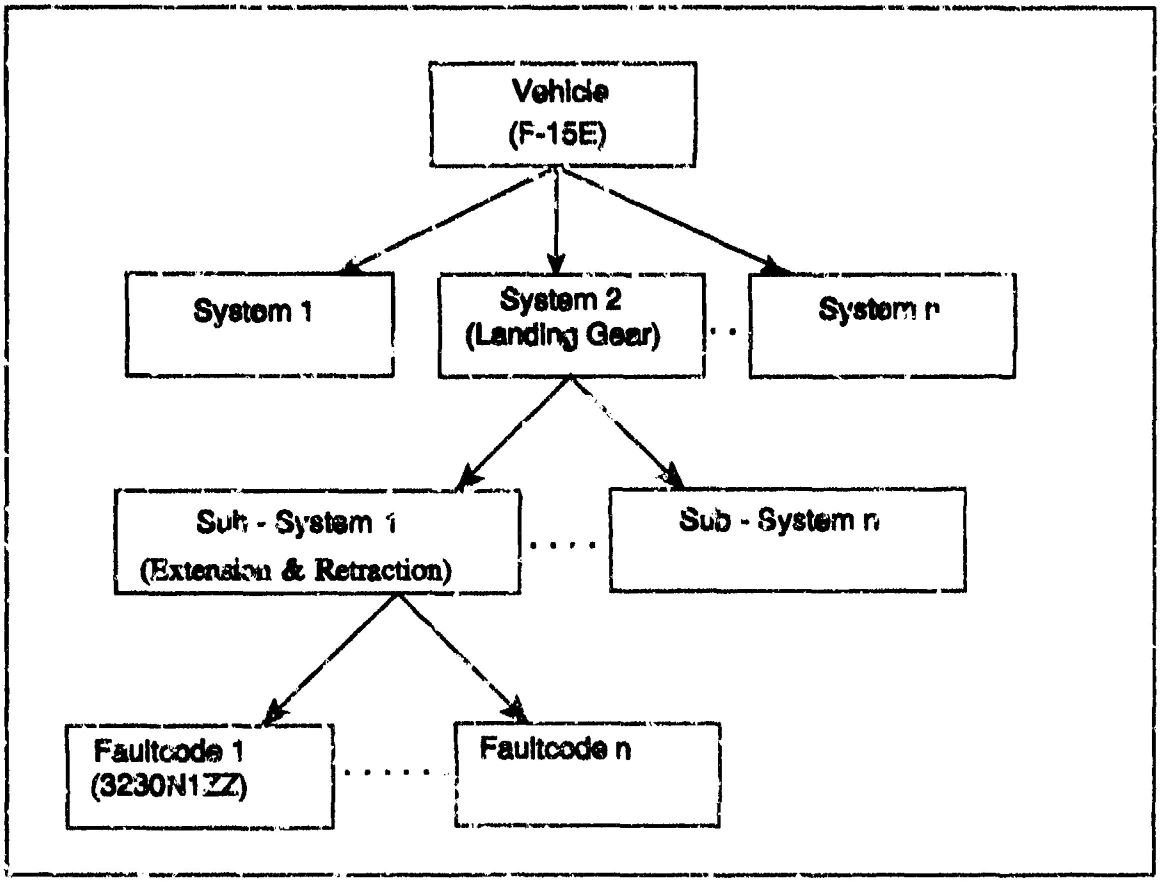

Figure 7. Expert System Submodel

The knowledge base at the faultcode level (e.g., 3230N1ZZ) comprises the specific rules associated with the identified fault and assists the technician to identify the faulty component. On identification of the faulty component, the system should be able to automatically load and run the associated removal/installation procedures. If, however, the technician already knows the faultcode or realizes that a particular item needs to be replaced, he/she should be able to select the relevant procedure from the higher-level menu without first having to access a checkout procedure.

Submodel Integration Shell

The submodel integration shell must be able to integrate with both the user interface, the expert system, and the hypermedia submodels. The shell must be able to provide indexed access to the hypermedia information, the necessary inference mechanism for execution of the expert system, and the layout requirements of the user interface (including a scroll capability for units of information that exceed one display screen and a maximize capability for graphics). This integration shell should be either written in a programming language by experienced programmers or purchased off-the-shelf.

Prototype Development

The final research objective was to prototype, test, and evaluate sample systems with the generic model. To test his model, FLTLT Cassell (7:57) developed a hypermedia prototype based on the F-15E Nose Landing Gear (NLG) system. Approximately 50 percent of the GV manual was converted to hypertext. Because one of the objectives of this design was to integrate the prototyped expert system with an existing hypermedia system, the prototype of the IDESM was based on the F-15E NLG system.

Because of the time limitation imposed on development of the prototype, the designers were unable to develop their own integration shell and purchased an off-the-shelf system. Several off-the-shelf expert system shells were evaluated for their hypermedia capabilities and applicability to the windows operating environment. Knowledge Pro® for Windows (KPW) was chosen as the software for use in the prototype. However, this selection should not be seen as a recommendation for the use of this package over any other product.

The concept behind the prototype development is illustrated in Figure 8. The complete text of the extension and retraction system fault analysis checkout procedure (15:30-11 - 30-17) was converted into a subsystem-level knowledge base (refer to Figure 7). This checkout procedure guides the technician to a faultcode in the range of 3230N1ZZ to 3230NYZZ (15:30-75 - 30-171). These 32 faultcodes were converted into modular faultcode-level knowledge bases which can be called by the "checkout procedure" expert system. Each of these modules was designed using a standard template which is included in Appendix A. Graphics scanning difficulties prevented the authors from providing a full set of graphics to accompany the checkout and faultcode procedures.

Two control modules, representing the aircraft and system level knowledge bases, were developed to demonstrate the integration of the expert system with the hypermedia publication. A considerable amount of the textual information called by the hypermedia links was based on FLTLT Cassell's SHADM. Overall, approximately 1 megabyte of ASCII and graphics files were produced representing a broad range of different textual and graphics information that pertains to the F-15E aircraft and F-15E NLG system.

An example of the text and index files created using the hypermedia submodel and KPW are also presented in Appendix A. The basic text file structure contains ASCII text and uses the delimiters // to divide the information into usable chunks. The character string between the delimiters and the first end of line character define the search keyword. KPW provides an indexing capability to speed up access to the chunks of information. An index file, required for each text file, contains the keyword, the start address, and the length of each chunk.

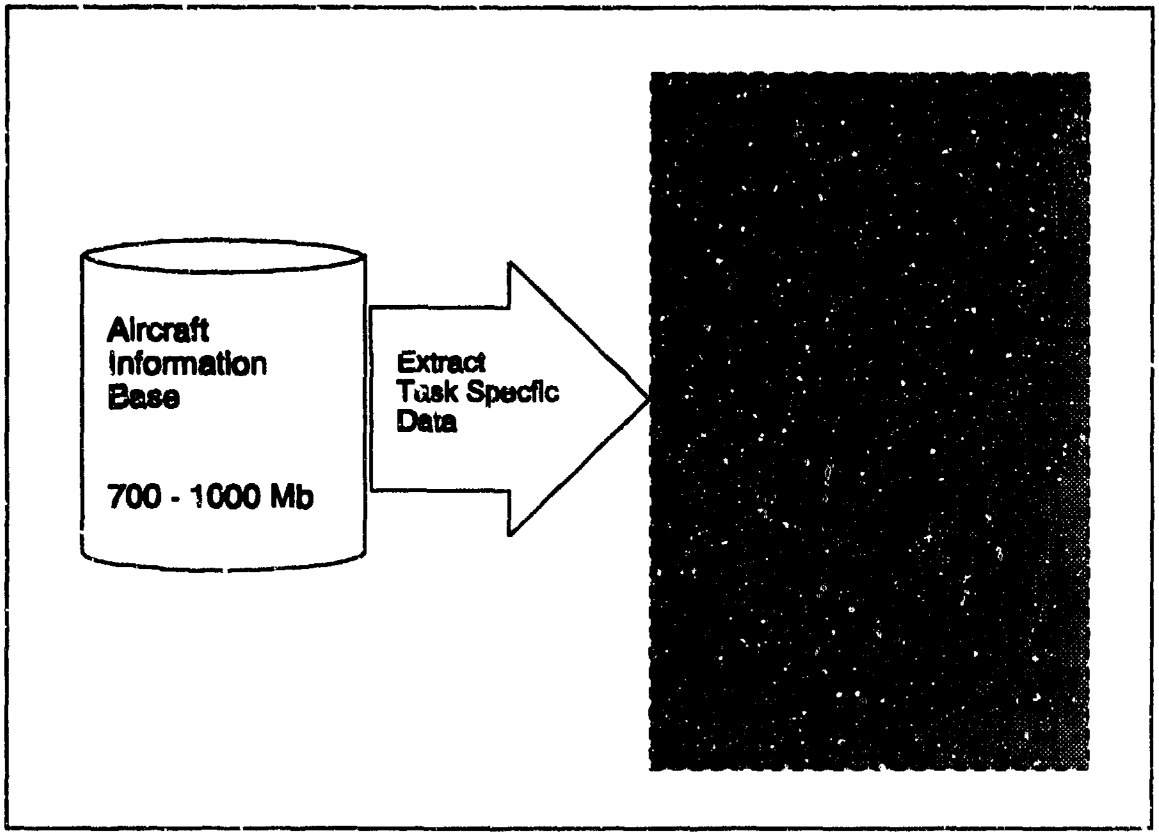

Figure 8. Developed Prototype

To establish its hypermedia links, KPW requires that the characters #m be placed around the keyword. e.g., SAFETY becomes #mSAFETY#m. These hypermedia links are underlined on the screen and displayed in a different color or font to provide the user with a visual indication that there is more information available on that topic. KPW lets the developer set the color and font of the hypertext links and therefore permits the use of different colors to signify different applications. For example, a "safety" hypertext link may be displayed in red, graphics may be displayed in blue, and other ordinary text links may be displayed in green. Several other control characters, such as #f and #b, allow the developer to select the color of the foreground and background for individual on-screen special effects. However, care must be taken not to overwhelm the user with garish effects.

Evaluation Plan

The two factors involved in selecting the test environment were proximity of testing personnel and the availability of a suitable hypermedia publication information system. The preferences were to find a maintenance section with the appropriate personnel that was prepared to test the prototype and was located at or close to Wright-Patterson Air Force Base. Such a situation would afford the researchers better access to the participants and simplify the survey procedures.

Engineers and maintenance personnel from the F-15E System Program Office (SPO), C-17 SPO, 4950th Test Wing, Armstrong Laboratories, and local RAAF maintenance community were approached to evaluate the research prototype. Where possible, the prototype was compared with existing hardcopy technical manuals. A survey of the engineers and maintenance personnel involved in the evaluation was conducted regarding the following criteria:

a. ease of use (user being able to do what he or she wants to do easily),

b. suitability of user interface (screen layout, buttons, colors, pointer, and scroll/maximize functions),

c. user level adequacy (experienced versus inexperienced),

d. correctness of converted procedure,

e. completeness of converted procedure,

f. efficiency (effect on time to make serviceable),

g. reliability and consistency of results, and

h. overall usefulness of the system.

Because the prototype was only to be a stage one/two prototype, the main thrust of the evaluation phase was to verify that the IDESM was adequate and that the technique used for domain knowledge representation was suitable. Two additional purposes of evaluating the prototype were to determine if the goals of a reduction in training commitment (evidenced by the ability of low-experienced users being able to effectively fault find with the aid of the prototype) and the integration of the information systems were effective. The results of the survey were used to evaluate the prototype and suggest areas of further development for the model.

Description of Population and Sample

In this particular study, the relevant population was all possible users of integrated expert systems that could be developed using this particular model. The sampling process conformed to the non-probability judgement sample design (16:275). The sample of interest was technical and engineering personnel of the USAF and RAAF who were based locally and available to evaluate the prototype. The size of the sample was to be in the range of fifteen to twenty-five participants.

Instrument Development and Testing

A survey instrument, which is included in Appendix B, was developed for evaluation of the prototype. Content and sampling validity of the survey instrument were confirmed with the assistance of Air Force Institute of Technology staff. External validity of the survey was based on the premise that the survey instrument was to be applied to a representative sample of United States and Australian Air Forces' engineers and technicians.

Data Collection Plan

The survey was conducted by questionnaire. The majority of questions in the survey instrument required respondents to express an opinion on the performance of the research prototype with respect to a particular measurement criterion. The survey also provided respondents with the opportunity to furnish either general or specific comments on each of the topics covered in the questionnaire. For the opinion questions, respondents were asked to score each performance criterion on a six point Likert scale (16:220). The scale ranged from strongly disagree (a score of 1) to strongly agree (a score of 6). The intervals between each score value were assumed to be equal, thus providing interval-scaled data for analysis.

Statistical Tests

Interval-scaled data can be statistically summarized by using an arithmetic mean as the measure of central tendency and a standard deviation as the measure of dispersion. The main statistic of interest in this analysis was the arithmetic mean. On a Likert scale of one to six, the middle score of 3.5 relating to a respondent's opinion of undecided was therefore discouraged. For the expert system prototype to be an improvement over the current hardcopy fault isolation manuals, the survey results should provide a mean that is greater than 3.5. The data from the survey was analyzed using the statistical package, Statistix© Version 3.5. The purpose of the analysis was to determine the central tendency of the data collected for each survey question and then determine which measures of the model scored in the categories of mean being less than 3.5, equal to 3.5, and greater than 3.5. The significance of the collected data was then analyzed with respect to the original research objectives. The analysis is presented in Chapter 4.

Summary

This chapter outlined the methodology used to solve the research problem stated in Chapter 1. The reasoning behind using a prototype approach to the problem was explained. The existing knowledge in the research area, revealed by the literature review, was summarized and used as a basis in planning the methodology behind the model and prototype design. A plan for evaluating the model and the prototype in the field and for surveying the participants was outlined. Finally, the basis for the statistical analysis of the survey results was explained.

IV. Findings and Analysis

Overview

The evaluation plan, as presented in Chapter 3, identified eight areas for measurement of the prototype performance. This chapter subdivides the 30 questions used in the survey instrument into those eight areas, analyzes the responses to each survey question, and then draws conclusions on the performance of the prototype. Any significant comments made by the survey respondents are also discussed. Finally, the overall performance of the prototype is assessed, and the IDESM is evaluated.

Survey Results

A total of 20 surveys were received from local engineering and maintenance personnel. The survey results are presented in Appendix C. Included are the comments made by the respondents, the statistical measurements of mean, standard deviation (SD), 95% confidence interval (95%CI), and the number of respondents (n) for each particular question. Questions 22, 23, and 24 produced a low survey response rate because many of the survey respondents did not have access to the necessary F-15E publications.

The sample of survey respondents included four members from the F-15E SPO, two members from the C-17 SPO, nine members from the 4950th Test Wing, two members from Armstrong Laboratories, and three local RAAF representatives. The rank level of the survey respondents included six officers, eight non-commissioned officers (technical sergeants), and four airmen. This sample was representative of the available population. Therefore, the results of the survey can be used to draw conclusions on the effectiveness of the prototype.

The survey was originally planned to be conducted using the NCR 3125 Notepad computer. However, because there were some importation difficulties, the notepad was not available when required and the survey was conducted using IBM personal computers. The notepad has since been used to demonstrate the prototype to several organizations at Wright-Patterson Air Force Base. Informal feedback from the demonstrations has indicated that higher scores may have resulted if the survey was conducted using the Notepad computer instead of personal computers.

The survey used a six point Likert scale ranging from Strongly Disagree (a score of 1) to Strongly Agree (a score of 6). A mean score of 3.5 would reflect neither agreement or disagreement (a result of indifference) with the statement being surveyed. The statistical analysis of the survey resulted in a mean of greater than 3.5 for all of the questions (statements). Furthermore, for 26 of the 30 questions, the entire 95%CI for the mean was above 3.5. This result allows the authors to state with confidence that the population would agree with the respective statements. Although questions 4, 20, 22, and 24 had the lower limit of the 95%CI below 3.5, these survey results are not discussed separately. Each question is addressed within its respective performance assessment area.

Ease of Use

'Ease of use' is an ill-defined term. Therefore, for the purposes of this research, 'Ease of use' was defined as 'the ability of the user to easily do what they want to do.' The following five questions were used to assess ease of use:

Q1. The program is easy to start. (Mean = 5.38)

Q2. The program is easy to use. (Mean = 4.49)

Q3. Navigating throughout the fault analysis system is easy. (Mean = 4.18)

Q4. Sufficient explanations (on-screen/documentation) are provided to use the system. (Mean = 4.08, 95%CI 3.46 - 4.70)

Q5. Exiting the system is easy. (Mean = 4.82)

The prototype scored highly in all five questions, with only question four not having the entire 95%CI above 3.5. Discussion of significant comments received in this area follows.

Several comments suggested that more guidance could have been provided to the user to further improve the ease of use of the system. Suggestions included more instructional messages advising the user to 'Press continue for next step' or advise whether a single or double click of the pointing device is required to make a selection. The requirement for single or double clicks was explained in the on-screen help function provided with the system. However, the feedback suggests that the average user does not use on-screen help (except as a last resort) and seldom reads instructions before using the program. The requirement for standardizing to single or double clicks (events) is debatable. (Does one standardize for simplicity or use separate events to differentiate between distinct functions?) This topic is a candidate for further research.

The combination of single/double clicks and lack of on-screen instructions were poor design features of the prototype. The prototype designers did attempt to standardize to one click because the software documentation and supplier indicated it was possible. However, as a result of their inexperience with the software package, the designers were unable to accomplish standardization. The prototype can definitely be improved in terms of providing more guidance to the user. However, an important goal of the designer is to provide sufficient guidance to the novice without slowing down the expert. Future versions of the prototype should be easier to use.

Several users commented on the loss of visibility of their position within the overall system, such as getting lost or having screens lock up. As these problems were caused by a lack of familiarity with the system, more guidance to the user should improve the situation. The capability to trap errors is also available in the software package. This feature could be used to capture incorrect user responses and prevent lock up.

Several users suggested that a back-up capability be added to the program that would allow the user to go back to the previous screen. Another suggestion was for context sensitive help, whereby the help provided to the user would depend on their location within the program. The normal observation or the default choice during the fault isolation procedure could also be highlighted to the user. All of these suggestions should be considered for inclusion in future versions of the prototype.

One user suggested that the system would be more user friendly with a pen. The authors and those users who saw the prototype demonstrated on the notepad system agree with this comment. Overall, the ease of use of the system scored highly and several significant comments on additional features were received from the survey. Incorporation of these features and the use of the Notepad system should ensure that the system becomes easier to use in future versions of the prototype.

Suitability of User Interface

A total of 11 questions were used to assess the adequacy of the user interface. This area accounted for the most survey questions because the success or failure of the system usually depends on whether or not the user likes using the system. The following questions were used to assess the user interface:

Q6. The screen layout is suitable for the system's purposes. (Mean = 4.37)

Q7. The overall textual presentation (font size, color, and typeface) is easy to read. (Mean = 4.98)

Q8. The use of on-screen buttons is acceptable. (Mean = 4.99)

Q9. The location of on-screen buttons is suitable. (Mean = 5.22)

Q10. The subjects to which the buttons are linked are appropriate. (Mean = 4.57)

Q11. The way in which information is presented in different windows is suitable. (Mean = 4.68)

Q12. The use of different colors to highlight warnings, cautions etc. is suitable. (Mean = 5.39)

Q13. The way that the system's graphics are presented is appropriate to users of all experience levels. (Mean = 4.12)

Q14. The method of control (pointer/mouse) is suitable. (Mean = 5.25)

Q15. The provision of scroll bars permits easy viewing of text and graphic information which is larger than the display window. (Mean = 4.93)

Q16. The maximize capability which enlarges the graphic images to full screen is a useful feature. (Mean = 4.77)

The prototype scored highly on all 11 questions. Significant comments received on the user interface with regards to screen layout, buttons, colors, pointing device, graphics, and the scroll/maximize function are now discussed.

The split screen layout approach, where procedural information was displayed on the left hand side of the screen and linked information (text/graphic) presented on the right hand side of the screen, was liked by most users. One improvement suggested by a respondent was to include a list of available graphics in a pull-down menu where it could be accessed as required. This recommendation should be considered in the next version of the prototype because having a pull-down menu of available graphics would also improve the useability of the system with technicians of different experience levels. Another suggestion was that if procedural information referenced a graphic then the graphic should be displayed automatically next to the referencing text. This feature should be implemented. However, where more graphics exist than can be displayed in the area provided, the user should be advised that additional graphical information is available.

Most users of the prototype were not impressed with the quality of the graphics displayed. This is a direct result of the designers not having access to a suitable optical scanner. Future prototypes should have higher quality graphics. One respondent suggested that a graphic should not be larger than the screen size. The display of graphics is an area that requires further research regarding the best method for display on a computer screen. For example, what is the best method for displaying the information that is normally shown on several fold-out pages of a schematic diagram - a one screen graphic enlarging segments of the drawing or a multi-screen graphic implementing scroll bars?

The scroll and maximize features displayed by the prototype were not as successful as the designers hoped. The main problem was that the right hand side scroll bar disappeared under the frame when a graphic was maximized to full screen, thus preventing this feature from being properly utilized. The problem was caused by a bug in the software package being used. However, future releases of the software should overcome this problem.

While the operation of the buttons was accepted by most users, two improvements were suggested. First, the buttons should be dynamic and context sensitive, whereby the information linked to should be dependent on the location within the system. Second, the button functions could be placed in a pull-down menu, which would also allow more button features to be added without crowding the current layout.

A variety of comments were received regarding the colors used within the system, indicating that the choice of colors is definitely a matter of personal preference. Several factors need to be considered in future prototypes. First, although the current version of the Notepad computer does not have a color display, a commercial color version is expected within the next few years. Second, as the system is designed for use in various lighting conditions in workshop and flightline environments, a review of existing research is required to optimize the screen presentation (i.e., colors, fonts, and formats).

As stated previously, most respondents believe that a pen would be more user friendly than a mouse and that the pointing device would be easier to use when the requirement to single or double click to select an input choice is removed from the system. Overall, the user interface received high scores from respondents. The incorporation of several suggestions should improve the user interface further.

User Level Adequacy

The following question was used to evaluate whether the prototype was suitable for use by technicians having a range of experience levels from novice to expert:

Q21. The system is suitable for users with different levels of knowledge/ experience. (Mean = 4.49)

Generally, survey respondents felt that the system was suitable for use by technicians with a range of experience levels. However, this area is one where the designers believe improvements are possible. Future versions of the prototype could include pull-down menus which allow selection of available graphics and current button functions. The system would then cater to technicians with different experience levels by giving them the opportunity to access as much of the available information as they desire.

The level of information provided could also be an automated function. A central file recording user experience could be invoked when a user's identification was entered at start-up. Information regarding the user's level of experience could be used to download the most appropriate data and set the applicable levels of information display.

Correctness of Converted Procedure

The methodology for conversion of the existing technical publications into electronic format was assessed using the following questions:

Q17. The steps of the maintenance procedure are segmented into logical presentation groups. (Mean = 4.77)

Q19. The hypertext links provide access to additional information at appropriate stages in the analysis. (Mean = 4.50)

Q22. The system correctly implements the fault analysis procedure as presented in the technical order. (Answer Not Applicable if user does not have access to the aircraft publications.) (Mean = 4.750, 95%CI 2.75 - 6.75)

The purpose of question 17 was to test the approach of "chunking" information into logical presentation groups. This approach was successfully accepted by respondents. The only significant negative comment received for question 17 was that, because the tasks were not labelled, the respondent could not keep track of where he was in the overall system. This loss of visibility of the current position has been previously mentioned. However, the prototype could be further improved by placing appropriate titles on tasks, graphics, and all referenced links. Another possible improvement would be to use a small area of the screen to graphically display the current status of overlayed pages. This display would help the user to identify what hypermedia links were currently activated.

Question 19 was used to assess whether the hypertext information was being correctly linked and whether sufficient hypertext links were available to the user. Generally, respondents were pleased with the hypertext capability of the model. Several comments that were provided require further discussion.

A very good comment from one of the F-15E SPO respondents was that a specific maintenance task (e.g., aircraft safe for maintenance) required to support the checkout procedure should not merely discuss the performance of the task at an overview level but should actually provide step-by-step instructions to perform the task. The incorrect linking in this instance was caused by the different levels of information contained within the various sections of the technical publications and the inexperience of the prototype designers with the F-15E NLG. The important lesson learned was that the correct level of data, be it system, subsystem, or sub-subsystem, should be used when establishing a referencing link. The level of the referenced data should be determined by the context of the information at the origin of the link.

Several other comments concerned the fact that some of the links led to dead ends and that there was a need for referential linking. The time available precluded extensive development of all the necessary links. The prototype's main purpose was to display a concept and to provide a demonstration of the linking possibilities and their operation. In the next stage of the prototype, the quantity of the links available will likely be expanded. Full authoring would be required to complete the linking process.

Question 22 attempted to determine if the knowledge contained within the knowledge base of the integrated expert system correctly reflected the hardcopy publication. Because of the inaccessibility of F-15E publications to all survey respondents, a very low response rate (four out of 20) was received, and the answer to this question was inconclusive. The comments received from the F-15E members who evaluated the prototype were that the knowledge contained within the system was correct but that the system did not contain sufficient levels of detail for a true evaluation. The correctness of the knowledge within the integrated expert system should be tested in an actual field environment by a technician attempting to isolate existing faults.

Overall, the procedure used for the conversion of the hardcopy technical publications into electronic format appears to be correct. However, further prototype development and actual field testing is required.

Completeness of Converted Procedure

The following question was used to assess whether the entire knowledge necessary to perform a task was contained within the knowledge base of the integrated expert system:

Q23. The system provides access to the knowledge necessary for the F-15E Nose Landing Gear Extraction and Retraction Checkout Procedure. (Answer Not Applicable if user does not have access to the aircraft publications.) (Mean = 4.67)

A low response rate to this question (six out of 20) was also received. However, the result of the statistical analysis was that the respondents agreed that sufficient knowledge was contained within the system to represent the complete knowledge required to perform the specific task associated with the landing gear extraction and retraction checkout procedure.

Efficiency

The following question was used to compare the prototype with the hardcopy technical publications to determine if the prototype would be more efficient than the existing method:

Q24. The system is more efficient than using conventional technical order publications. (Answer Not Applicable if user does not have access to the aircraft publications.) (Mean = 4.14, 95%CI = 3.31 - 4.98)

Again, the low response rate (seven out of 20) to this question resulted in an inconclusive answer. Ideally, the system should be field tested and a comparison made between the two methods based on the measurement of time to make serviceable. The results are best summarized by the following comment:

> Difficult to assess. There are advantages over paper TOs, but the difficulties of computers have not been experienced. [Could] answer better after actual flightline test.

Reliability and Consistency of Results

Reliability and consistency of the prototype were evaluated using the following question:

Q25. The system provides expected results. (Mean = 4.62)

Most survey respondents answered this question favorably. They commented that the system followed the papercopy fault isolation publication and led the technician to probable repairs. However, this criterion requires further assessment in the field environment.

Overall Usefulness of the System

The following seven questions were used to assess the overall usefulness of the prototype:

Q18. By limiting the user to a direct path through the analysis procedure, the system eliminates the complexities of fault analysis. (Mean = 4.32)

Q20. The system is likely to be more acceptable to the technician (end user) than the current hardcopy publications. (Mean = 3.84, 95%CI = 3.37 - 4.30)

Q26. Overall, the system is useful. (Mean = 4.83)

Q27. The system would be useful in a workshop environment. (Mean = 4.85)

Q28. The system would be useful in a flightline environment. (Mean = 4.20)

Q29. The system would be useful to manage technical maintenance. (Mean = 4.82)

Q30. The system could be used to manage technical publications. (Mean = 4.99)

The purpose of question 18 was to assess the usefulness of the system in eliminating the complexities of fault isolation and to determine if a novice technician could perform the task. Even though the net result from the survey was agreement that the complexities of fault isolation were reduced, two noteworthy comments were received. One technician noted that the user should be guided and not handcuffed into a certain fault path, and another individual claimed that fixed fault trees are obsolete.

The authors do not agree that fixed fault trees are obsolete. They do, however, acknowledge that a small percentage (hopefully) of faults will not be solved by using the existing LTTAs. An expert system is only as good as the knowledge stored within its knowledge base. The system therefore needs to be designed to cope with the exception. The prototype coped with the exception by requiring the user to consult his supervisor. An improvement would be for the system to trace the path taken to reach the exception situation. This capability would allow for back-tracking and further (higher level) fault analysis by suitable experts.

Question 20 was used to assess the preference of the respondents for either the prototype or the existing technical publications. The survey results indicated a marginal, but not conclusive, preference for the prototype. Comments favoring the existing system were "that they were better for users who weren't quite sure where to look" and that "hardcopy will still be required." An element of resistance to change was also noted in the survey responses. Further field testing of the prototype will be required to determine the technicians' preferences. The statement that "overall, the system is useful" was highly scored by all respondents (range of scores received were from 3.5

to 6.0), which provides encouragement for continued development of the prototype.

Questions 27 and 28 asked the respondents whether the system would be useful in workshop and flightline environments. General agreement was reached that the system was useful in a workshop environment, but respondents were not as convinced of the usefulness of the system in the flightline environment. Most respondents believed that technology suitable for the flightline was not yet available. They observed that, for the system to be useful in an outdoor environment, better visibility in sunlight, a long lasting battery, compact size, ruggedized design, and portability were needed. The NCR 3125 Notepad computer has most of these technological advancements. However, the battery has only a four hour capacity under normal use, and the computer is not ruggedized. Also, while a ruggedized version is under development by NCR, such a version is already offered by the Slate Corporation. Therefore, a different result to question 28 may have occurred if the Notepad computer had been used in the evaluation phase.

Questions 29 and 30 asked the respondents if the system would be useful to manage technical maintenance and technical publications. Respondents agreed that the system was useful and has the capability but needs some work.

IDESM Evaluation

Overall, the evaluation has resulted in approval of the stage 1/2 prototype and provided a list of suggested improvements. The survey has demonstrated that the concepts underlying the IDESM are valid. Incorporation of some minor modifications to the model and development of a second version of the prototype should now proceed. Further development and testing of the model/prototype is required to determine if the IDESM can achieve the desired goals of reducing the technical training commitment, providing more effective fault isolation by technicians with reduced experience levels, and producing higher quality maintenance.

Summary

This chapter presented the results obtained from the survey. A statistical analysis of the results was used to evaluate the prototype in the eight performance areas identified in Chapter 3. All significant comments received from the survey were addressed and improvements to the prototype were identified. The major improvements to the prototype include: providing more guidance to the user (instructions and extended and context sensitive help screens), providing a back-up (to previous screen) feature, placing lists of available graphics and buttons in pull-down menus, enhancing the graphics, and providing context linking of the hypermedia information. The overall assessment of the prototype, and hence the model, was agreement that the prototype was an improvement over the existing fault isolation manuals. Further development and testing of the model/prototype should now proceed.

V. Conclusions and Recommendations

Introduction

This chapter presents the authors' conclusions with respect to the research conducted to meet the objectives stated in Chapter 1. Also, areas for future development of the Integrated Diagnostic Expert System Model (IDESM) and topics for further research are recommended.

The purpose of this research was to develop a model to convert existing hardcopy maintenance manual fault isolation procedures into electronic format and to partially automate the fault isolation process. A comprehensive model was developed which comprised four major components: a user interface, an expert system submodel, a hypermedia submodel, and a submodel integration shell. Using this model, the F-15E nose landing gear fault isolation procedures were transformed into an expert system. An existing hypermedia information base, developed using Cassell's SHADM, was expanded and subsequently integrated with the expert system to form a prototype application.

Engineering and maintenance personnel at Wright-Patterson Air Force Base evaluated the prototype in eight performance areas: ease of use, suitability of user interface, user level adequacy, correctness of converted procedure, completeness of converted procedure, efficiency, reliability and consistency of results, and the overall usefulness of the system. An analysis of the survey responses demonstrated favorable acceptance of the prototype and validated the IDES model. Therefore, the following conclusions can be drawn from this research.

Conclusions

1. **The IDES model is suitable for converting LTTAs into rule-based expert systems.** Since 1976 the majority of USAF fault isolation manuals, including the F-15E manuals, have been based on Logic Tree Troubleshooting Aids. Because the F-15E NLG fault isolation procedures were easily converted into an integrated expert system using the IDES model, a major benefit to the Australian Defence Force from this research is that any publication which has the fault isolation procedures expressed in LTTA format can now be converted into an expert system using the developed model.

2. **The PMA concept is a suitable platform on which to base further expert system development.** Based on current developments in information systems technology and the research being undertaken by Armstrong Laboratories, a portable maintenance aid was considered to be the most likely device that the technician would use in the work environment. Consequently, the user interface specification of the IDESM was designed around the PMA concept. Although the Notepad computer was unavailable for the survey, the enthusiastic response received when demonstrating the prototype to several agencies at Wright-Patterson AFB endorsed the PMA concept. A second benefit to the ADF from this research is that future technical information systems can now be developed utilizing the PMA concept.

3. **Draft Military Specification MIL-M-GCSFUI provides comprehensive guidance for user interface design.** The user interface developed in this research was consistent with (draft) MIL-M-GCSFUI (9) and will prove useful in the development of other similar types of expert systems. Extensive design effort on the user interface was undertaken because of its importance to end product acceptance by the user. In order to simplify the task and minimize user interaction, input was limited to "point and click" functions rather than keyboard entry. The split screen layout presented text and graphics in a format similar to its hardcopy predecessor. Although some training will be required to operate the system, technicians who currently use the existing publications, should not require training to become familiar with this presentation format. Presentation of the information was enhanced by the use of colors (where available), and features such as scrolling and maximization were included. The survey results demonstrated that the user interface was highly accepted by the user population. The third benefit from this project is that a useable product, which may be subsequently refined by continuing research into human-computer interaction, has been developed.

4. **The modular design of the current IDESM prototype allows it to be easily expanded to a full-scale standardized system.** Considerable research into the existence of models that convert fault isolation procedures into expert systems was not productive. Therefore, Senn's principles of software design were used in the construction of the expert system and hypermedia submodels. Modularity was introduced by structuring the expert

system into several layers of knowledge bases. The layers corresponded to the system, subsystem, and sub-subsystem technical assignment, as detailed by MIL-STD-1808. Each layer comprised task specific modules, each of which contained the knowledge required to perform that particular fault isolation procedure. The hypermedia submodel was based primarily on graphical and textual information contained within the existing hardcopy manuals. However, the potential to include other forms of media, e.g., video and audio, was recognized. Because of the necessity to reference common information (e.g., drawings, warnings, and cautions) throughout the text, hardcopy manuals contain redundant information. The hypermedia submodel, which stores information in modules, overcomes this redundancy problem by allowing the shared use of the modular information. The design principles of modularity and shared use of modules provide significant benefits in minimizing the memory storage requirements of information systems and simplifying software maintenance. Further, software programming templates could be developed for each of the levels/functions in the IDESM, providing faster development and greater standardization of integrated expert systems.

5. **KnowledgePro® for Windows is a suitable off-the-shelf software package for continued development of the integration shell.** The final component of the IDESM was the integration shell submodel, which allows the user to transparently access information within the hypermedia and expert system knowledge bases. KPW was selected for this application because of its ability to perform hypertext and expert system functions and its versatile

display capabilities. In addition, it was easy to learn and use. As KPW is a relatively new product, the software developers at Knowledge Garden are keen to improve the performance of their product. Significant improvements have been made to the product in the 12 months since FLTLT Cassell completed his research. During the development of this prototype, the authors provided some recommendations for product improvement. Consequently, the company is interested in providing the next release of software for alpha site testing with the prototype. The next version of KPW will permit the compilation of developed programs into C++ executable code for distribution. This is expected to improve the execution time of the application software by a factor of 10 to 30 times. The benefits from co-operative development of a hypermedia/expert system software product could be significant to the ADF. Possible benefits include cognizant development of a product which considers military unique requirements such as MIL-M-GCSFUI, CALS, and the PMA concept. Consequently, this proposal will be forwarded for consideration by the relevant authorities.

Recommendations for Further Research

Recommendations from this research are made in two areas - those that relate directly to the prototype and those that concern expert system development in general. First, the prototype should undergo further development and testing. As a result of ongoing research and comments received from survey respondents, several improvements to the prototype were suggested in Chapter 4. These improvements include the use of single click in place of double click, improvements to the maximization function, the inclusion of a pull-down menu bar, graphics enhancement, the addition of a back-up (to previous step) feature, an error trapping capability, and a context sensitive help feature. A field test using actual faults is recommended to more fully evaluate the correctness and completeness of the information within the prototype. Some of the criteria that need further evaluation include:

a. success rate and accuracy of isolating the fault,

b. effectiveness of reasoning displayed by system, and

c. improving the technician's efficiency (evidenced by any noticeable reduction in time to make serviceable).

Second, the coupling of the IDESM with existing ADF management information systems, e.g. maintenance management and supply systems, to provide the next level of system integration should be investigated. The process of recording the maintenance action (repair/replacement of components) in the RAAF's Computer Aided Maintenance Management system and demanding the replacement components through the Defence Supply Retail Management System are two possibilities. These processes are the next logical steps in providing the technician with access to integrated information systems and providing a paperfree technical environment.

Third, the authors recommend that the expert system, hypermedia, and integration submodels undergo further development. As part of this ongoing development, research into the storage and processing of photographic quality graphics and audio/video information is recommended. Also as the information available within the integrated system becomes larger, the performance of the system concerning peak loads, access times, and correct linkage of information needs evaluation and possible refinement.

Fourth, as stated in Chapter 4, a candidate for further research is the graphical presentation of information on small screen devices. Research is required to determine the optimal methods for displaying schematic and wiring diagrams. These graphics are normally larger in size than one screen, too complex to read when reduced to one screen, and too difficult to comprehend when segmented. Because the trend to miniaturize computing devices will continue, more emphasis on the effectiveness of graphical display methods will be required.

Finally, the authors' inexperience with the software package (KPW) prevented them from fully utilizing the object-oriented programming (OOP) capabilities of the software. Therefore, OOP should be investigated to determine its applicability for structuring knowledge in an expert system environment.

Summary

Several significant findings have resulted from this research. First, the IDESM has been developed which enables fault isolation procedures recorded in the LTTA format to be converted into expert systems. Second, the model provides for integration of the expert systems with a hypermedia base and is suitable for integration with other information systems. The success of the developed prototype, and hence the model, indicates that this research will be beneficial to the ADF and other military organizations. Finally, the following suggested improvements to the prototype have already been incorporated: pull-down menu capability, more user guidance in the form of window titles, and correct linking of information.

Appendix A: Sample File Formats

Faultcode Module Template

```
* * * Sets screen title * * *
set_title(?wText,'<Procedure Title>').

* * * Loads, runs, and unloads warning module/screens * * *
load ('<warning screen filename>',topic1).
    topic1().
   remove_topic (topic1).

* * * Displays introductory text * * *
text ('#e

 Test indicator 2 not turning white is caused by
 one of the below:

 a. NLG down limit switch;
 b. NLG/door selector valve;
 c. NLG diode panel;
 d. aircraft wiring.').

* * * Open window - ask question - close window * * *
window (,1,15,47,6,'NLG forward door',[child,visible,thinframe,
  titlebar,showChildren,siblings],?wText,blue,white,,).

ask (' Did NLG forward door open?', result_nlg, [YES,NO]).
close_window().

* * * set up branching according to LTTA * * *
if ?result_nlg = YES
then do (step_nlg_yes)
else do (step_nlg_no).

* * * The YES branch * * *
Topic 'step_nlg_yes'.

* * * Displays introductory text * * *
text ('#e

 1. Hydraulic off.
 2. Install NLG forward door ground safety pin
    #m(05-10-12)#m.
```

```
3. Manually press NLG down limit switch.').

* * * Open window - ask question - close window * * *
window (,1,15,47,6,'Indicator2',[child,visible,thinframe,
   titlebar,showChildren,siblings],?wText,blue,white,,).

ask (' Does test indicator 2 on secondary #n power system test set turn white?',
result2, [YES,NO]).
close_window().

* * * next branch according to LTTA if applicable * * *
if .........
then .......
else .......

* * * close this module & return to calling module * * *
and exit (next_kb).
end. (* step_nlg_yes *)

* * * The NO branch or other branches as applicable * * *
Topic 'step_nlg_no'.
text..........
end. (* step_nlg_no *)

* * * Hypermedia calling module * * *
topic super_mark (item).
 set_file_pos ('genmaint.ndx' ,0).
  :IndexInfo is read ('genmaint.ndx' , concat ('//',?item),'//').
  set_file_pos ('genmaint.hyp', first (?IndexInfo)).
  :t is read_char ('genmaint.hyp', element (?IndexInfo, 2)).
  markWindow is window(,48,1,44,26,,[child,visible,thinFrame,vertScroll,
     showChildren, siblings],?!wHandle,blue,white,,).
  text (?t).
  wait().
  Close_window ().
end. (* super_mark *)
end.
```

Index File Format Sample

//Description
5683 . . . . . . (indicates start position in file)
1160 . . . . . . (indicates length of information)
//Operation
6858
2179
//TCTO
9047
875
//Safety
9934
821

Text File Format Sample

//Description (This ASCII information starts at position 5683 of the file)

The NLG is mounted in the forward fuselage at FS 372.00. The gear is normally extended by using the wheel-shaped handle on the LDG GR Control Panel. Moving the handle to DOWN releases the uplatch and opens the gear doors, which allows [etc.]

//Operation (This ASCII information starts at position 6858 of the file)

The NLG and NLG forward doors are operated by the LDG GR control handle. The door is electrically sequenced and hydraulically operated. When required for ground maintenance, the forward door may be opened and closed manually or [etc.]

//TCTO (This ASCII information starts at position 9047 of the file)

The record of applicable time compliance technical orders is a list of all TCTOs which affect the technical content (text or illustration) of this manual. Only currently effective TCTOs are listed. A TCTO is deleted from the list when any [etc.]

Appendix B: Model Evaluation Questionnaire

After using the F-15E FAULT ANALYSIS system please indicate the extent to which you agree/disagree with the following statements. If you score a statement below 3, please provide supporting comments for your score. If there is insufficient space, please continue on the reverse side of the page. Please complete this questionnaire and have it ready for collection by Friday 29 May 1992. Thank you in advance for your participation.

USER INTERFACE

1. The program is easy to start.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

2. The program is easy to use.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

3. Navigating throughout the fault analysis system is easy.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

4. Sufficient explanations (on-screen/documentation) are provided to use the system.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

5. Exiting the system is easy.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

DISPLAY STANDARDS

6. The screen layout is suitable for the system's purposes.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

7. The overall textual presentation (font size, color, and typeface) is easy to read.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

8. The use of on-screen buttons is acceptable.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

9. The location of on-screen buttons is suitable.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

10. The subjects to which the buttons are linked are appropriate.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

11. The way in which information is presented in different windows is suitable.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

12. The use of different colors to highlight warnings, cautions etc. is suitable.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

13. The way that the system's graphics are presented is appropriate to users of all experience levels.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

14. The method of control (pointer/mouse) is suitable.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

15. The provision of scroll bars permits easy viewing of text and graphic information which is larger than the display window.

STRONGLY DISAGREE — STRONGLY AGREE

1 2 3 4 5 6

Comments:

16. The maximize capability which enlarges the graphic images to full screen is a useful feature.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

CONTENT

17. The steps of the maintenance procedure are segmented into logical presentation groups.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

18. By limiting the user to a direct path through the analysis procedure, the system eliminates the complexities of fault analysis.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

19. The hypertext links provide access to additional information at appropriate stages in the analysis.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

GENERAL

20. The system is likely to be more acceptable to the technician (end user) than the current hardcopy publications.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

21. The system is suitable for users with different levels of knowledge/ experience.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

22. The system correctly implements the fault analysis procedure as presented in the technical order. (Answer Not Applicable if user does not have access to the aircraft publications.)

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

23. The system provides access to the knowledge necessary for the F-15E Nose Landing Gear Extraction and Retraction Checkout Procedure. (Answer Not Applicable if user does not have access to the aircraft publications.)

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

24. The system is more efficient than using conventional technical order publications. (Answer Not Applicable if user does not have access to the aircraft publications.)

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

25. The system provides expected results.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

26. Overall, the system is useful.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

27. The system would be useful in a workshop environment.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

28. The system would be useful in a flightline environment.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

29. The system would be useful to manage technical maintenance.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

30. The system could be used to manage technical publications.

STRONGLY DISAGREE					STRONGLY AGREE
1	2	3	4	5	6

Comments:

Please feel free to address any specific strengths or weaknesses you observe in the package but were not addressed specifically by the questionnaire. Use the space below or attach additional sheets as required.

Comments:

Name (Optional): ______________________________

Rank or Title : ______________________________

AFSC (or equivalent): ___________________________

Please list any previous relevant experience (Technical orders, F-15E maintenance, hypertext systems, expert systems, etc.):

Appendix C: Questionnaire Responses

USER INTERFACE

Question 1. The program is easy to start.

Mean = 5.38, SD = 0.84, 95% CI = 4.98 - 5.77, n = 20.

Comments:

a. Starting the application from windows is very easy.

b. Once the application is running, getting into the contents of the system is also easy.

c. There should be some sort of message line to 'steer' the user through the screens, e.g. 'Press continue for next step.'

d. Automatic installation program would be an advantage.

e. Screen opens, then appears to close and reopen.

f. No problem here.

Question 2. The program is easy to use.

Mean = 4.49, SD = 0.98, 95% CI = 4.03 - 4.95, n = 20.

Comments:

a. Could not back up a screen.

b. Had two versions running at the same time.

c. Navigating through the program is relatively easy, but I often got lost in the big picture, i.e. where I was in the procedure, where I'm headed. It's not real bad but could use some thought.

d. If you followed the predicted path you were fine, but it was difficult to backup or find your place if you jumped to button options (several in a row without returning to task).

e. Would be more user friendly with a pen.

f. I kept having a problem with the screens locking up. I don't know if this was a program malfunction or something I did. I would have to shut down and restart to continue.

Question 3. Navigating throughout the fault analysis system is easy.

Mean = 4.18, SD = 1.04, 95% CI = 3.69 - 4.66, n = 20.

Comments:

a. No direct link between text and graphic. Step J of procedure and graphics selection '3 level experience'.

b. Needs some instructions to go along with system. Just getting in and roving around doesn't seem adequate enough.

c. Its OK. Is the normal observation defaulted on the fault analysis prompts? (maybe they should be to let the user know what the normal observation is. A yes isn't always a pass)

d. No way to back up or change a test result (i.e., I selected no when I should have selected yes).

e. Could use titles for procedures on every screen so you know what particular task/test you are performing and where you are in an overall structure.

f. Like to explain and ask question to show someone in person while operating the system.

Question 4. Sufficient explanations (on-screen/documentation) are provided to use the system.

Mean = 4.08, SD = 1.32, 95% CI = 3.46 - 4.70, n = 20.

Comments:

a. Had a real hard time understanding graphic mode/text mode difference.

b. Decent for the amount of content in the system.

c. Might want to explore context sensitive help, i.e., rationalization for maintenance actions. Again, might want to provide a message bar.

d. How to navigate correctly was unclear if you branched away to see button alternatives.

e. Where use of 'Continue', single/double click should be given on each occasion they are required.

f. Numerous times, I got a spot where it didn't do anything or tell me to do anything.

g. It may be helpful to have index labelled or have it automatically come up when you start the program.

Question 5. Exiting the system is easy.

Mean = 4.82, SD = 1.16, 95% CI = 4.27 - 5.36, n = 20.

Comments:

a. It is very easy to exit with the quit button, but you should be able to start from introduction screen instead of checkout procedure, if you don't want to exit completely.

b. Yes, however exiting the current screen for the initial page should always be available, i.e., the first screen.

c. Possible use of an automatic exit icon may enhance this.

d. Machine locked up twice on the exit. Had to reboot to exit.

e. Change buttons to standard window type radio buttons.

f. No problem here.

DISPLAY STANDARDS

Question 6. The screen layout is suitable for the system's purposes.

Mean = 4.37, SD = 1.17, 95% CI = 3.82 - 4.91, n = 20.

Comments:

a. Left right format OK.

b. Good. Same as TOs.

c. Too much screen real estate is taken up with the available graphics panel on the right hand side, put them in a menu.

d. Text/graphic panels side by side seemed to work well.

e. Large diagrams are difficult to comprehend using a small scrollable window.

f. Maximize is useful but not ideal.

g. Screen needs to split and/or have full screen capability with a zoom addition for ease of utility.

Question 7. The overall textual presentation (font size, color, and typeface) is easy to read.

Mean = 4.98, SD = 0.88, 95% CI = 4.56 - 5.39, n = 20.

Comments:

a. Color should be consistent between the leftside and the rightside of the procedure.

b. Lime green not good.

c. The blue text color would be hard to read after a period of time. Black may be boring, but it is still the easiest text color to read.

d. Good color, font. Great.

f. Warning color, for example, stands out as important.

g. Easy to read in a controlled environment. May need some added capability (Screen needs to split and/or have full screen capability with a zoom addition for ease of utility.)

h. Outside on a sunny day, it may not be too easy to read.

Question 8. The use of on-screen buttons is acceptable.

Mean = 4.99, SD = 0.82, 95% CI = 4.61 - 5.37, n = 20.

Comments:

a. No backup button.

b. Yes, buttons are good but lets say that on a full graphic screen you have buttons that may not apply to that graphic in any way. Can the buttons change dynamically depending on screen content? Put other buttons on a pull-down menu or something.

c. Navigation to them, back from them, and between them must be clear.

d. Buttons should be uniform. Bottom buttons only require 1 click, others require 2 clicks. Suggest all 2 click.

<u>Question 9</u>. The location of on-screen buttons is suitable.

Mean = 5.22, SD = 0.69, 95% CI = 4.89 - 5.54, n = 20.

Comments:

a. In good view of user.

b. Use of a 'pen' will enhance this capability.

<u>Question 10</u>. The subjects to which the buttons are linked are appropriate.

Mean = 4.57, SD = 0.92, 95% CI = 4.14 - 5.00, n = 20.

Comments:

a. Links to description OK. General maintenance provides discussion of example 'Solo flight,' but should provide actual procedures to do the task. When selecting (05-00-05) actual task should appear, not just verse.

b. With training to explain the function of each button, the short subject titles will be acceptable.

c. Yes, buttons are good, but let's say that on a full graphic screen you have buttons that may not apply to that graphic in any way. Can the buttons change dynamically depending on screen content? Put other buttons on a pull-down menu or something.

d. There are a lot of other good subjects/links that could be used in addition, but I realize this is just a limited demonstration.

e. For the NLG system, small examples were linked to each button. Would more information for each button be accessible?

f. Use of a 'pen' will enhance this capability.

Question 11. The way in which information is presented in different windows is suitable.

Mean = 4.68, SD = 0.92, 95% CI = 4.25 - 5.10, n = 20.

Comments:

a. Easy to move back and forth.

b. Available graphics window is unnecessary in my opinion. If a step has a graphic associated with it, show it; if not, don't worry about it.

c. Might want to think about making all Notes/Warnings/Cautions pop-up windows. Sometimes they appear this way, other time they are displayed on left side of screen - inconsistent.

d. Zoom capability in both text and graphics would add more utility to the windows.

e. It may be better to have safety items come up automatically rather that having the user decide if he will read them or not.

Question 12. The use of different colors to highlight warnings, cautions etc. is suitable.

Mean = 5.39, SD = 0.58, 95% CI = 5.12 - 5.65, n = 20.

Comments:

a. The way Cautions and Warnings dominate the screen prior to reading the procedures was effective.

b. Yes. Red catches viewer's vision.

c. Don't know if color makes a big difference, but in this system it works OK.

d. Excellent.

<u>Question 13</u>. The way that the system's graphics are presented is appropriate to users of all experience levels.

Mean = 4.12, SD = 1.27, 95% CI = 3.52 - 4.71, n = 20.

Comments:

a. It is impossible to see an entire graphic on the screen at one time.

b. In addition to manual diagrams, actual scanned photographs would be more appropriate in the fault analysis.

c. Definitely need to work in this area.

d. These graphics are not acceptable due to quality of transferring from paper to digital.

e. IPB seems very grainy. Enhancement to graphics might make picture better.

f. An initial training course would be a must.

g. Some graphics items are a little indistinct.

<u>Question 14</u>. The method of control (pointer/mouse) is suitable.

Mean = 5.25, SD = 0.86, 95% CI = 4.84 - 5.67, n = 19.

Comments:

a. Mouse is OK.

b. A number of selections with the mouse require correction as many require multiple selections to operate.

c. Would help later to go to portable system.

d. I am unfamiliar with a program that requires double clicks occasionally. Further instruction would make it easier.

e. A pointer would be a lot better.

<u>Question 15</u>. The provision of scroll bars permits easy viewing of text and graphic information which is larger than the display window.

Mean = 4.93, SD = 1.15, 95% CI = 4.39 - 5.46, n = 20.

Comments:

a. All graphic not able to be on screen.

b. While the method implemented is ideal, the loss of the right hand scroll bar when window size changed could present a problem. The addition of an expand to full screen box for each window would help if scroll bar cannot be implemented on all window sizes.

c. Graphic information is difficult to comprehend (i.e., 'the big picture') using scroll bars.

d. Graphic information should be no larger than a full screen.

<u>Question 16</u>. The maximize capability which enlarges the graphic images to full screen is a useful feature.

Mean = 4.78, SD = 1.27, 95% CI = 4.15 - 5.42, n = 18.

Comments:

a. Maximize buttons hidden on right side of screen, maybe programming problem.

b. All graphic not on screen.

c. Never found it. Was it clear where it was and how to use it.

d. But cannot always be seen to select if window not full size.

e. If the quality of graphics and zoom capability were added.

f. Did not use this option.

g. A zoom feature of the graphic would be a welcome addition. Also better scans.

h. Needs explanation of how to do it. Someone who is not computer literate could have problems with it.

i. Did not see.

<u>CONTENT</u>

<u>Question 17</u>. The steps of the maintenance procedure are segmented into logical presentation groups.

Mean = 4.77, SD = 0.75, 95% CI = 4.41 - 5.14, n = 19.

Comments:

a. But they were not labelled, so I couldn't track where I was and what I was accomplishing. I felt trapped in a path.

<u>Question 18</u>. By limiting the user to a direct path through the analysis procedure, the system eliminates the complexities of fault analysis.

Mean = 4.32, SD = 1.14, 95% CI = 3.78 - 4.85, n = 20.

Comments:

a. There wasn't enough experience in this area to adequately rate fault analysis. When Yes was selected on the first step, the system locked up.

b. The user should be guided but not handcuffed into doing some other procedure that they think may help them.

c. So much more can be accomplished now with expert systems and interfacing with the aircraft that fixed fault trees are obsolete.

d. But they were not labelled, so I couldn't track where I was and what I was accomplishing. I felt trapped in a path.

e. Further insight to the decision process at every step.

f. This capability doesn't eliminate the complexities. It will probably slow the process down rather than expedite matters.

g. Would help to back track and know what decisions you made to get to the point you are at that moment.

h. Will this create difficulties in those rare 'exception' trouble shooting problems? Will there be enough detail?

i. I would like to have seen trouble analysis of a system closer to what I work on (avionics).

<u>Question 19</u>. The hypertext links provide access to additional information at appropriate stages in the analysis.

Mean = 4.50, SD = 1.09, 95% CI = 3.97 - 5.03, n = 19.

Comments:

a. Provides information discussion, but should provide step by step to accomplish Aircraft Safe for Maintenance.

b. Some lead you to dead ends but that understandable.

c. Hypertext links are a good method to get at additional information. Again a lot more useful links could be made given enough time and money.

d. User should be able to access any screen from any other screen (e.g. a graphic bar on screen can select any particular screen if required).

e. Did not see.

GENERAL

Question 20. The system is likely to be more acceptable to the technician (end user) than the current hardcopy publications.

Mean = 3.84, SD = 0.99, 95% CI = 3.37 - 4.30, n = 20.

Comments:

a. A full up system may. This has limited application.

b. Past experience proves that the user is not always exactly sure where to look for information (i.e. the IPB) and the ability to pan through the hardcopy is needed.

c. Original change will be rejected, but through use program will be acceptable.

d. Old habits die hard. I guess in the long term it will be cost effective.

e. They may like the hypertext links a lot but its still just an electronic version of the paper.

f. Technology allows us to integrate systems like this to other databases and the aircraft.

g. System is too rigid.

h. Easy to use format, but as database is increased will the amount of information help or overwhelm the technician? Will they be able to access everything they need?

i. Hard copies would still be used in some situations.

j. Good for training purposes, may be more time consuming that paper.

k. Computer hardware is very limited in my workcenter.

l. Except for some difficulties, like pushing button on mouse, nothing happens.

m. I think they will still need some information - especially wiring and schematics in hard copy. Don't throw them away yet.

n. Everyone will resist change.

o. Because of computer downtime to reprogram or bad weather, it could never fully replace the hardcopy.

p. I believe many technicians will strongly resist change (but I could be wrong).

Question 21. The system is suitable for users with different levels of knowledge/ experience.

Mean = 4.49, SD = 0.94, 95% CI = 4.05 - 4.93, n = 20.

Comments:

a. No levels of maintenance exist that I saw, i.e., expert vs novice. Could be implemented fairly easily though.

b. However, I think a novice might get lost more easily, as I did.

c. Difficult in times.

<u>Question 22</u>. The system correctly implements the fault analysis procedure as presented in the technical order. (Answer Not Applicable if user does not have access to the aircraft publications.)

Mean = 4.75, SD = 1.26, 95% CI = 2.75 - 6.75, n = 4.

Comments:

a. System didn't run far enough to evaluate. Another vote for hardcopy.

b. Program is an on-screen technical order.

<u>Question 23</u>. The system provides access to the knowledge necessary for the F-15E Nose Landing Gear Extraction and Retraction Checkout Procedure. (Answer Not Applicable if user does not have access to the aircraft publications.)

Mean = 4.67, SD = 0.82, 95% CI = 3.81 - 5.52, n = 6.

Comments:

Nil.

<u>Question 24</u>. The system is more efficient than using conventional technical order publications. (Answer Not Applicable if user does not have access to the aircraft publications.)

Mean = 4.14, SD = 0.90, 95% CI = 3.31 - 4.98, n = 7.

Comments:

a. More direct. Ignores Not Applicable data.

b. Difficult to assess. There are advantages over paper TOs, but the difficulties of computers have not been experienced. An answer better after actual flightline test.

c. But, I expect it is.

Question 25. The system provides expected results.

Mean = 4.62, SD = 0.94, 95% CI = 4.13 - 5.10, n = 17.

Comments:

a. Followed papercopy Fault Isolation.

b. Not having paper TOs its tough to tell. It does take you to probable repairs when you fail a test at the end of a tree though.

Question 26. Overall, the system is useful.

Mean = 4.83, SD = 0.89, 95% CI = 4.41 - 5.24, n = 20.

Comments:

a. As a substitute for paper TOs, it does its job. If there were more data it might be easier to see its usefulness and full capabilities.

Question 27. The system would be useful in a workshop environment.

Mean = 4.85, SD = 0.83, 95% CI = 4.46 - 5.24, n = 20.

Comments:

a. More so than flightline. Hardware applications need exploration.

b. This system would better suit the in-shop environment than the flightline.

c. Wouldn't work too well on flightline, since it needs to be portable and not mouse driven, but it would be suitable for the workshop.

d. Consider weather factors, availability of hardware, and possible use in a wartime scenario - maybe!

Question 28. The system would be useful in a flightline environment.

Mean = 4.20, SD = 1.37, 95% CI = 3.56 - 4.84, n = 20.

Comments:

a. Dependent on hardware.

b. If technology can provide on-screen text and graphics that can be seen in sunlight and a battery that can last 12 hours, otherwise it would be difficult to use on flightline.

c. Extremely ruggedized equipment will be needed.

d. See previous comment.

e. If all available on Notebook PC would allow better access to information.

f. Touch screen would be more appropriate.

g. Only if compact and portable.

h. Not ruggedized, no austere capabilities.

i. If could be made portable and also have access to a large enough monitor if needed.

j. Consider weather factors, availability of hardware, and possible use in a wartime scenario - maybe!

Question 29. The system would be useful to manage technical maintenance.

Mean = 4.82, SD = 0.97, 95% CI = 4.36 - 5.27, n = 20.

Comments:

a. Would need extension of the program and mature system.

b. As specialty increases and shop scope decreases the technician would find the computer method better in the shop environment.

c. Needs work, but has the capability.

Question 30. The system could be used to manage technical publications.

Mean = 4.99, SD = 0.83, 95% CI = 4.59 - 5.39, n = 19.

Comments:

a. Needs work, but has the capability.

b. The system, if under tight configuration management, could ensure only accurate information is in use, i.e., easy audit.

c. With proper formatting.

General comments received.

a. Scanned graphics have poor resolution (common, we have experienced the same).

b. Callouts need to be selected, and I assume they will be.

c. Missing data for a lot of links.

d. List of available graphics is OK, but why not make a menu button to get at them or only display those for the steps that have graphics.

e. Need a way to backup in a procedure.

f. Need a way to change the answer to a prompt.

g. If a fuller database existed, I assume when description, operation, TCTO, etc. were selected that only information for the particular system being worked or selected would be displayed.

h. Is the safety button warning for the whole task or for a particular step? Kind of confusing.

i. General maintenance information needs to be structured in some logical manner. I couldn't find it. Maybe alphabetical or by system?

j. Need the name of the task (test/repair) displayed on the titlebar or somewhere.

k. The name of the link on the right side title bar gets truncated, needs to wrap or be made shorter.

l. Need locator graphics for a lot of steps, connectors, doors, etc.

m. When a repair is required, why not take them right to the repair instead of having the user select the link to the procedure?

n. The links for support data give the user no idea where the links will take them.

o. Why keep paper references in electronic format?

p. I don't know if it was my computer or what, but I got a lot of Knowledge Pro errors.

q. Why stack the links up on one another.

r. Need a more elegant way to restart from the beginning rather than the start of the checkout procedure.

s. Backup? How do I get back?

t. Soft keys - contain only one piece of information and it is static. How will organization/traversal work when there is more information available?

u. Graphics - how do they tie in to particular procedures? Or do you just reference whatever you think you need to see?

v. Procedure format was confusing - it didn't seem to have much continuity and I needed titles to see where I was currently.

w. Hard to envision an overall structure/procedure hierarchy.

x. Wanted to get back to original sectional aircraft graphic.

y. Prompt format is nice. However, would it be helpful to know what the 'correct' response is on a checklist like this?

z. Warning/Note/Caution format is good, although it doesn't seem obvious what steps they are applicable to ... future steps, right?

aa. Why is support equipment stuck in the middle of the procedure? Or did I get sent off to another procedure because I identified a fault? Again, it needs titles for sets of procedural steps so you know where you are.

ab. The system presents current documented data in a more usable medium.

ac. Locks up a lot.

ad. Right button on mouse inoperable.

ae. Hard to go back to screen prior.

af. Hard to look at diagram after looking at procedures.

ag. Hard to get to troubleshooting features.

ah. Can be a good program, has lot of potential.

ai. Like to show and explain my experience to someone while working with a computer.

aj. Great start on an overwhelming project!

ak. How will user be able to access TO information of other than primary system? (Will he be able to get the electric or hydraulic TO without going back to the shop if the task didn't list it as a requirement?)

al. Use of pen notebook in low light situations?

am. TOs do take a lot of abuse. This is an expensive bit of equipment, and I'll be interested to see how you are going to make it 'mechanic proof.'

an. A training module would be a useful addition to the system. A system that demonstrated how to use the system and then offered practice would help introduce new users to the system.

Bibliography

1. Abu-Hakima Suhayya and others. "Jet Engine Technical Advisor (JETA)," Proceedings, the Second International Conference on Industrial & Engineering Applications of Artificial Intelligence and Expert Systems. 154-160. New York: Association for Computing Machinery, 1989.

2. Akscyn, Robert M. and others. "KMS: A Distributed Hypermedia System for Managing Knowledge in Organizations," Communications of the ACM, 31: 820-835 (July 1988).

3. Allen, Mary K. and Omar Keith Helferich. Putting Expert Systems to Work in Logistics. Oak Brook IL: Council of Logistics Management, 1990.

4. Bielawski, Larry and Robert Lewand. Expert System Development Building PC Based Applications. Wellesley MA: QED Information Sciences Inc, 1988.

5. Black, W. J. Intelligent Knowledge Based Systems an Introduction. Berkshire, England: Van Nostrand Reinhold (UK), 1986.

6. Braden, Barbara and others. "Developing an Expert Systems Strategy," MIS Quarterly, 13: 459-467 (December 1989).

7. Cassell, FLTLT (RAAF) Peter W. Structured Hypermedia Application Development Model (SHADM): A Structured Model for Technical Documentation Application Design. MS Thesis, AFIT/GIR/LSY/91D-3. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright Patterson AFB OH, December 1991 (AD-A244268).

8. Chen, Jen-Gwo and Kazuhiko Ishiko. "Automobile Air-Conditioner Compressor Troubleshooting - An Expert System Approach," Computers in Engineering, 13: 337-345 (March 1990).

9. David Taylor Research Center. Proposed Draft Military Specification for General Content, Style, Format, and User-Interaction Requirements for Interactive Electronic Technical Manuals. Report DTRC-90/028. Bethesda MD, July 1990.

10. Davis, Michael W. Applied Decision Support. Englewood Cliffs NJ: Prentice-Hall Inc, 1988.

11. Department of Defense Military Standard. MIL-STD-1840A. Automated Interchange of Technical Information. Washington, Department of Defense. 22 December 1987.

12. Department of the Air Force. MIL-M-28001A. Military Specification Markup Requirements and General Style Specification for Electronic Printed Output and Exchange of Text. 20 July 1990.

13. Department of the Air Force. MIL-M-83495A. Military Specification: Manuals, Technical: On-Equipment Set, Organizational Maintenance Manuals; Detailed Requirements for Preparation of (for USAF Equipment). 12 October 1990, AMSC F5023.

14. Department of the Air Force. TO 1F-15E-2-00GV-00-1. Aircraft Description and Maintenance Orientation: USAF Series F-15E Aircraft: General Vehicle Technical Manual. ASD/TAFLT, Wright-Patterson AFB OH. 15 November 1987.

15. Department of the Air Force. TO 1F-15E-2-32FI-00-1. Landing Gear System: USAF Series F-15E Aircraft: Fault Isolation Technical Manual. WR-ALC/LZDT, Robins AFB GA. 15 May 1990.

16. Emory, C. William and Donald R. Cooper. Business Research Methods (Fourth Edition). Homewood IL: Richard D. Irwin, Inc. 1991.

17. Finn, Gavin A. and Kenneth F. Reinschmidt. "Expert Systems in Operation and Maintenance," Chemical Engineering, 97: 131-138 (February 1990).

18. Ford, Brian and Ira Gordon. "The Application of Multimedia Expert Systems to the Depot Level Maintenance Environment," Proceedings of the IEEE 1991 National Aerospace and Electronics Conference (NAECON 1991). 1038-1041. New York: Institute of Electrical and Electronics Engineers, 1991.

19. Forsyth, Graham F. and Michael D Larkin. "Concept Demonstration of the Use of Interactive Fault Diagnosis and Isolation for TF30 Engines," Proceedings, the Second International Conference on Industrial & Engineering Applications of Artificial Intelligence and Expert Systems. 15-20. New York: Association for Computing Machinery, 1989.

20. Larkin M.D. and others. IFDIS - An Expert System for Diagnosis of Failures in Jet Aircraft Engines. Melbourne, Australia: Aeronautical Research Laboratory, January 1987 (AD-A227757).

21. Miller, David M. and others. "An Image Enhanced, Knowledge Based Expert System for Maintenance Troubleshooting", Computers in Industry, 16:187-202 (November 1990).

22. Morgan, Rory P. and Julian R. Bond. "Methods of Artificial Intelligence - Some Applications for Market Research," Journal of the Market Research Society, 31: 375-397 (July 1989).

23. Nolan, Richard L. "Managing the Crisis in Data Processing," Harvard Business Review, 57:115-126 (March-April 1979).

24. Pigford, Darleen V. and Greg Baur. Expert Systems For Business: Concepts and Applications. Boston MA: Boyd & Fraser Publishing Company, 1990.

25. Potter, Norman R. and Donald L. Thomas. Evaluation of Three Types of Technical Data for Troubleshooting: Results and Project Summary. AFHRL-TR-76-74 (I), Wright-Patterson AFB OH: Air Force Human Resources Laboratory. September 1976. F33615-75-C-5103.

26. Rouska, LT (USN) Aaron M. Conversion, Integration, and Maintenance Issues of Navy Stock Points Expert Systems. MS Thesis. Naval Postgraduate School, Monterey CA, March 1990 (AD-A230668).

27. Senn, James A. Analysis & Design of Information Systems(Second Edition). New York NY: McGraw-Hill Publishing Company, 1989.

28. Shim, J.M. "Living Up to the 'HYPE'," OR/MS Today, 11: 34-45 (February 1992).

29. Van Hook, LTCDR (USN). An Expert System for Shipboard Maintenance. MS Thesis. Naval Postgraduate School, Monterey CA, September 1990 (AD-A239424).

30. Waterman, Donald A. A Guide to Expert Systems. Reading MA: Addison-Wesley Publishing Company, 1986.

Vita

Mr. Robert J. Lacey was born 13 March 1949 in Brisbane, Queensland, Australia. He enlisted in the Royal Australian Air Force in 1967 and served as a radio technician until 1975, when he was selected to attend the Royal Melbourne Institute of Technology, Melbourne, Australia. He received a Diploma of Engineering in Communication Engineering in 1978 and was commissioned with the rank of Pilot Officer.

As an engineering officer in the RAAF, Mr. Lacey worked as Officer in Charge of General Engineering Maintenance and Avionics Sections at Number 3 Aircraft Depot, Amberley, project officer at Headquarters Logistics Command, and Instructor of the Radio Officers' Familiarization Course at Laverton. In 1985, he resigned his commission as a Flight Lieutenant to accept a senior engineering position in the Project Development and Communications (PDC) Division of the Deputy Secretary Acquisition and Logistics Organization. The First Assistant Secretary of PDC Division is sponsoring Mr. Lacey's attendance at the School of Systems and Logistics, Air Force Institute of Technology.

Mr. Lacey is married with two teenage children.

Permanent Address: 15 Beck Street
Clontarf Beach, Qld 4019
Australia.

Vita

Squadron Leader Glen Steemson was born 29 September 1961 in Bundaberg, Queensland, Australia. He enlisted in the Royal Australian Air Force in 1979 and attended the Royal Melbourne Institute of Technology, Melbourne, Australia. In 1982 he received a Bachelor of Engineering majoring in Electronic Engineering, and was commissioned with the rank of Flying Officer.

Postings include Engineering Support Flight 492 Squadron, various project management positions at Headquarters Logistics Command, and Officer in Charge of Avionics Maintenance for the P3C Orion aircraft at 492 Squadron. He was posted to the School of Systems and Logistics, Air Force Institute of Technology, in May 1991.

Squadron Leader Steemson is married with one, soon to be two, children.

Permanent Address: 8 F.E. Walker Street
Bundaberg, Qld 4670
Australia.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1992	Master's Thesis

4. TITLE AND SUBTITLE

INTEGRATED DIAGNOSTIC EXPERT SYSTEM MODEL (IDESM): A MODEL FOR THE CONVERSION OF FAULT ISOLATION PROCEDURES INTO AN INTEGRATED DIAGNOSTIC EXPERT SYSTEM

5. FUNDING NUMBERS

6. AUTHOR(S)

Robert J. Lacey, Mr

Glen D. Steemson, Squadron Leader

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology, WPAFB OH 45433 6583

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GIR/LSY/92D-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of this research was to develop a model to convert existing hardcopy maintenance manual fault isolation procedures into electronic format and to partially automate the fault isolation process. A comprehensive model was developed which comprised four major components: user interface, expert system submodel, hypermedia submodel, and a submodel integration shell. Using this model, the F 15E nose landing gear fault isolation procedures were transformed into a rule based expert system. An existing hypermedia information base was expanded and subsequently integrated with the expert system to form the prototype application.

The prototype was evaluated by engineering and maintenance personnel at Wright Patterson Air Force Base. An analysis of the survey responses demonstrated favorable acceptance of the prototype and validated the IDES model. Several conclusions from this project and recommendations for further research are presented.

14. SUBJECT TERMS

Management Information Systems, Integrated Systems, Expert Systems, Information Processing

15. NUMBER OF PAGES

130

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)

AFIT Control Number AFIT/GIR/LSY/92D-8

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/LSC, Wright-Patterson AFB OH 45433-9905.

1. Did this research contribute to a current research project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Please estimate what this research would have cost in terms of manpower and/or dollars if it had been accomplished under contract or if it had been done in-house.

   Man Years ______________ $ ______________

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3, above) what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments

______________________ ______________________
Name and Grade Organization

______________________ ______________________
Position or Title Address