ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF INFORMATICS
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KNOWLEDGE BASED SYSTEM FOR FAULT ISOLATION AND DIAGNOSIS OF AIRCRAFT MAINTENANCE IN ETHIOPIAN AIRLINES

BY
MESKEREM ABEBE YIGREM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE DEGREE OF MASTER OF SCIENCE IN INFORMATION SCIENCE

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Knowledge Based System for Fault Isolation and Diagnosis of Aircraft Maintenance in Ethiopian Airlines

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LIST OF ABBREVIATIONS

ACS: Aircraft Configuration System

AD: Airworthiness Directives

ADB: Area Distribution Box

AMM: Aircraft Maintenance Manual

ATE: Automatic Test Equipment

AVU: Audio Video Unit

BITE: Built In Test Equipment

BPCU: Bus Power Control Unit

CAA: Civil Aviation Authority

CB: Circuit Breaker

CFS: Cabin File Server

COMF: Communication Failure

DPCU: Digital Passenger Control Unit

DVO: Display Video Only

EPCP: Electrical Power Control Panel

FA: Failure in Application software

FAA: Federal Aviation Authority

FAR: Federal Aviation Regulation

FIM: Fault Isolation Manual

FMT: Fault Management Team

IFE: In Flight Entertainment

MOCC: Maintenance and Operation Control Center

OEU: Overhead Electronic Unit

OPS: Operating System

PA: Passenger Address

PAT: Primary Access Terminal

PSS: Passenger Service System

PMA: Portable Maintenance Aid

SB: Service Bulletin

TES: Total Entertainment System

TQM: Total Quality Management

TK: Troubleshooting Kit

TSM: Troubleshooting Manual

SDU: Seat Display Units

VA: Video Announcement

VMOD: Video Modulator

VTR: Video Tape Reproducer

ABSTRACT

Fault isolation and diagnosis is one of the key aircraft maintenance activities performed in Ethiopian Airlines. The main features of fault diagnosis in aircraft maintenance involve multidisciplinary knowledge in aircraft functional systems and the indefinite relationship between symptom and source of failure. In order to facilitate these activities the experience and knowledge of aircraft technicians plays a significant role in quickly solving aircraft system failures without delaying flight schedules. However the airline is losing significant amount of skilled and experienced technicians whose contribution to the fault diagnosis was invaluable.

A knowledge based system is developed to facilitate the fault isolation techniques in aircraft maintenance using the experience and knowledge of skilled technicians along with the relevant maintenance documents and maintenance records. The domain knowledge modeling is performed using decision trees in such a way that a rule based inference can be implemented for knowledge representation. The prototype developed employs the utilization of facts and come up with conclusions based on the backward chaining inference. The rules in the knowledge base are constructed from analyzing the records of the aircraft maintenance resume book along with the available maintenance documents. A prolog programming language is used to demonstrate the prototype and the result of the study has revealed that there is an accuracy of 86%. Adopting the knowledge based system is supposed to retain the aircraft maintenance knowledge and makes the airline stronger by itself rather than depending fully on human experts.

The knowledge based system needs further works in updating its knowledge base when new facts are introduced besides of creating generalized pattern for identifying system faults.

CHAPTER ONE

INTRODUCTION

1.1 Background

Transportation is the movement of people and goods from one location to another. The transport of a person may involve one mode or several modes of transport. A mode of transport is a technological solution that makes use of a particular type of vehicle, infrastructure and operation. The major modes of transport are air, rail, road, water, cable, pipeline and space.

Air travel remains a large and growing industry. It facilitates economic growth, world trade, international investment and tourism and is therefore central to the globalization taking place in many other industries. Governments in developing countries realized the benefits of tourism to their national economies and spurred the development of resorts and infrastructure to lure tourists from the prosperous countries in Western Europe and North America. As the economies of developing countries grow, their own citizens are already becoming the new international tourists of the future.

Business travel has also grown as companies become increasingly international in terms of their investments, their supply and production chains and their customers. The rapid growth of world trade in goods and services and international direct investment has also contributed to growth in business travel. However the complex issues affecting operations management are daunting. People, luggage, freight and aircraft have to be moved over vast distances. Flights, crews, maintenance, cargo and even meals have to be scheduled. Fuel, spares, tools, training and publications have to be provisioned. All of these factors have to be considered against a background of timetables coupled with operating and maintenance costs, that is time and money which makes the airline industry one of the most unique businesses in the world.

1.1.1 The Ethiopian Airlines

Ethiopian Airlines was founded on December 30, 1945 and commenced operations on April 8, 1946, with a weekly service between Addis Ababa and Cairo with five Douglas DC-3 propeller driven aircraft. The airline started long-haul services to Frankfurt in 1958 and inaugurated its first jet service in January 1963 from Addis Ababa to Nairobi.

According to the airline official website the airline is currently operating with 34 aircrafts which includes ten Boeing 767-300, eight Boeing 757-200, two Boeing 757-260F, two Boeing 747F, one MD-11F, five Boeing 737-700NG, one B737-800W and five Fokker 50. The airline has already ordered ten B787 Dream Liner jets from Boeing, five B777-200LR from Boeing, twelve A350-900 from Airbus, one MD-11F from Boeing and eight Q400 aircrafts from Bombardier.

Using these aircrafts Ethiopian Airlines transports passengers and cargo to 54 international destinations. The Ethiopian Airlines has code share agreements with Lufthansa, Brussels Airlines, Gulf Air, South African Airways, TAAG-Angola Airlines, Air One Saudi Arabian Airways and several other agreements in the pipeline so as to serve customers with same standard as these airlines. Ethiopian Airlines has an advanced maintenance base, which is fully operational for Airframe maintenance, Engine Overhaul, Component repair and overhaul, Light Aircraft maintenance and technical and management assistance for other airlines.

The maintenance base is certified by the US-Federal Aviation Administration (FAA). The aircraft maintenance activities are performed based on the maintenance manuals and other maintenance documents released by aircraft manufacturers and regulatory bodies. Aircraft maintenance Technicians uses these manuals as basic documents to rectify aircraft, engine and component failures. Though these documents provide fundamental knowledge to the aircraft systems, the fault isolation technique is very much dependent on the acquired experience through time.

The pressures of modern business demand efficient system that provides customer satisfaction. Consequently, high reliance is placed on availability of experienced and knowledgeable employees.

However, experienced services can be lost by change of employment, retirement and death. In addition, in the real world of night shifts, sickness and holidays, expertise of the required quality is not always available.

1.1.2 Aircraft Maintenance

Aircraft maintenance activities form an essential part of airworthiness. The common objective of aircraft maintenance, civil or military, is to provide a fully serviceable aircraft when it is required by the operator at minimum cost (Seref et al., 2008). Aircraft maintenance implies actions that restore aircraft units, specific system or the whole aircraft system to a serviceable condition and consists of servicing, repair, modification, overhaul, inspection and determination of condition. Moreover the discipline requires a vigilant activity as it is the maintenance work performed on the ground that keep the aircraft flying on the air.

The aircraft maintenance system of an airline is complex structure with information flow involving various stakeholders ensuring aircraft airworthiness while adhering to several regulatory standards policies and procedures of the Federal Aviation Administration (FAA).

An aircraft system basically includes the Airframe, Avionics and Engine. The maintenance activities are performed based on the documents prepared by Maintenance Engineering Technical Services (METS) of the Boeing Commercial Airplane Group in accordance with Air Transport Association of America. It contains the data necessary to service, troubleshoot, check, and repair systems and equipment installed in the airplane for maintenance done on the line or in the maintenance hangar. The Maintenance Manual is divided into chapters and groups of chapters. The chapterization separates the manual into the primary functions and systems of the airplane. These chapters include the following aircraft systems: Air conditioning System, Autopilot System, Communication System, Electrical power System, Flight controls System, Engine fuel and control, Hydraulic and Pneumatic power, indicating and recording systems, Landing gear, Navigation, Power plant, Oil system and many others.

Like any other maintenance activity aircraft maintenance is also performed in scheduled and unscheduled program. The unscheduled maintenance provides mostly new problems that cannot be maintained within specified period of time.

Discrepancies and remarks observed during the normal operation of an aircraft triggers for unscheduled maintenance activities. Solving these problems with specified period of time requires ample experience and knowledge of the particularly affected system. Proper and efficient fault isolation techniques need to be developed to come up with the time sensitive maintenance activities of the airline industry.

1.2 Knowledge Based System

Complex machinery has diverse technology standards, thus one expert is unlikely to possess all existing system knowledge. A knowledge based system, developed to capture system knowledge, expertise and experience, will produce more accurate and consistent results than its human counterpart. This is because all the solutions provided by the knowledge based system is based only on the fundamental facts obtained from the exposure of the expertise from experience and recommended manuals. The system makes expertise available to many users, offering expert knowledge to guide and direct less skilled maintenance staff. Organizations can benefit from a knowledge based system in that instead of depending on the presence of individuals to carry out different tasks, a system that can retain the knowledge of the organizational activities provides a permanent solution in maintaining a standard output. Knowledge based system can exclude those problems associated with a human element which includes negligence, family related problems, incompetence, experience related problems and others.

Knowledge based system has been used in assisting and partially replacing the human counterparts in different fields like, patient illness diagnosis, car problem troubleshooting, computer hardware and software problems troubleshooting, selecting employees for promotion and training and other related areas of specialization. There are also many applications of the knowledge based system in the airline industry which are focusing on customer satisfaction and trends, fault isolation of aircraft components and engine, reduction of errors in aircraft maintenance and others.

Knowledge based systems have major potential benefits such as: Increased output and productivity as expert system can work much faster than humans; reduced downtimes which can be achieved using expert systems in diagnosing malfunctions, and predicting repairs; performing the same tasks with lower cost instrument because of their ability to investigate more thoroughly and quickly the information provided by the instruments.

Moreover expert systems are reliable in that they don't become tired bored and they consistently pay attention to all details and so do not overlook relevant information and potential solutions. Apart from the above advantages, there are also challenges that hinder the efficiency of knowledge based system. Some of them are listed below.

- Knowledge is not always readily available
- Each expert's approach may be different, yet correct
- Knowledge engineers are rare and expensive
- The vocabulary of experts is often limited and highly technical

1.3 Statement of the Problem and Justification of the Study

The Ethiopian airline has long been known for its remarkable reputation of providing safe, reliable and profitable air transport service all over the world. The safety of the aircrafts operated by Ethiopian is dependent on the standard of maintenance activities.

The airplane manufacturers like Boeing; operators like Ethiopian Airlines are obliged for the compliance of the requirements of the Federal Aviation Regulation (FAR). The maintenance activities in aviation industry are all based on the recommended maintenance practices of the Portable Maintenance Aid (PMA) that includes the Aircraft Maintenance Manual (AMM) and Fault Isolation Manuals (FIM). The fault diagnoses and maintenance of modern commercial aircrafts have the following three main features (Haiqiao et al., 2004):

a. *The requirements of airworthiness should be met:*

The operation and maintenance of commercial aircraft are under control of the laws and regulations of international association and nation. The purpose of enacting above laws and regulations is to ensure airworthiness of commercial aircraft. Airworthiness is "fit to fly", as it is explained in Oxford English Dictionary (2001). When diagnosing the failures of commercial aircraft, airworthiness is embodied on aircraft maintenance manuals (AMM), trouble shooting manual (TSM), illustrated parts catalog (IPC), etc.

b. *The relation between symptom and source of failure is indefinite:*

In terms of the concept of fault diagnosis, aircraft is a complicated system. Its structure is a multiple hierarchical architecture, which is comprised of many subsystems, for example, aircraft structure, engine, auto flight system, landing gear, communications system, hydraulic power and navigation system. Each subsystem is formed by subsystems or subunits of lower level. And the subsystems or subunits are usually interactive with each other. Connections among levels of aircraft structure usually are difficult to define due to the multiplicity and heterogeneity of the structures and functions of aircraft. The quantitative relationships between the input and output of subsystem or unit usually are unavailable or inexact.

c. *Multidisciplinary knowledge is required to diagnose the fault of aircraft:*

Advanced technology of much techno sphere has been applied to modern aircraft synthetically, such as machinery, electrics, computer, automatic control and electronics. More and more electromechanical equipments have been used in aircraft.

The mechanical and electric components of these equipments have been integrated in the manner not only of control but also of functions and of structures. Multidisciplinary knowledge is required to diagnose the fault of aircraft. Ethiopian is committed to the provision of quality service to its customers. In order to ensure this, the airline strives to maintain a highly trained, motivated and dedicated workforce and enhance its internal capacity in various fields through the use of modern and environmentally friendly technology in all areas.

Ethiopian endeavors to play an important role in the well being of the society and equip its employees with a high level of skill through transfer of technology. However, due to various reasons the airline is losing skilled manpower in the key areas of the organization. In the earlier times when the airline was young, employees work for the airline till their retirement with great motivation and commitment. Nowadays with the advent of the Internet and the overwhelming demand of the market, skilled and experienced employees are being offered a lucrative deal with rival airlines and maintenance bases like Emirates, Qatar Airways, Sudan Airways, Gulf Aircraft Maintenance Company and others.

According to the Annual Human Resource Analysis Report (2009) in table 1.1 prepared by the HRM of the company, the five years average turnover rate of the airline is 4.8%.

Fiscal Year	**Average No. of Employees**	**No. of Terminated Employees**	**Turnover %**
2003/04	4487	206	4.6
2004/05	4614	199	4.3
2005/06	4700	192	4.1
2006/07	4837	240	5.0
2007/08	4896	295	6.0
Average/Total	**4707**	**226**	**4.8**

Table 1.1 Employee Turnovers from 2003/04 to 2007/08

As the data is depicted in table 1.1 that 4.8% turnover rate might not be considered as high, there is a justifiable reason for concern as most leaving the airline are key professionals. Such as: Aircraft Technicians, Marketing agents, Cockpit and Cabin Crews. The Annual Human Resource analysis report (2009) further presented the reason for employees' turnover, which is summarized in table 1.2.

Reason for Turnover	2003/04	2004/05	2005/06	2006/07	2007/08	Total	% Out of the Total
Resignation (Both with & without notice)	152	137	143	132	206	**770**	**68%**
Retired	19	16	12	29	33	**109**	**10%**
Death	13	10	10	8	8	**49**	**4%**
Discharged	17	33	23	68	38	**179**	**16%**
Furlough	5	3	4	3	10	**25**	**2%**
Total	**206**	**199**	**192**	**240**	**295**	**1132**	100%

Table 1.2 Employees reason for turnover from 2003/04 to 2007/08

As shown in Table 1.2, there are different reasons for employees' turnover though 68% of the share due to resignation with or without notices. This indicates that the airline has lost employees at the critical time of exploiting their experience and potential. The Airline has invested highly on their training and thus are difficult to easily replace from the market. Table 1.3 shows comparison of employees that are trained by the Ethiopian Training Center from 2002/3 – 2006/7 and resigned employees from the company.

Profession	Total number of trained employees	Resigned Employees After Training	% out of the total
Aircraft Technician	396	106	26.77%
Agent	415	110	26.51%
Cabin Crew	505	75	14.85%
Pilot	106	26	24.53%
Total	**1422**	**317**	**22.29%**

Table:1.3 Trained Vs Resigned Employees from Ethiopian Airlines in years 2002/3 to 2006/7

Table 1.3 shows that within the aforementioned five years 317 employees trained by Ethiopian Training Center were left the company. This represents 22.29% of the resigned employees that include trained Aircraft Technicians, Pilots and Marketing Agents. These trained employees are not readily available from the market. Aircraft technicians' turnover rate is 26.77% for the indicated 2002/03 to 2006/07 in table 1.3, which needs a serious attention in terms of aircraft maintenance. The airline has a good reputation as long as safety and reliability are concerned. Losing these potentially important human resources could wipe out the reputation of the airline in the blink of an eye. It is the maintenance activity done in the ground that keeps the airplane fly in the air. Safety and reliability are key for any success in the airline industry.

These key factors can be achieved by effective and efficient maintenance activities. The various nature of failure in aircraft system demands quick fault isolation and timely diagnosis with judgment achieved from experience.

The aircrafts operated by Ethiopian do not have sufficient ground time under normal operation. When a technical problem exists, it should be fixed as quickly as possible. Otherwise the delay of the aircraft will mess up different sectors of the company.

Effects of lack of experienced technicians in maintenance activities results in tangible delay costs. The extra costs incurred include the following:

- Passenger costs-food, accommodation, transport, payoffs
- Airport fees
- Rescheduling costs
- Labor Charges

The Ethiopian Airlines has a Service Recovery Program to compensate for passengers in a delayed flight from its schedule. The service recovery program for flight delays, cancellations or disruptions caused by different reasons including technical failures within the control of the airline provides compensation for the passengers. The compensation includes lunch/dinner and beverages, Hotel accommodation, compensation fees that ranges from 100Br. for domestic flight to 300US dollar in international flights for each passenger with respect to the delay period from its schedule.

Apart from the delay costs mentioned, unnecessary costs usually happen due to wrong diagnosis of an aircraft fault by inexperienced technicians. As a result of which the airline incurs unexpected costs to foreign repair that penalizes the airline if in-house capability is not developed. Man-hour costs to check the serviceability of a normal unit if it is found serviceable.

When a problem occurs and the cause of the problem is not really identified a solution proposed by a technician without exposure of such problem may replace a serviceable component of the aircraft system. If there is no capability developed to check the unit, it will be sent to foreign repair. This results different costs as the aircraft may wait until the unit is returned where the problem is not in the unit and the man-hour and transport cost for the unit returned as No Fault Found (NFF).

As in all environments of maintenance and support, time is money. Therefore efficient fault diagnosis associated with aircraft maintenance can support airline operations. Other important criteria are servicing turnaround time, system and equipment reliability and maintenance down time. The increasing complexity of systems places demands on system maintenance to contain and reduce maintenance down times.

Every system and associated component has a function to perform. The primary objective of maintenance is to keep the system serviceable, and thus available to perform that function. When the system fails the maintenance technician has to diagnose the fault and rectify the failure as quickly as possible to return it to a serviceable condition. Although the problems mentioned above were very serious, to the best of my knowledge no research work has been done in the Airline to solve such kinds of problems.

There is one attempt made by HaileLeol (2004) which focuses on classifying the performance of gas turbine engines by evaluating its basic parameters with the help of neural network approach. However there are different research works worldwide which are done based on their own problems. An expert system illustrated by the development process of an Airbus A340 fault diagnostic expert system (Haiqia et al., 2004) using case based reasoning and fuzzy logic is one of the works done in this area. A fuzzy-logic based automated engine health monitoring for commercial aircraft (Seref et al., 2008) is also another research work which uses engine performance parameters gathered from aircraft for every cruise flight as an input for the fuzzy logic. The system produces output values between 0-faulty and 1-not faulty for every fault or deterioration on a time series.

An Advanced Diagnostic Software which was originally developed to assist U.S Air Force technicians in performing organizational level maintenance on B-1B AN/Alq-161A Defensive Avionics System (DAS) which uses an expert heuristic knowledge, maintenance tools and online documentation to support specifically the less skilled technicians.

Most of the researches were specifically designed to tackle their working environment problems with respect to learning efficient fault isolation technique. Nevertheless these solutions may not fit to the actual problems of the airline that suffers in brain drain. As it has been discussed earlier the tacit knowledge which is needed by many airlines across Africa and in the Middle East can be captured by using knowledge based systems.

As a matter of fact, documents provided by Boeing (aircrafts manufacturing company) for aircraft maintenance organizations like the aircraft maintenance manuals and fault isolation manuals are the primary tools to be consulted during any maintenance activity.

However, records from efficient maintenance practices applied by experienced technicians that are done based on the aircraft maintenance manuals and the existing problems were the source of inspiration for this research. The test procedures, maintenance and fault isolation manuals contain recommended steps for detecting and rectifying defects nevertheless their use alone does not guarantee success in timely diagnosis and repair. This research is intended to be used as knowledge based system that can facilitate the "collection of the maintenance knowledge" and by coupling it with the "connectivity knowledge" to make knowledge management system a viable entity.

1.4 Objectives of the Study

1.4.1 General Objective

The main objective of this study is to design an applicable knowledge based system that can facilitate fault isolation and diagnosis for aircraft maintenance in Ethiopian Airlines.

1.4.2 Specific Objectives

To achieve the general objective, the following are the specific objectives of the study.

- To review literatures and documents for identifying challenges and opportunities associated with fault isolation and detection of aircraft systems.
- To analyze documents and interview experts in order to acquire the domain knowledge, procedures, and variables used in aircraft maintenance.
- To represent and model domain knowledge using suitable knowledge representation technique.

- To develop prototype knowledge based system that demonstrates a fault isolation and detection for aircraft system maintenance.
- To test the reliability and performance of the new system with the help of experts;
- To recommend suggestions for further work;

1.5 Methods of the Study

The literature review, data collection methods and implementation tools are included in the methodology to fulfill the overall objective of the study. In the methods section how the data is collected and analyzed is discussed. The implementation tools available to acquire knowledge from experts are understood, collected and represented in this section.

1.5.1 Literature Review

To understand the exact contribution of the work, literature review is necessary. Thus previous works in the same area are assessed for their inputs, design method and other unique features. Some research has been done regarding the previous and current technology of knowledge based system employed for aircraft maintenance especially in fault isolation. The research has reviewed the literature of underlying concepts behind the development of several applications of knowledge based systems.

1.5.2 Data Collection Methods

The data collection method for this study is performed mainly using direct and participant observation along with the review of efficient maintenance practices. Participant observation is used in the data collection technique to exploit the opportunity of the researcher as knowledge engineer and domain expert. Such observations cover events in real time, and with their contextual meaning. Efficient maintenance practices will be collected from the aircraft maintenance resume book which contains the records of each maintenance activity for every flight schedule. Samples of outstanding maintenance activities will be collected from the resume book using purposive sampling.

In the development of this knowledge based system for fault isolation in aircraft maintenance, most of the information and knowledge are acquired by performing structured interview with skilled technicians and reviewing records of efficient maintenance practices.

Moreover documents available in the Portable Maintenance Aid which includes Aircraft Maintenance Manual, Fault Isolation Manual and Illustrated Parts Catalog are used as the reference materials if the maintenance practices are compliant with these documents.

The design of data collection process begins with the collection of outstanding and efficient maintenance practice from the daily recorded maintenance resume book. Manuals and related documents are consulted for preparing a structured interview with the experts in the different specialties of aircraft maintenance by approaching from general concept to particular and detail topics of the domain. Once the efficient maintenance practice and structured interview questions are prepared, the next step of identifying skilled experts in Avionics and Airframe fields is performed. The experts are selected because of their experience and knowledge. The final step of data collection is performed by making structured interview with experts frequently.

1.5.3 Knowledge Based System Design and Implementation Tools

The knowledge acquired through the skilled technicians and maintenance records are represented in such a way that it can be understood by the computer through coding. This knowledge is later used for decision making by the knowledge based system. Among the various formal methods that are used for knowledge representation, rule-based backward chaining method is adopted as it is suitable for diagnostic problems.

A rule based approach supports for the use, in a very direct fashion, experiential knowledge acquired from human experts particularly for domain problems that rely heavily on heuristics to manage complexity or missing information.

As a primary contribution for the problems the airline is facing in improving the skill of inexperienced technicians a rule based system is helpful in keeping the discipline of aviation maintenance by performing maintenance activities based on recommended practices. The system uses production systems approach of a rule based knowledge representation. The learning algorithm provides a hypothesis that does a job of predicting the classification of unseen maintenance activities based on the training set. The quality of the hypothesis is assessed by checking it with the test set of fairly chosen maintenance records done by skilled technicians. After all of the elements are designed, the development phase has started for both programming and the construction of the user interfaces.

Prolog programming language is used to program the system and constructing the interface. It is selected based on availability, suitability of the backward chaining inference, for reasoning using domain knowledge, easy to learn design tools, error handler and debugging tools. According to the SWI prolog documents, the full development environment of SWI prolog including graphics, libraries and many interface packages requires approx. 40MB hard disk. The non-graphical kernel is about 650Kb, the graphics library adds about 1.2Mb to the image. XPCE is the platform independent GUI toolkit for SWI-Prolog.

The SWI prolog has a flexible and fast interface to the **C-** and **C++**-Language. The interface allows for calling both-ways, handling of non-determinism both ways and embedding of the SWI-Prolog kernel in C/C++ projects. SWI prolog supports execution profiler (time and call statistics) for Linux, most Unix platforms and Windows NT/2000/XP/Vista.

SWI prolog is Portable to many platforms, including almost all Unix/Linux platforms, Windows (NT/2000/XP/Vista, including 64-bit editions), MacOS X (using X11 for graphics) and many more. Both 32-bits and 64-bits hardware is supported. Sources are plain C99, configured automatically using GNU autoconf (configure, make, make install).

The prototype is capable of solving problems related with the aircraft systems in general and the passenger service/entertainment systems in particular as long as the knowledge acquisition and inference rules are represented properly. The result of the knowledge practices. The system uses production systems approach of a rule based knowledge representation. The learning algorithm provides a hypothesis that does a job of predicting the classification of unseen maintenance activities based on the training set. The quality of the hypothesis is assessed by checking it with the test set of fairly chosen maintenance records done by skilled technicians. After all of the elements are designed, the development phase has started for both programming and the construction of the user interfaces.

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The prototype is capable of solving problems related with the aircraft systems in general and the passenger service/entertainment systems in particular as long as the knowledge acquisition and inference rules are represented properly. The result of the knowledge based system can also be used by aircraft maintenance foremen and managers for internalizing the working principle of specific aircraft systems.

Designing phase is considered as the phase of prototype development. A prototype which represents the initial part of the full knowledge based system is developed. The prototype is built in step wise for the purpose of getting a deeper insight and better understanding of the problem and system's requirements. In fact, system's design is inherently an iterative process where findings from system testing are used to refine the system's knowledge and structure.

1.5.4 Testing Mechanism

The knowledge based system has to be tested for effectiveness and efficiency so as to evaluate its performance by comparing it with experienced technicians' problem solving approach. A maintenance record of major failures and their solutions is compared with the newly developed system.

Outstanding aircraft system failures that include cabin passenger service and entertainment system, are collected and prepared as questions to the experts (see table 4.1 for details). The solutions provided by experienced technicians are compared with the knowledge based system solutions. Solutions without significant differences between the experts and the knowledge based system are accepted as good performance for the knowledge based system.

1.6 Scope and Limitation of the Study

In this research a prototype of fault isolation using knowledge based system in Communication System of a Boeing 767-300 aircraft is designed after analyzing the data collected from the observations and efficient maintenance records particularly in total entertainment/service system, airshow and passenger address systems. Three of the Ethiopian Airlines aircrafts which are usually used for US and Europe flights with computer based entertainment system are selected for this research work.

An aircraft system basically includes the Airframe, Avionics and Engine. The maintenance activities are performed based on the documents prepared by Maintenance Engineering Technical Services (METS) of the Boeing Commercial Airplane Group in accordance with Air Transport Association of America. It contains the data necessary to service, troubleshoot, check, and repair systems and equipment installed in the airplane for maintenance done on the line or in the maintenance hangar.

The Maintenance Manual is divided into chapters and groups of chapters. The chapterization separates the manual into the primary functions and systems of the airplane. These chapters include the following aircraft systems: Air conditioning System, Autopilot System, Communication System, Electrical power System, Flight controls System, Engine fuel and control, Hydraulic and Pneumatic power, indicating and recording systems, Landing gear, Navigation, Power plant, Oil system and many others. The knowledge based system development of the research work encompasses the knowledge acquisition phase which includes observation, interview and document analysis and the domain knowledge modeling using decision tree along with rule based knowledge representation technique. The aircraft built in test equipment (BITE) information is not used in this study due to the time constraint. The other limitation of this research work is that some of the maintenance resume book records are lost as aircraft discrepancies, defects and their corrective actions are recorded in Excel files.

1.7 Application of the Results and Beneficiaries

The knowledge base system developed is applicable to guide and direct less skilled maintenance staff. The system is used in the aircraft hangar or in line maintenance where the airplanes are dispatched. However the prime beneficiaries of this system are the maintenance personnel's in the newly established Fault Management Team (FMT) and the Maintenance & Operation Control Center (MOCC) where the maintenance activities are coordinated in the home maintenance center and in other stations outside the country. It also helps to isolate and diagnose aircraft system and component failures within short ground time of the aircraft using the knowledge based system which alleviates the cumbersome nature of maintenance publications, together with their inefficiency and lack of effectiveness as diagnostic aids leads to unstructured and illogical fault diagnosis.

Moreover it reduces frequent equipment removals which results in No Fault Found situations, adding unacceptable expenditure to the cost of maintenance. It can also be used as a major tool for giving technicians a thorough understanding of a certain system, its components, input outputs and the other system it will affects.

1.8 Organization of the Thesis

The study is organized into six chapters. Chapter one is the introductory part, which contains the background, problem statement and their justifications, objectives, methodology, scope and limitations to carry out the research. Review of literatures on the knowledge based systems, about its background, architecture, and knowledge based system development and its applications in the area of aircraft maintenance in general and fault isolation and diagnosis in particular is presented in chapter two.

Chapter three deals with the fundamentals of aircraft maintenance in general and a detail discussion on fault identification, isolation and diagnosis of aircraft maintenance in particular. This chapter also includes fault isolation and diagnosis practices of aircraft maintenance in Ethiopian Airlines.

Chapter four is concerned about the methods that are used for knowledge acquisition, knowledge representation and modeling processes in the present study.

Chapter five presents the development of the prototype knowledge based system under study. It also shows the performance of the knowledge based system for fault isolation and diagnosis and report's findings of the study.

Finally chapter six highlights the conclusion and recommendations made for further research work in the future.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Artificial intelligence (AI) is directed towards building a machine and improving our understanding of intelligence. One of the most successful applications of artificial intelligence reasoning techniques using facts and rules has been in building expert systems that embody knowledge about a specialized field of human endeavor, such as medicine, engineering, or business. Artificial intelligence programs that achieve expert-level competence in solving problems by bringing to bear a body of knowledge are called knowledge-based systems or expert systems (Zili and Chengqi, 2003). Often, the term expert systems is reserved for programs whose knowledge base contains the knowledge used by human experts, in contrast to knowledge gathered from textbooks or non-experts. Some successes have been achieved in mimicking specific areas of human mental activity. For instance, machines are now able to play chess at the highest level, to interpret spoken sentences and to diagnose medical and technical complaints. In achieving these modest successes, research into artificial intelligence (together with other branches of computer science) has resulted in the development of several useful computing tools.

Area of Application	Problems Addressed
Interpretation	Forming high level conclusions or descriptions from collections of raw data.
Prediction	Projecting probable consequences of a given situation.
Diagnosis	Determining the cause of malfunctions in complex situations based on observable symptoms.
Design	Configuring objects under constraints
Planning	Devising a sequence of actions that achieves a set of goals given certain starting conditions.
Monitoring	Comparing the observed behavior of a system to its expected behavior.
Debugging	Prescribing remedies to malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosis, debugging and correcting student performance
Control	Governing the behavior of a complex environment.

Table 2.1. Areas of application and their relevant problems are addressed

The knowledge based systems have different areas of application depending on the problems which needs to be addressed as shown in table 2.1.

2.2 Knowledge Based System Architecture

The knowledge based system structure is composed of the following main components as illustrated in the figure 2.1 (Nilsson, 1998).

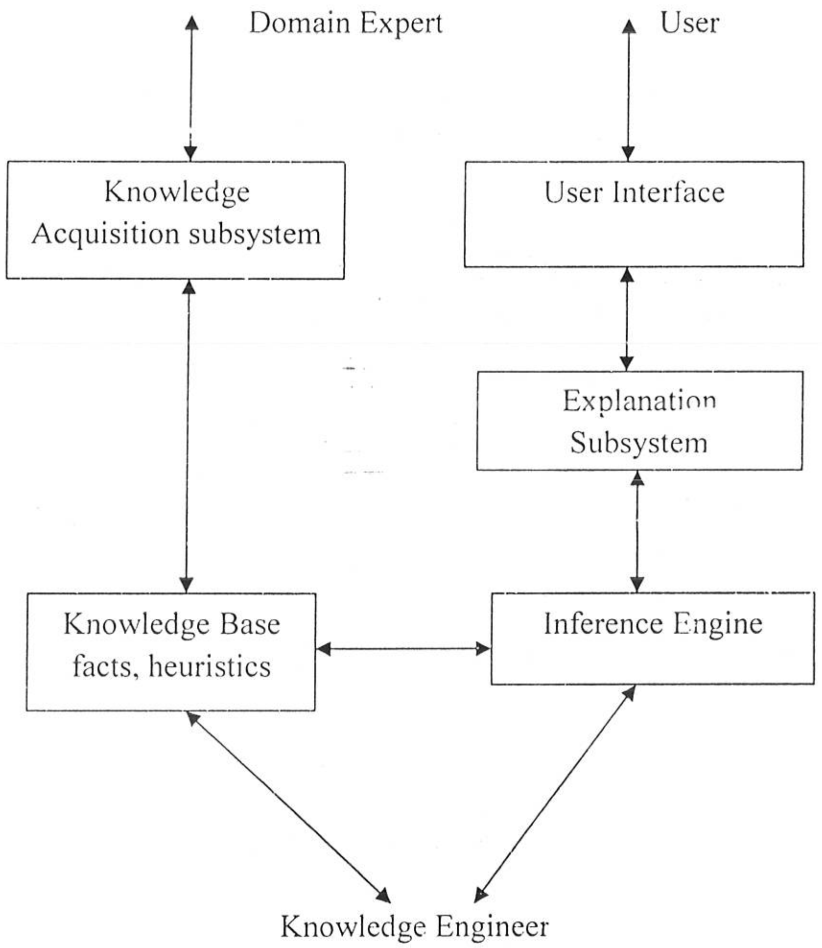


Figure 2.1 Basic Structure of Knowledge Based System

User Interface: A user can interact with the knowledge based system via user interface. User can enter commands, respond to questions, etc. Advanced interfaces make heavy use of pop-menus, natural language, GUI or any other style of interaction.

Inference Engine: It is also known as ***rule interpreter*** and is the problem-solving component. It allows new inferences to be made from the case specific data and the knowledge in the KB. These new facts represent conclusions about the state of the domain given the observations.

The inference engine implements the recognized act cycle of the production system; this control may be either data-driven or goal-driven. Inference engines are of two kinds: categorical and non-categorical (Luger and Stubblefield, 1998). A non-categorical inference engine calculates confidence level for each conclusion it reaches, where as categorical engine does not. For rule-based expert systems, the inference engine performs inference mechanism by carrying out:

- ***forward chaining*** (also known by names: *event driven*, data driven, bottom-up, condition driven), or
- ***backward chaining*** (also known as *goal-driven, top-down approach*)

Knowledge Base facts, heuristics: The knowledge base holds the expertise that the system can deploy and is constructed by the knowledge engineer in consultation with the domain expert. For many knowledge based systems, knowledge representation is through the use of production rules, frames and semantic nets.

Explanation Subsystem: - analyzes the structure of the reasoning performed by the system and explains it to the user.

Domain expert - the individual or individuals who currently are experts in solving problems of the domain area.

Knowledge engineer - the individual who encodes the expert's tacit knowledge along with related documents in a declarative form that can be used by the knowledge based system;

User - the individual who consults with the system to get advice which would have been provided by the expert.

The explicit separation of knowledge from control makes it easier to add new knowledge either during program development or in the light of experience during the program's lifetime. There is an analogy with the brain, whose control processes (the inference engine) are approximately unchanging in their nature, even though individual behavior is continually modified by new knowledge and experience (updating the knowledge base).

The knowledge is represented explicitly in the knowledge base, not implicitly within the structure of a program.

Thus the knowledge can be altered with relative ease. The inference engine uses the knowledge base to tackle a particular task in an analogous fashion to a conventional program using a data file.

The principal difference between a knowledge-based system and a conventional program lies in its structure (Adrian, 1992). In the conventional program, data is intimately intertwined with software for controlling the application of a given facts as described in table 2.2 (Susanne and Abraham, 1993).

Knowledge based Systems	**Conventional Software**
Represent and Manipulate knowledge	Represent and manipulate data
Symbolic information	Numeric information
Heuristic solution	Algorithmic solution
Requirements are vague	Requirements are well defined
Approximate answers	Exact answers
Control and data separate	Control and data intermingled

Table 2.2 Comparisons of Expert Systems and Conventional Software

2.3 Knowledge Representation

Knowledge representation can best be understood in terms of five distinct roles it plays and expressed each as crucial to the task at hand (Randall et al., 1993).

- A knowledge representation (KR) is most fundamentally a surrogate, a substitute for the thing itself, used to enable an entity to determine consequences by thinking rather than acting, i.e., by reasoning about the world rather than taking action in it.

- It is a set of ontological commitments. i.e., an answer to the question: In what terms should I think about the world?
- It is a fragmentary theory of intelligent reasoning, expressed in terms of three components:
  - (i) the representation's fundamental conception of intelligent reasoning;
  - (ii) the set of inferences the representation sanctions,
  - (iii) the set of inferences it recommends.
- It is a medium for pragmatically efficient computation, i.e., the computational environment in which thinking is accomplished. One contribution to this pragmatic efficiency is supplied by the guidance a representation provides for organizing information so as to facilitate making the recommended inferences.
- It is a medium of human expression, i.e., a language in which we say things about the world.

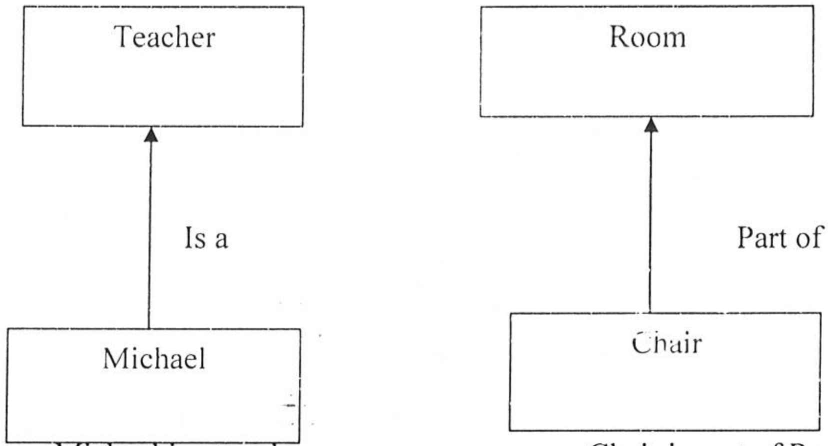
2.4 Knowledge Representation Methods

In building a knowledge base, several methods of knowledge representation can be used. However the most widely used knowledge representation techniques includes semantic networks, frames and rules.

2.4.1 Semantic Networks

Semantic networks are directed graph for describing semantic relationships between knowledge items in a knowledge base. The most common relationships (suitable for object-oriented case) is shown in figure 2.2.

- "is a": *object 'A'* is an instance of *object 'B'* when object 'A' "is_a" object 'B' holds.
- "part of": *object 'A'* is a part of or an attribute of *object 'B'* when object 'A' "part_of" object 'B' holds.



Michael is a teacher

Is_a(Michael, Teacher)

Chair is part of Room

Part_of(Chair, Room)

Figure 2.2 Example for semantic network

Semantic networks involve nodes and links between nodes. The nodes represent objects or concepts and the links represent relations between nodes. The links are directed and labeled; thus, a semantic network is a directed graph. In print, the nodes are usually represented by circles or boxes and the links are drawn as arrows between the boxes. The structure of the network defines its meaning. The meanings are merely which node has a pointer to which other node. The network defines a set of binary relations on a set of nodes.

2.4.2 Frames

A frame is a collection of slots (attributes) that characterizes an object. Each slot may be filled with a value, a default, another frame, or procedures. Embedding procedure within a frame is called procedural attachment.

Coffee mug Frame	
IS_A	Mug
CAN_HOLD_LIQUID	True
NUMBER_OF_HANDLES	Default =1
SIZE	Range: Small, Medium, Large
PURPOSE	Value: drinking coffee
COST	Demon ($ needed)
MATERIAL	Default = pottery

Table 2.3. An example of Frame on coffee Mug Object

If stored with a slot, procedures that are triggered whenever the slot is changed are known as *demons*. A slot in a frame is equivalent to a link in semantic net. A frame allows both data and procedures to be included within one structure.

A slot includes details of each data object, provide links to other frames, contain procedural code, linking to other applications to obtain data or write data, and indicate whether or not certain properties of each object are needed within that frame.

2.4.3 Rules

Rules are the most applicable and relatively easier way of knowledge representation in the development of a knowledge based system. A rule based system consists of a set of IF-THEN rules, a set of facts and an interpreter controlling the application of the rules, given the facts.

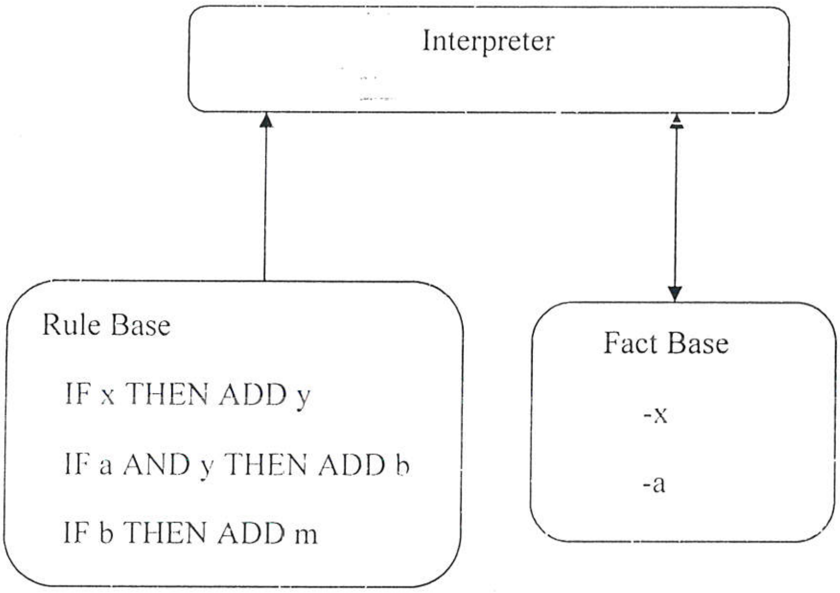


Figure 2.3 Rule based system architecture

The interpreter could be either a forward chaining or backward chaining system.

2.4.3.1 Forward Chaining Inference

Forward chaining inference is practical when combinatorial explosion creates a seemingly infinite number of possible right answers, such as possible configuration of a machine. For many problems it is not possible to enumerate all of the possible answers before hand and have the system select the correct one. For example, configuration problems fall in this category.

These systems might put components in a computer, design circuit boards, or lay out office space. Since the inputs vary and can be combined in an almost infinite number of ways, the goal driven approach will not work. The data driven approach, or forward chaining, uses rules similar to those used for backward chaining, however, the inference process is different. The system keeps track of the current state of problem solution and looks for rules which will move that state closer to a final solution (Amzi, 2000). In the following example the set of rules based on given data "A" and "B" yields a conclusion "E"

If A and B then C (Rule 1)

If C then D (Rule 2)

If D then E (Rule 3)

When more than one rule can be invoked, the strategy of selecting one rule to execute its actions is known as conflict resolution (Amzi, 2000). The guidelines are: select the rule with highest priority, or with most specific rule, or most recently used rule, or rule which matches the database element with the highest order. According to Amzi, the difficulty of a data driven inference comes when the rule base is very large and the whole process is not directed toward goal.

2.4.3.2 Backward Chaining Inference

Backward chaining inference is practical when there are a reasonable number of possible final answers, as in the case of a diagnostic or identification system (Amzi, 2000). That is, the aim of the system is to pick the best choice from many enumerated possibilities. For example, an identification problem falls in this category. Diagnostic systems also fit this model, since the aim of the system is to pick the correct diagnosis.
The system matches rule conclusions with the goal, selecting one rule and placing its premises in the working memory. The process continues in the next iteration of the production systems, with these premises becoming the new goals to match against rule conclusions. The following small knowledge based system depicts diagnosing automotive problems using goal driven inference engines.

Rule 1

If The engine is getting gas, and

The engine will turn over

Then The problem is spark plugs

Backward chaining or goal driven inferences have an advantage of directed search despite the requirement of a known goal (Luger and Stubblefield, 1998). The system methodically tries to prove or disprove each possible answer, gathering the needed information as it goes.

2.5 Knowledge Based System Development

Knowledge based system technology has no widely recognized and accepted methodology by which the development of knowledge based systems is achieved. The most commonly used method of development is an iterative refinement or prototyping (Susanne and Abraham, 1993). This method consists of obtaining a set of example test cases, determining from the domain expert how he/she would solve each of these test cases, and encoding this expertise into a knowledge base. This process is repeated until a knowledge based expert system evolves which satisfies the research being conducted or which meets the customer's needs. When the iteration stops, the knowledge based system is validated on a small set of test cases. These test cases are often the same ones upon which the knowledge base is built or scenarios encountered in the operational environment.

The verification and validation testing and the analysis of the results from the testing are performed in an informal, arbitrary manner. This testing and analysis entails the knowledge engineer or customer manually executing test cases and checking the results against the expected results. While this empirical approach was satisfactory for the development of knowledge based systems within the research laboratory environment, more systematic, structured approaches to development are needed to produce quality expert systems for commercial applications (Susanne and Abraham, 1993).

2.6 Challenges of Fault Isolation Techniques in Aircraft Maintenance

It is unavoidable for aircraft to malfunction in routine use, because of operation mistakes, faults in material, manufactured errors, fatigue, abrasion and degradation. A disaster might be caused by faults of aircraft, so fault diagnosis is a very important guarantee of its flight safety. A process of fault diagnosis for an aircraft system is to establish the possibility that each of the components may lead to a malfunction. Aircraft is a complicated system in terms of the concept of fault diagnosis. Its structure is a multiple layer architecture, which is comprised of many subsystems. Each subsystem is formed by subsystems or subunits of lower level.

The subsystems or subunits are usually interactive with each other. Connections between levels of aircraft structure usually are difficult to specify due to the multiplicity and heterogeneity of the structure and function of aircraft units. The mechanical and electric components of these equipments have been integrated in aspects not only of control but also of function and structure. Components of a certain aircraft flight control system for instance involves mechanical movements of an actuator, a display unit which informs the status of flight control movements such as indication and crew alerting message display unit and its computer, solenoid valves, hydraulic/electrical motor driven pumps, sensors, flight control cables, and others. Specific knowledge of only mechanical or electrical technology is not enough to visualize the system at higher order functionality. A multidisciplinary knowledge is required to understand and diagnose the fault of an aircraft system. The increasing complexity of systems and technology leads to the difficulty of developing an applicable model to fault diagnosis. The approaches based on statistical methods are more applicable to fault diagnosis for aircraft units, because of the relative easiness for building statistical model.

The design of integrated systems has been carried out in isolation to the development of maintenance procedures. More recently system design and development accepted the need to consider future in-service maintenance. Specification of rectification activities resulted from work in identifying potential failures which led to equipment malfunction. Robert (1999) has stated the following deficiencies in this approach:

- Corrective actions/procedures stemmed only from identification of system malfunctions.
- Difficulties in recording the experience and expertise of system specialists.
- Difficulties in retaining and exploiting expert knowledge.

- Cumbersome and inefficient diagnostic aids leaving maintenance personnel to either remember test procedures or otherwise transport system documentation to the fault diagnosis and rectification site.

Pressures of modern business demand rapid diagnosis and rectification of a system which experiences a malfunction. However, diagnosing and isolating faults in a complex system requires detailed analysis of systems characteristics which takes time. Associated lack of expertise, low skill levels, poor system knowledge, ineffective failure definition together with poor maintenance and diagnostic support tools demand a better way of handling malfunctions that aid timely fault diagnosis and provide a capability of predicting diagnosis times.

Ineffective fault diagnosis can be attributed to a number of factors. First, high reliability and integrated systems where infrequently occurring complex failures limit a technician's exposure to a problem which inhibits the learning curve.

Second, unavailability of test resources such as experienced technicians, meaningful manuals, effective fault diagnosis aids and efficient BIT (Built-in Test) and external test equipment. Third, poor understanding of system configuration can also lead to an ineffective fault diagnosis.

Time covering access, defect rectification (adjustment, repair or replace), test and close up can be predicted, either from in-service experience or from predictive techniques using time standards such as method time measurement (MTM). However, little, if any, attention seems to have been given to producing time prediction techniques covering fault diagnosis and isolation.

There is no reason why the time needed to diagnose and isolate a fault cannot be predicted if a structured and disciplined expert approach is adopted.

Logical test procedures, developed by a system expert, can be broken down and subjected to timing analysis, either by timing test procedure activities against an actual system or by time standard analysis.

2.7 Knowledge of Experts and the Knowledge Based System Solutions

In isolating a fault in a complex system a domain expert develops a search strategy based on knowledge, experience and reasoning logic. Such a strategy will direct an immediate course of action based on success probability from past experience, moving to lesser probability areas if the fault is not immediately isolated. Resolution of unusual defects adds to the expert's knowledge and defect probability data set for future diagnosis work. If this approach is developed, a knowledge based fault isolation strategies can form part of the direction offered by such a tool and can be used to direct less skilled maintenance staff in effective and timely fault diagnosis. In addition, if the knowledge based system is used to time test procedure and fault isolation activities the fault diagnosis time prediction and probability data set can be fine tuned against in-service experience.

The human expert's electronic counterpart can expand its knowledge base of frequency and type of defects to allow amendment of future search strategies, coupled with predicted times against each defect probability. Traditionally maintenance technicians rely heavily, if not totally, on technical publications for all reference information covering configuration details, functionality descriptions, fault diagnosis procedures and test procedures. On isolating a fault reference is made to maintenance manuals for procedures on component adjustment or removal, having first consulted a zonal reference document to identify the location of the relevant component and related access panel. The illustrated parts catalogue is used to identify part numbers and formal component descriptions for use in ordering replacement spares and related expendables. The maintenance manuals and test procedures provide reference information for fitting and testing of a serviceable component. Their cumbersome nature and inefficiency in fault diagnosis restrict portability and often force maintenance technicians to try and remember test procedures and related maintenance activities, contributing to unstructured fault finding and excessive down time (Robert, 1999). Related equipment removals may well be classified as no fault found (NFF), adding unacceptable expenditure to the cost of maintenance.

Fault diagnosis also relies on the technician's experience, knowledge and reasoning skills to develop a fault isolation strategy, while extreme difficulty is experienced in forecasting the diagnosis time.

An expert is not always available. Moreover, feedback and update of procedures, manuals and all related publications rely on manual effort. A system is envisaged where all reference material is centrally and electronically stored, which directs fault diagnosis isolation, thus assisting technicians lacking system expertise, and which allows prediction and update of diagnosis times.

In short a rugged PC, offering access to all relevant data and information, replaces numerous publications and serves as an electronic toolkit for use by technicians at the work site. Robert (1999) sets a vision of such a fault diagnosis system as:

- Expert knowledge is collected and modeled in a central system to provide a knowledge-based fault diagnosis system.
- Reference functional, configuration, maintenance and test procedure data and information are contained electronically in the expert system in textual, graphical and diagrammatic formats.
- The knowledge-based fault diagnosis model and reference information is downloaded to a rugged PC.
- The PC is issued to the maintenance technician.
- The knowledge-based fault diagnosis system provides a strategy to direct the maintenance technician in isolating the fault, at the same time offering relevant reference information as required or as requested.
- The maintenance technician's diagnosis activities are timed by the PC to generate a data set of diagnosis prediction times.
- The PC system has the facility to incorporate new symptoms and related diagnostic procedures in temporary memory for subsequent human expert analysis and validation prior to updating of the central system.

- Fault diagnosis search strategies, coupled with forecast success probability, are modified in the system with in-service experience.

Manual fault diagnostic aids and low-level maintenance technician expertise are suited for simple systems. However, as system complexity increased greater levels of maintenance technician expertise are needed, together with the sophistication of test equipment, which started to exceed the technician's.

The situation brought about development of a number of techniques to assist the technician, including Built-In Test Equipment (BITE), Automatic Test Equipment (ATE) and electronic manuals (Esker *et al.*, 1990). BITE is incorporated in a design to continuously test system functionality while the system is operating. It is important to note that BITE was not originally intended to isolate faults, only to detect faults. It is also important to note that the skills demanded of a maintenance technician far exceed just fault detection. In addition to detecting faults, they involve testing, diagnosing and rectification which are knowledge-intensive and experience-based activities.

Knowledge applied has been acquired by study, investigation, observation and experience. Robert (1999) explains the techniques which will be gained from experts with years of experience as: a detailed understanding of system functionality; an intuitive behavior of system when certain sub system(s) fail; and an understanding of the relationships between symptoms, failed subsystem(s) and symptom interaction

According to the definition of cognition science (Robert, 1999) thinking is the processes that various how mental tasks of human are performed. Human thinking could be classified into intuitive thinking, logical thinking and creative thinking.
When diagnosed failures, a domain expert begins with a intuitive thinking that is the chief manner of human cognitive process, then applies a logical thinking if the fault diagnosis based on intuitive thinking fails, and may ask for help of creative thinking finally.
Robert (1999) has classified knowledge into shallow and deep from diagnostic point of view. Shallow knowledge includes basic system knowledge covering first order functionality and interconnectivity.

This is a snap shot understanding of a certain system where technicians with some basic training can easily visualize the functions of system components. It is the description and operation of system components in block diagrams where the detail of each component and their interconnectivity is not well defined. Moreover this knowledge is local to specific part of the overall system.

Deep knowledge, a combination of system knowledge covering higher order functionality and diagnostic expertise, is accumulated over time and with experience. It includes the details of components and their interconnectivity within the system and other systems. Deep knowledge is acquired through experience by facing the various natures of a system under normal operation and whenever a system fails due to different reasons.

Sometimes the actions taken to correct failures might resolve the current problem, but another problem could be introduced if there is no basic system knowledge combined with higher order functionality.

Research has shown that when confronted with a problem a system expert analyses problem in a disciplined and structured manner, rather than randomly trying possible alternatives in the hope of finding a solution (Grigouri and Willey, 1987). Hypotheses are established, based on symptoms, which are then tested and linked to potential corrective actions.

Other approaches are used when diagnosing a fault of aircraft unit. It is desirable to use a mixed quantitative/qualitative method that may combine the advantages of both types of approach and may help to solve problems (Haiqiao. et al., 2003). Either a purely quantitative or a strictly qualitative method may be difficult to solve on its own. A fault probability of components. of which an aircraft unit is comprised, is generated by a self-organizing feature map (SOM). The Self-Organizing feature Map (SOM), has established its position as a widely applied tool in data analysis. The notable advantage of the SOM is in exploratory data analysis, which differs from standard statistical data analysis in that there are no presumed sets of hypotheses that are validated in the analysis. Instead, the hypotheses are generated from the data in data-driven exploratory phase and validated in the confirmatory phase (Lampinen and Kostiainen, 2000). So the SOM can be used in the fault diagnosis for aircraft unit. It could preserve neighborhood relations in the input data, and reflect the probability distribution of input data by its output, after it has been trained.

The training process of the SOM requires a lot of samples. But the fault sample of a specific aircraft unit is small, and the above requirement cannot be matched. According to the analysis of historical data of aircraft fault, the faulty components of an airline fleet were classified into seven types, i.e. valve, control unit, sensor, computer, mechanical component, structure and circuit element (Haiqiao, et al., 2003). The qualitative possibilities that the components of a specific unit may cause a failure were estimated by a maintenance expert in natural language terms, e.g. "impossible", "improbable", "indeterminable", "possible" and "probable" (Haiqiao, et al., 2003). In artificial intelligence, popular methods, which handle the above qualitative possibilities expressed by language, include MYCIN-based certainty factors (CF), Bayesian probability, the Dempster Shafer method, and Zadeh's fuzzy logic (Haiqiao, et al., 2003).

It has been shown that Zadeh's fuzzy logic is the best way to resolve this kind of problem. The qualitative possibility expressed by natural language was defined as linguistic variables on fuzzy logic. Each of these terms, for example "improbable" and "impossible", is called a linguistic value of the variable, with values representing a fuzzy subset of the unit interval [0, 1].

2.8 Researches in the Area of Aircraft Maintenance in Ethiopian Airlines

There are many possibilities for exploiting potential researches of aircraft maintenance in Ethiopian Airlines like tracing the cause of frequently failing aircraft parts, predicting the advice time for troubleshooting an aircraft system failure, improving the efficiency of maintenance processes and so on. However there is one research done by Haileleol (2004) which focuses in classifying the performance of gas turbine engine by evaluating its basic parameters. The research uses neural network approach to classify the performance of gas turbine engine by analyzing the basic engine parameters of EGT (Exhaust Gas Temperature), N1 & N2 Turbine Speeds and EPR (Engine Pressure Ratio). Nevertheless, as to the best of my knowledge there is no research done for facilitating the fault isolation and diagnosis of aircraft maintenance in Ethiopian Airlines.

CHAPTER THREE

BUILDING A KNOWLEDGE BASE SYSTEM

A knowledge base system contains domain-specific knowledge which is required to solve a certain problem. It is created by a knowledge engineer, who conducts a series of interviews with experts and collects relevant documents for organizing the knowledge in a form that can be directly used by the system. A knowledge base for knowledge based systems is constructed through a process of iterative development. After initial design and prototype implementation, the system grows incrementally both in depth and breadth.

In this research, the following steps were used to come up with a knowledge based system for fault isolation and detection in aircraft maintenance. The acquisition of domain-specific knowledge begun by collecting efficient maintenance activities from the maintenance resume book. Structured interviews with the domain experts are performed based on these maintenance records and relevant maintenance documents. The next step formalized the knowledge model in such a way that suits the knowledge representation techniques such as semantic networks, production systems and frames.

3.1 Knowledge Acquisition

3.1.1 Aircraft Maintenance Practices in Ethiopian Airlines

The overall aircraft maintenance activity in Ethiopian Airlines is carried out based on the available reference manuals provided by aircraft manufacturers. These maintenance documents were available in hard copy occupying too much space and taking too much time in accessing the relevant section of the reference manuals. These reference manuals have been converted to electronic documents and available as PMA (Portable Maintenance Aid).

The reference manuals which includes the aircraft maintenance manual (AMM), illustrated parts catalog (IPC), fault isolation manual (FIM), structural repair manual (SRM), schematic diagrams and the wiring diagrams are available in the portable maintenance aid (PMA).

Whenever a revision to these references is required the publication department responsible for these activities will release the revised edition via the network. When discrepancies or failure remarks of an aircraft system or part are observed, unscheduled maintenance will be undertaken. Some kind of failures can be easily rectified within short period of the aircraft's ground time. However there are failures that cannot be resolved in the aircraft's ground time which causes the aircraft to be delayed for indefinite period of time. Fault isolation and diagnosis for aircraft maintenance in Ethiopian Airlines is performed by experienced aircraft technicians in the hangar if it is under scheduled maintenance or in the dispatch if it is unscheduled maintenance. Effective troubleshooting of problems is undertaken by technicians who have the experience and the required trainings on specific aircraft categories. All scheduled or unscheduled maintenance activities are recorded in the technical services resume book for future reference and trace back the maintenance history of an aircraft.

The technical recurrent training department provides aircraft system courses which are specifically prepared for each aircraft category such as B767, B757, B737-700, and Foker-50. Apart from the 24 months of basic training in aircraft maintenance as required by the regulatory bodies these specific courses enable the technicians with adequate knowledge in visualizing and understanding the different aircraft systems operations and functions.

The knowledge acquired in these trainings along with exposure to various problems throughout some definite years, makes technicians capable in dealing with new challenges that require effective fault isolation and diagnosis.

The Ethiopian Civil Aviation Authority prepares Rating examinations to evaluate the performance and knowledge of technicians who have worked on all systems of a specific aircraft. Aircraft technicians rated in B767 for instance can sign on a certificate that confirms the airworthiness of the aircraft before it is released to fly. The presence of FAA and CAA approved training centers and maintenance base in the airline was pivotal in acquiring basic knowledge from aircraft maintenance and its activities. The Ethiopian Airlines is nowadays providing its maintenance service to many African, and Middle East airlines apart from its own aircrafts. However the Airline is struggling in keeping the experienced technicians in the company.

According to the reports of Ato Girma Wakie, the CEO of Ethiopian Airlines, to the Parliament recently, "despite the successes in the market the airline is suffering in losing significant number of experienced employees". After acquiring all the required training, experience and knowledge in aircraft maintenance, many technicians have resigned from the airline. Even though different things could be mentioned for their reasons, the airline is suffering with the loss of these skilled technicians.

3.1.2 Opportunities in Knowledge Acquisition

After recognizing the potential problems posed in the fault isolation and diagnosis of malfunctions in aircraft systems, the airline has established Fault Management Team (FMT) and Specialized Avionics Department. The FMT prepares troubleshooting kit (TK) when repetitive problems and remarks are reported. The team records fault remarks and their corresponding actions taken for preparing relevant documents that helps in resolving the problem.

The relevant documents obtained from aircraft maintenance manual, wiring diagrams, fault isolation manuals and others will be collected and the problem is traced by logically following through the documents. If the problem persists the concerned manufacturer will be consulted for the presence of modification, service bulletin compliance or other technical assistance. Effective and efficient fault isolation and diagnosis practices will be recorded for future reference. However these processes require adequate time until the problem is rectified once and for all. Unfortunately the aircrafts operated by Ethiopian Airlines don't have sufficient ground time under normal operation. The less experienced technicians lack all the necessary skills for easily isolating and diagnosing of aircraft system faults within short period of time.

The other problems of the maintenance activity includes the difficulty of properly collecting effective fault diagnostic practices in such a way that can be modeled to a central computer system which could have helped the application of knowledge based fault diagnostic system. Moreover, the present methods of maintenance technicians fault diagnostic activities cannot be timed which results in failing to predict the appropriate advice time for informing the passengers and concerned departments before the maintenance work is completed.

3.1.3 Knowledge Acquisition Methods

The knowledge acquisition process starts with domain recognition, where potential and available knowledge are analyzed with respect to the goals of the system. It then continues with knowledge elicitation, where knowledge is gathered so that problems are divided into sub-problems, basic entities, information items, and so that the structural relationships are identified. Knowledge acquisition ends with the creation of knowledge model, which is defined explicitly and independently from the methods of subsequent life cycle phases.

In this research the primary sources of knowledge were obtained from the day to day maintenance activity records called "Resume Book" in accordance with the way skilled technicians rectify chronic aircraft system problems. After the records are properly collected maintenance and fault isolation manuals were consulted for internalizing the functional relationships of aircraft system components and guiding for potential interview questions of aircraft system failures. The next basic process was undertaking structured interview including detailed discussions with experienced technicians based on the efficient maintenance practices collected from the resume book. Direct and participant observations were also involved in the knowledge acquisition process as the researcher has the knowledge of aircraft maintenance. Therefore the knowledge acquisition process is supplemented by using introspection technique, as a knowledge engineer can also serves as a domain expert. The personnel for the interview were selected based on their experience, skill and reputation who have worked in avionics department of particularly communication and IFE systems. The kind of knowledge acquired involves the cause and effect of a defective unit in a certain aircraft system. When one of the factors that make the unit or system functional is missed or distorted at some stage of the system process, a malfunction to the specified aircraft system occurs. The malfunction of the aircraft system is modeled in such a way that it is suitable to be represented in a knowledge base.

3.1.4 Knowledge Modeling

Before the knowledge based system is built, the knowledge is identified and collected in knowledge acquisition phase. A model of domain knowledge is constructed using facts from knowledge domain, inferential relationships and the problem solving strategies. In this research work decision trees are used for the knowledge modeling process because of their cognitive nature that allows a human expert to easily comprehend the solution of a problem as shown in figures 3.1 to figure 3.3.

Decision trees often play a major role in modeling process. The graphical representation of the search space of a problem is expressed as decision tree in the knowledge modeling process. A node in the tree represents a decision to be made when solving the problem, and the branches growing out from the node depict the possible values of the decision.

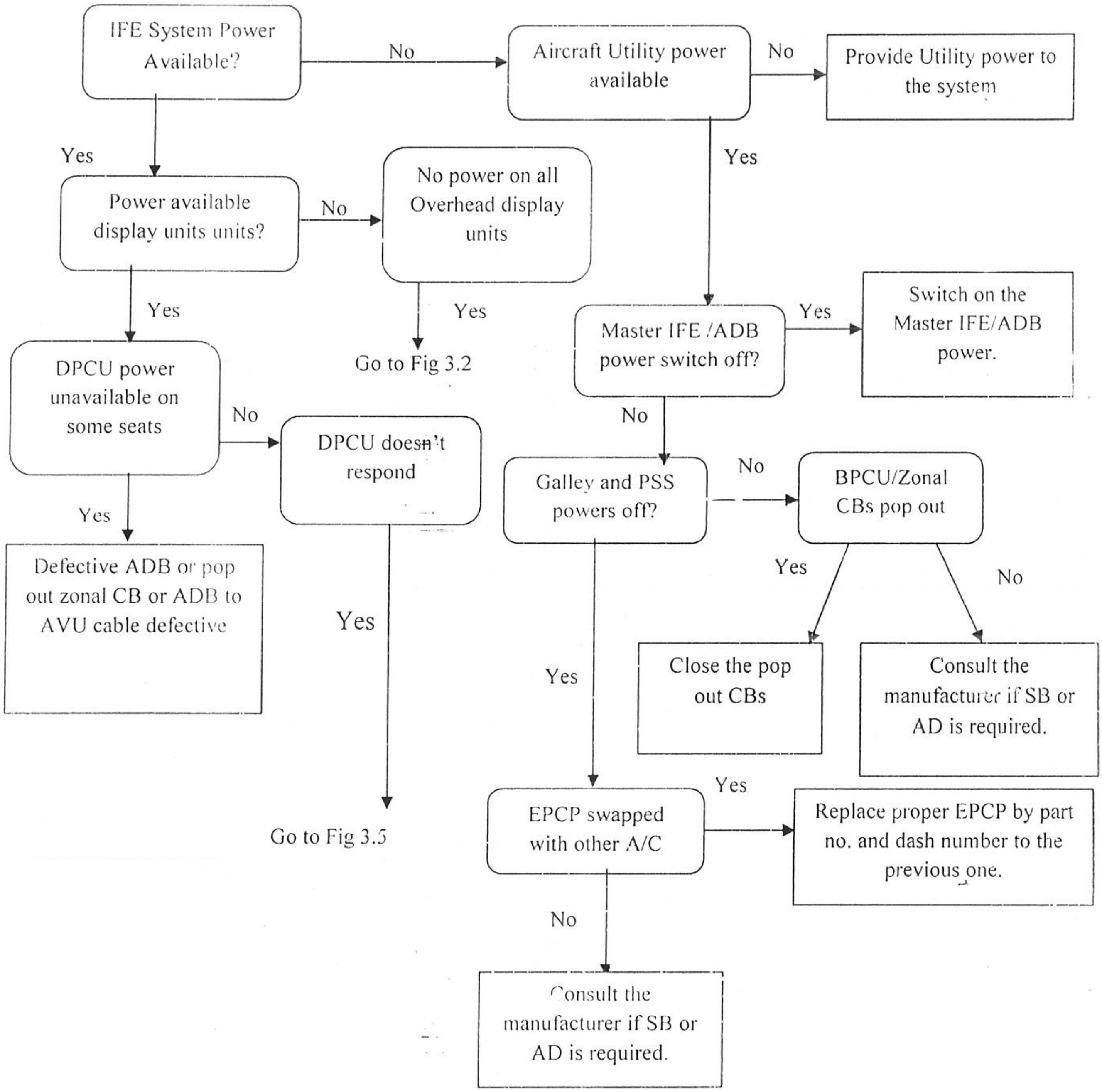


Figure 3.1 Decision tree for modeling a problem related to IFE system power.

Key

BPCU: Bus Power Control Unit, PSS: Passenger Service System, SB: Service Bulletin, AVU: Audio Video Unit, EPCP: Electrical Power Control Panel, AD: Airworthiness Directive, DPCU: Digital Passenger Control Unit, IFE: In-Flight Entertainment, CB: Circuit Breaker, ADB: Area Distribution Box.

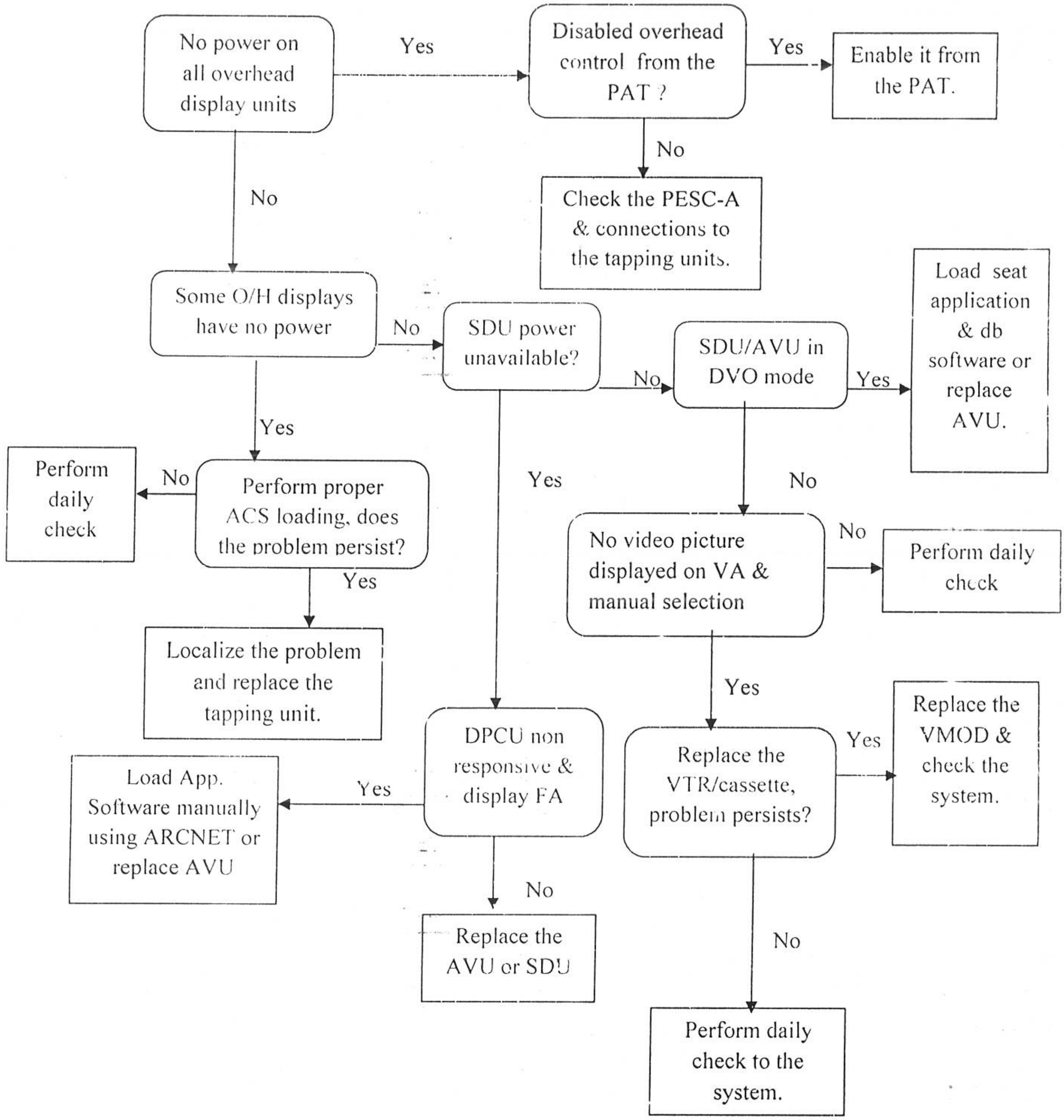


Figure 3.2 Decision tree for modeling Overhead & seat display unit problems.

Key:

VA: Video Announcement, VMOD: Video Modulator, SDU: Seat Display Unit, VTR: Video Tape Reproducer, DVO: Display Video Only.

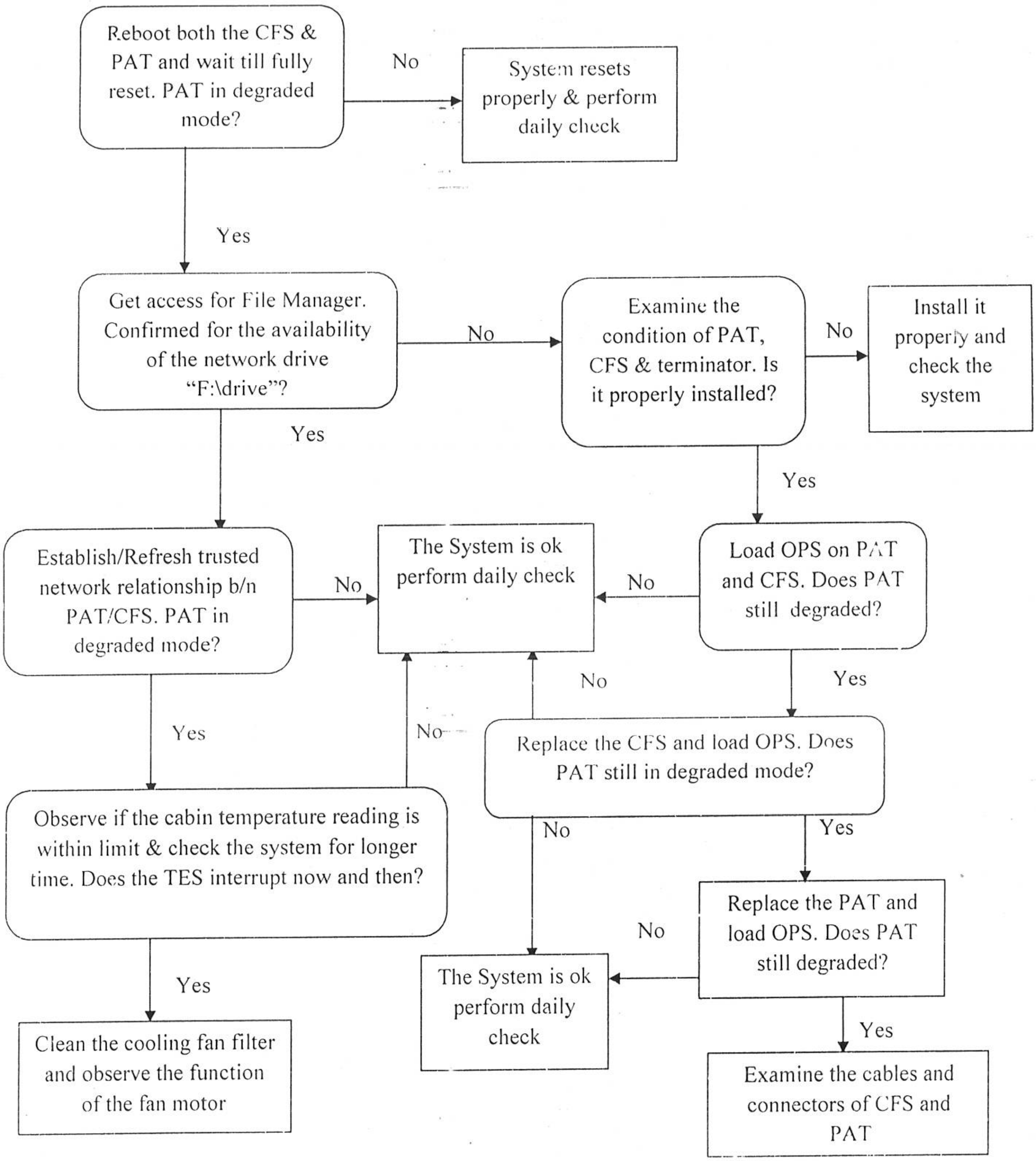


Figure 3.3 Decision tree for modeling problems when PAT is Degraded mode

Key: PAT: Primary Access Terminal, CFS: Cabin File Server, OPS: Operational Software

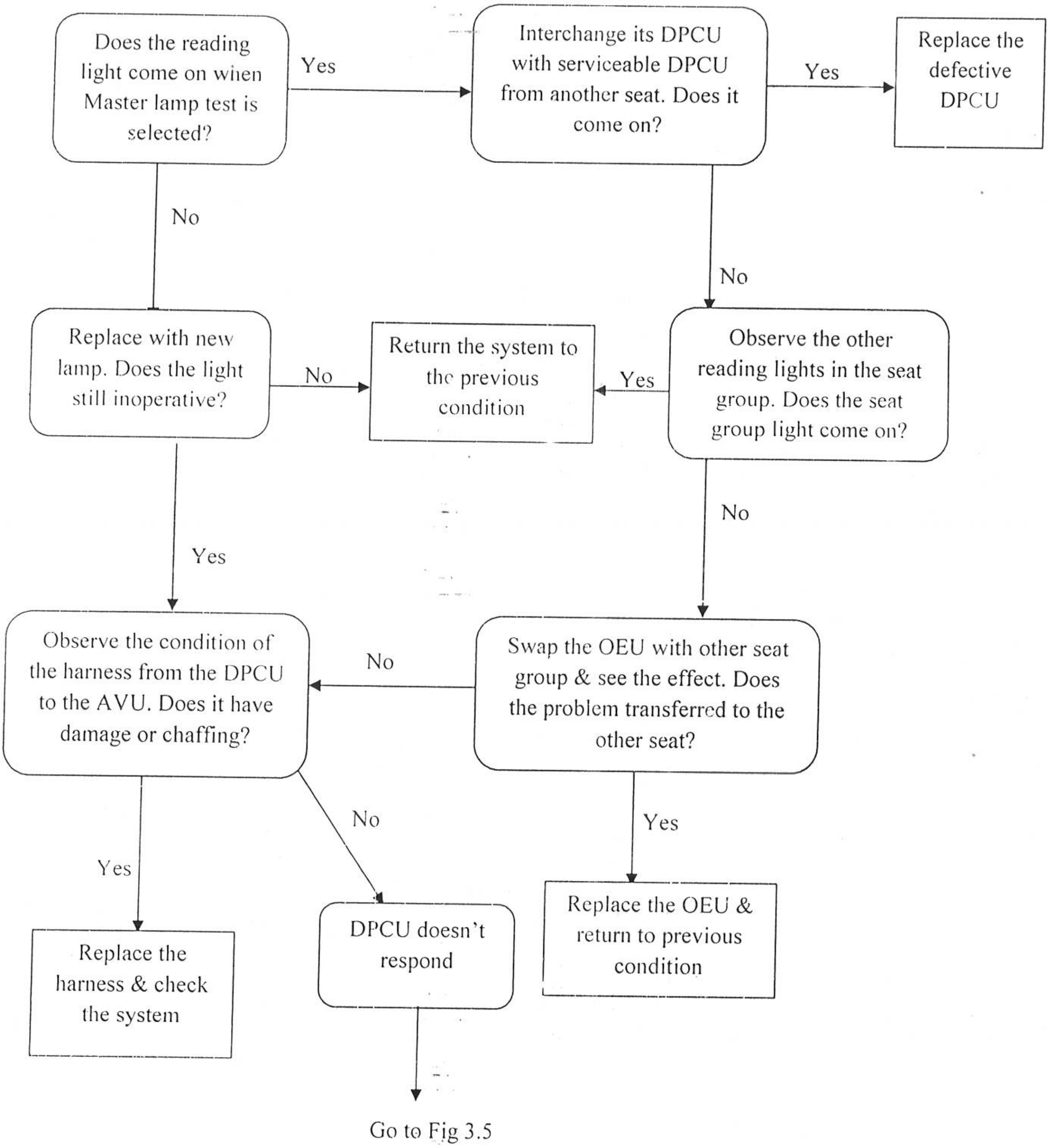


Figure 3.4 Decision tree for modeling inoperative reading light

Key: OEU: Overhead Electronic Unit, DPCU: Digital Passenger Control Unit.

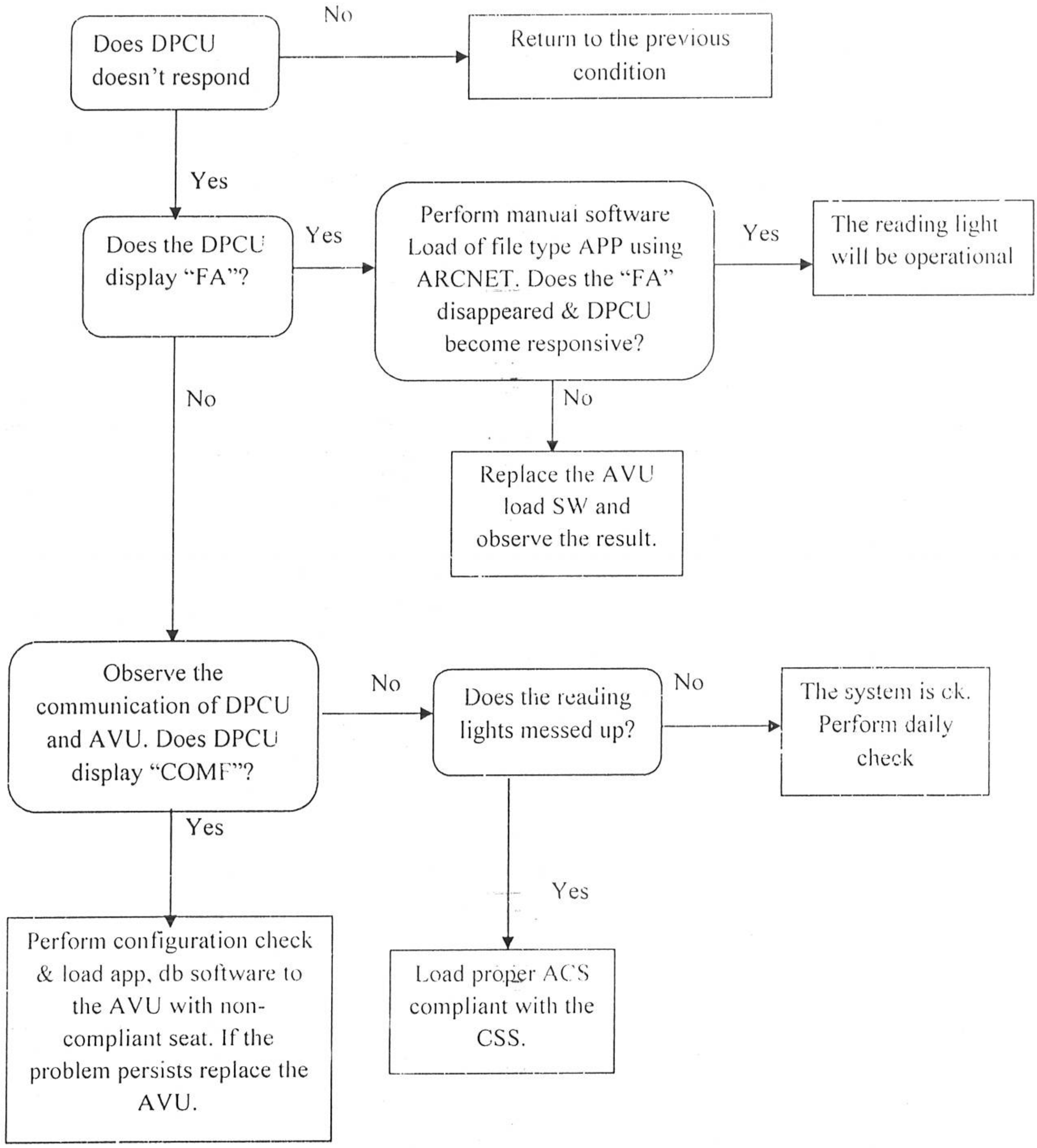


Figure 3.5 Decision tree for modeling the problems of passenger service system

Key

ACS: Aircraft Configuration System, CSS: Cabin Service System, COMF: Communication Failure FA: Failed Application.

3.2 Knowledge Representation

This is the second phase of the knowledge based system life cycle in which the knowledge model is formalized in such a way that an appropriate method of knowledge representation can be used.

3.2.1 Knowledge Representation Method

In building a knowledge base, several methods of knowledge representation can be used. However in this research work production rules are used for the representation of the acquired knowledge.

3.2.1.1 Rules

The knowledge representation technique employed in this study, production rules, are relatively easier way of knowledge representation in the development of a knowledge based system. The rule based system consists of a set of IF-THEN rules, a set of facts and an interpreter controlling the application of the rules, given the facts.

The interpreter could be either a forward chaining or backward chaining system. The knowledge based system methodically tries to prove or disprove each possible solution, gathering the needed information as it goes. In this research a backward chaining rule based knowledge representation system is employed as it fits to both the fault isolation (diagnostic) process and software tool (prolog) chosen to develop the prototype. The rules are represented in such a way that the consequence is stated before the cause of the problem. Sample rules of the knowledge based system using prolog are presented below.

"Then (Interrupting TES now and then)

If (IFE cooling duct is clogged) And (Overheating of VCC)"

For convenience the following sample rules are represented in an "If Then" form.

If *aircraft system power is unavailable,*

Then *TES/PSS system is inoperative.*

If *aircraft system power is available,*

And there is no communication in the system units,

Then *TES/PSS system is inoperative.*

If *PSS power is not available,*

And power not available in display units,

And *DPCU power displays blank,*

Then *the aircraft system power is unavailable.*

If *PSS/TES power is available,*

And power not available in display units,

And *DPCU power displays blank,*

Then *the zonal CBs in Electrical and Electronic rack are pop out.*

If *PSS/TES power is available,*

And overhead display unit is inoperative,

And *not disabled from monitor control,*

Then *tapping unit is defective.*

If *PSS/TES power is available,*

And overhead display is ok,

And not disabled from monitor control,

Then *the system is ok.*

If *PSS/TES power is available,*

And *overhead display unit is inoperative,* And *disabled from the monitor control.*

And *displays operational when monitor control is enabled,*

Then *tapping unit is not defective.*

If *PSS/TES power is available,*

And *overhead displays are inoperative,*

And *there is no audio in PA and seats,*

And *airshow inoperative,*

Then *PESC A is inoperative or its receptacle is loose.*

If *PSS/TES power is available,*

And *some of the overhead display units are inoperative,*

And *monitor controls display VDU only,*

Then *proper ACS DB is not loaded.*

If *PSS/TES power is available,*

And overhead display units are ok,

And power not available in SDU,

And *DPCU power displays "FA",*

Then Seat Application has failed & requires APP sw. to be loaded manually.

If *PSS/TES power is available,*

And overhead display units are ok,

And power is available in SDUs,

And DPCU reading/call light service messed up, Then *proper ACS database is not loaded.*

If *PSS/TES power is available,*

And overhead display units are ok,

And power is available in SDUs,

And DPCU reading/call light service messed up

And PAT monitor control function displays each monitor ON & OFF status,

Then *there is defective AVU.*

If *PSS/TES power is available,*

And overhead display units are ok,

And power is available in SDUs,

And pictures not displayed on display units,

And there is no problem in triple decks and cassettes,

Then *the VMOD is defective.*

If *PSS/TES power is available.*

And overhead display units are ok,

And power is available in SDUs,

And pictures not displayed on display units,

And there is problem in triple decks and cassettes,

Then *the VMOD is not defective.*

If *PSS/TES power is available,*

And overhead display units are ok,

And power is available in SDUs,

And pictures displayed on display units,

And displays video only (DVO mode),

And PAT is in degraded mode,

Then the communication between PAT and CFS has failed.

The techniques used in knowledge modeling and knowledge representations has revealed a new and better ways of collecting outstanding maintenance practices and employing a connectivity knowledge through developing a knowledge based system using "if then" rules. The aircraft maintenance tasks recorded daily in the resume book was used for collecting effective and efficient maintenance practices. These records of the resume book have been used for collecting the domain knowledge instead of being used only for future reference of the maintenance activities.

The knowledge acquisition, modeling and representation are performed in the communication system of the aircraft system particularly in the cabin service system, total entertainment system, and airshow system of B767-300ER aircrafts. The knowledge modeling and representation techniques can also be used for other aircraft systems to provide a full fledged knowledge based system for fault isolation in aircraft maintenance.

CHAPTER FOUR

DESIGN AND DEVELOPMENT OF THE PROTOTYPE

This section involves design, testing and evaluation mechanism of the knowledge based system with respect to the sample data given to the system. The prototype design employs an inoperative aircraft system as a top goal in which the cause for the defect is isolated through a dialog type user interface expressed logically to potential users. The fault isolation and recommended actions of the knowledge based system is tested and evaluated to ensure the validity of the system by comparing it with human experts.

4.1 System Design

The design of the prototype involves user interface, knowledge base, inference engine and the explanation facility as shown in figure 4.1.

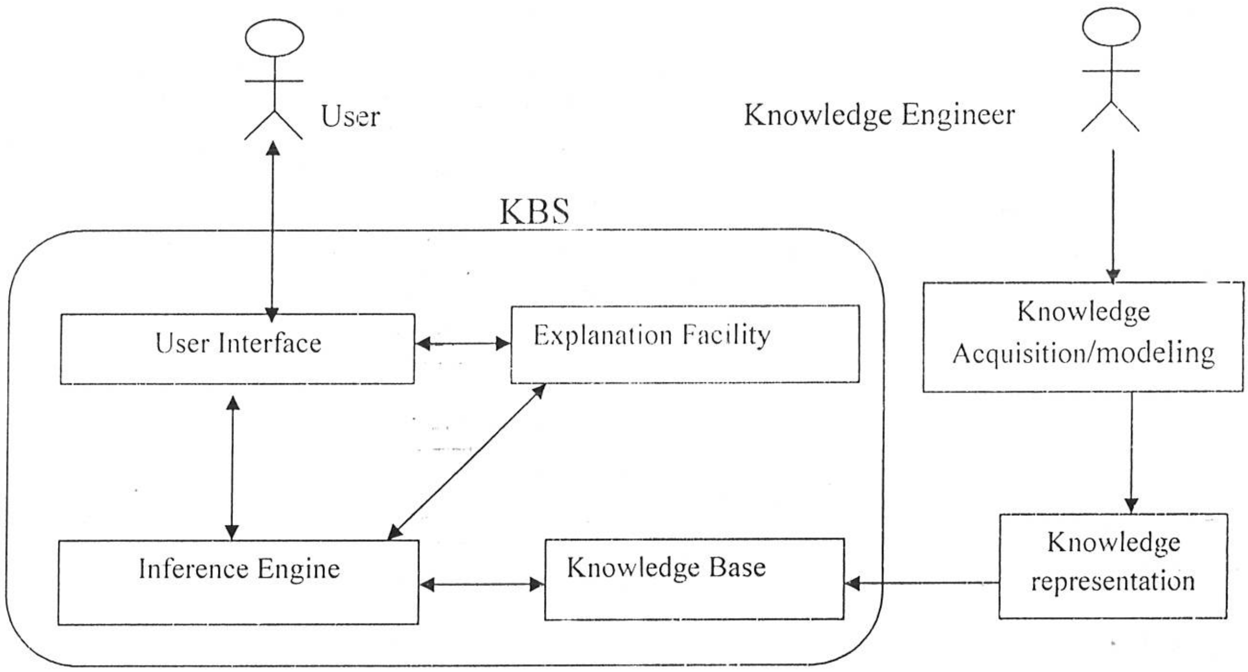


Figure 4.1 Knowledge based system architecture

The knowledge acquisition and knowledge representations are carried out by the knowledge engineer. The user responds to a series of dialogs in such a way that there is a logical flow of the affected aircraft system functionality that can be expressed in the explanation facility.

4.1.1 User Interface Design

In the user interface design, a single line dialog type user interface is employed which is suitable for the potential users in troubleshooting. The first interface displayed to the user to interact with the system is the initialization of the prolog user interface. The introduction user interface is displayed with once the word "start" is entered to the command prompt. Then the welcome message and the menus in which a specific function are selected displayed as shown in the figure 4.2.

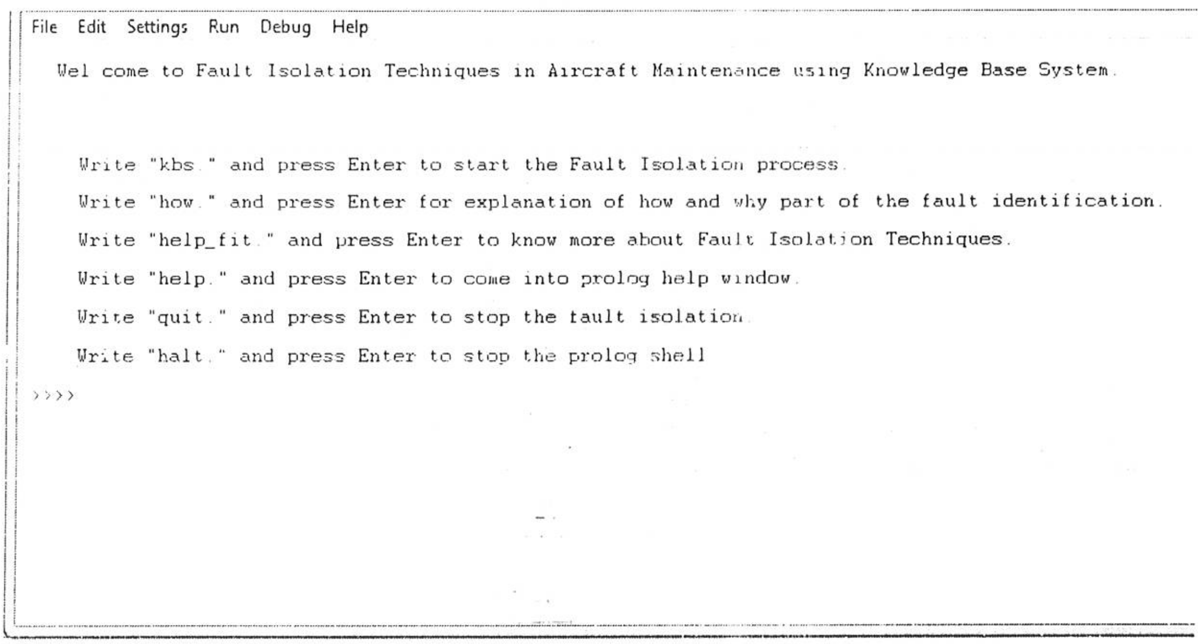


Figure 4.2 The introduction user interface

The welcome message is displayed as "Welcome to Fault Isolation Techniques in Aircraft Maintenance" and the menu that involve actions to be taken are explained just before the prompt. Entering "kbs." to the prompt will start the fault isolation dialogs or recommended actions to be taken when a problem is already identified as shown in the figure 4.3.

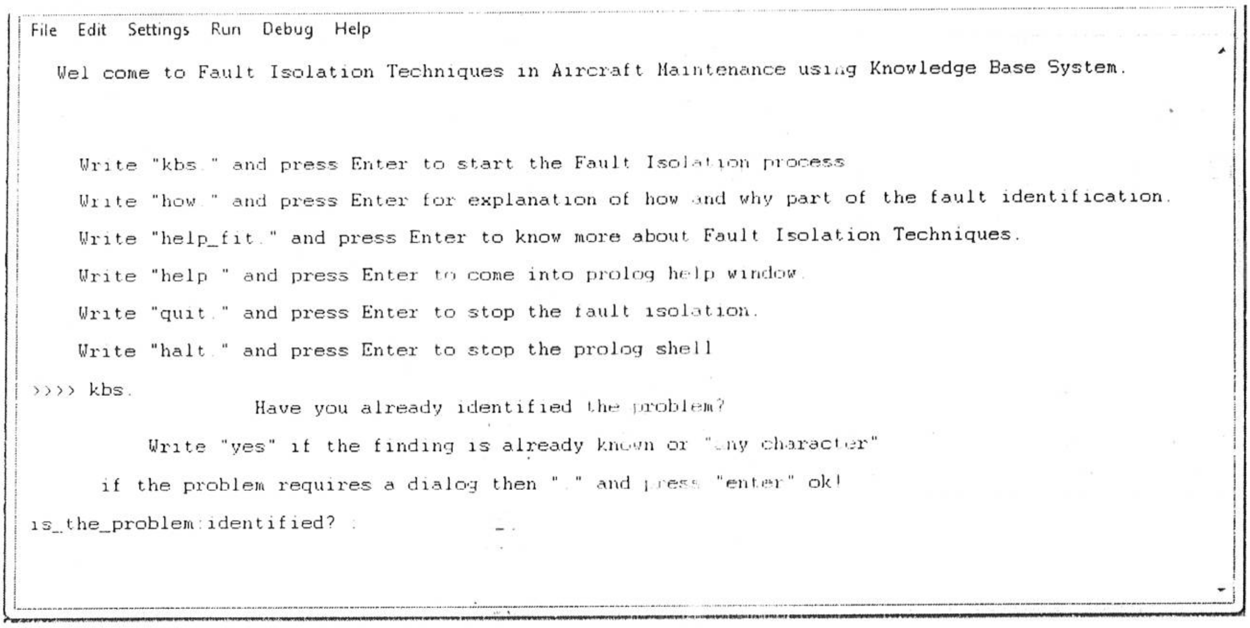


Figure 4.3 The dialog command for responding to identified or unidentified problems

4.1.2 The Knowledge Base Design

The design of the knowledge base is performed by collecting fault isolation and diagnosis rules which are logically organized from a top level problem of inoperative aircraft system to a bottom level possible causes of the problem. The possible causes for a certain problem to happen are collected as facts and these facts along with their consequences provide "if-then" rules in the knowledge base.

4.1.3 The Inference Engine

The inference engine employed in the Knowledge based system is a backward chaining inference which is suitable for the prolog programming language. A top level goal is achieved after the low level and medium level goals are obtained. The following sample rule indicates the way in which backward chaining inference derives conclusion from the middle level goals and given facts.

finding(system_is_inoperative):- .... (Top level goal)

fault_involve(system_power_unavailable),nl.

finding(system_is_inoperative):-

fault_involve(system_not_communicating),nl.

fault_involve(system_power_unavailable):-nl,nl, ... (Middle level goal)

fault_observed(service_not_available_in_pss),nl, ... (Fact)

fault_observed(power_not_available_in_display_units),nl ..... (Fact)

fault_observed(dpcu_displays_blank),nl......................... (Fact)

The first task of the inference engine performs confirmation for the truth of the facts. Then the inference tracks back to the middle level goal if all the facts are fulfilled as affirmative. The middle level goal, system power unavailable, then will be the precondition for the top level goal of "system inoperative". The backward chaining inference of the full knowledge based system uses the same procedures as discussed above.

4.2 Knowledge Based System User Interfaces

If the cause of the fault is already identified and no further troubleshooting is required, the user can enter the cause of the problem to get the recommended actions. Responding to the system for the dialog "is the problem identified?" as "yes" allows going to a dialog as shown in the figure 4.4.

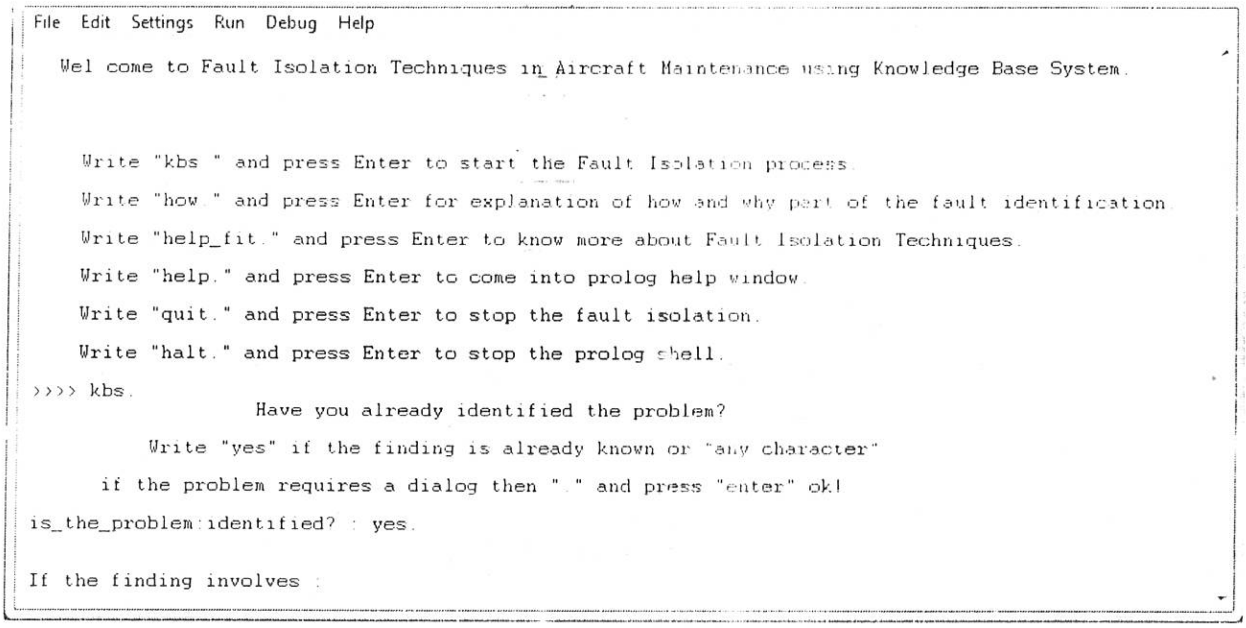


Figure 4.4 A dialog for already identified causes of problems.

The user is required to enter the finding identified to respond for the dialog "If the finding involves:" The system then provides the fault isolation approaches and recommended actions to be taken to rectify the problem as shown in figure 4.5.

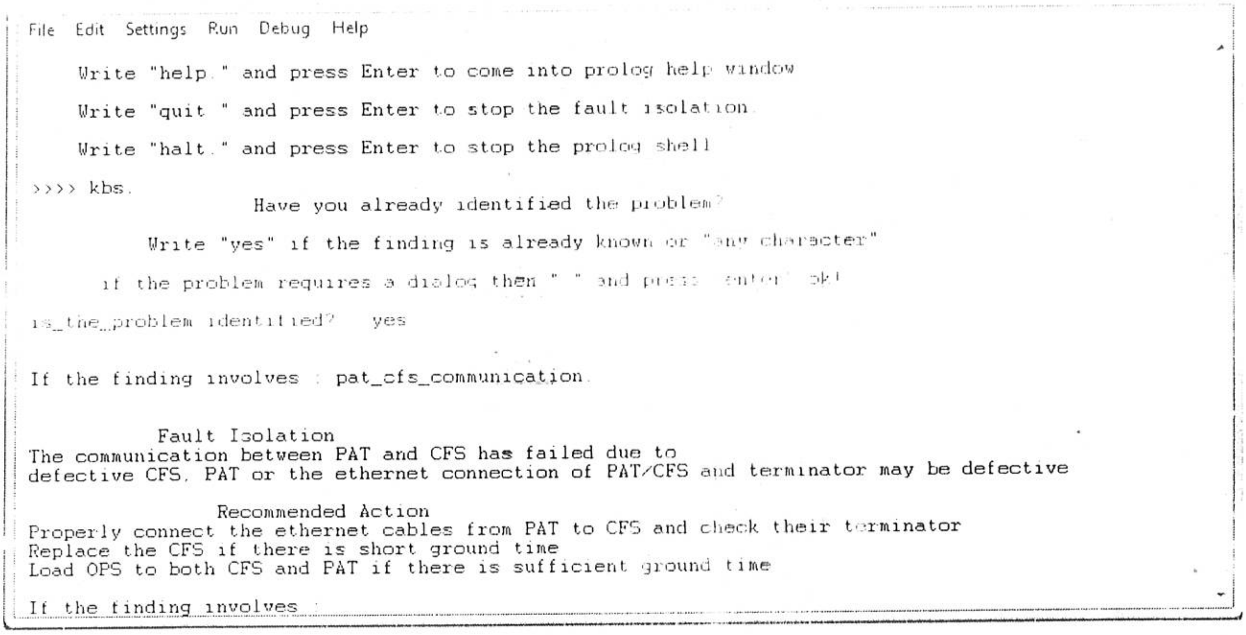


Fig 4.5 A dialog that responds to a predefined finding.

If there is a remark or a daily finding the user enters "no" to the prompt of "is the problem identified?" to go through the dialog. The computerized passenger address & service system, computerized passenger entertainment system and the airshow system of the newly purchased B767-300 aircrafts operated by the Ethiopian Airlines in particular have been used for prototype development. Figure 4.6 shows a message that tells the user on which part of the aircraft system can this prototype be applied.

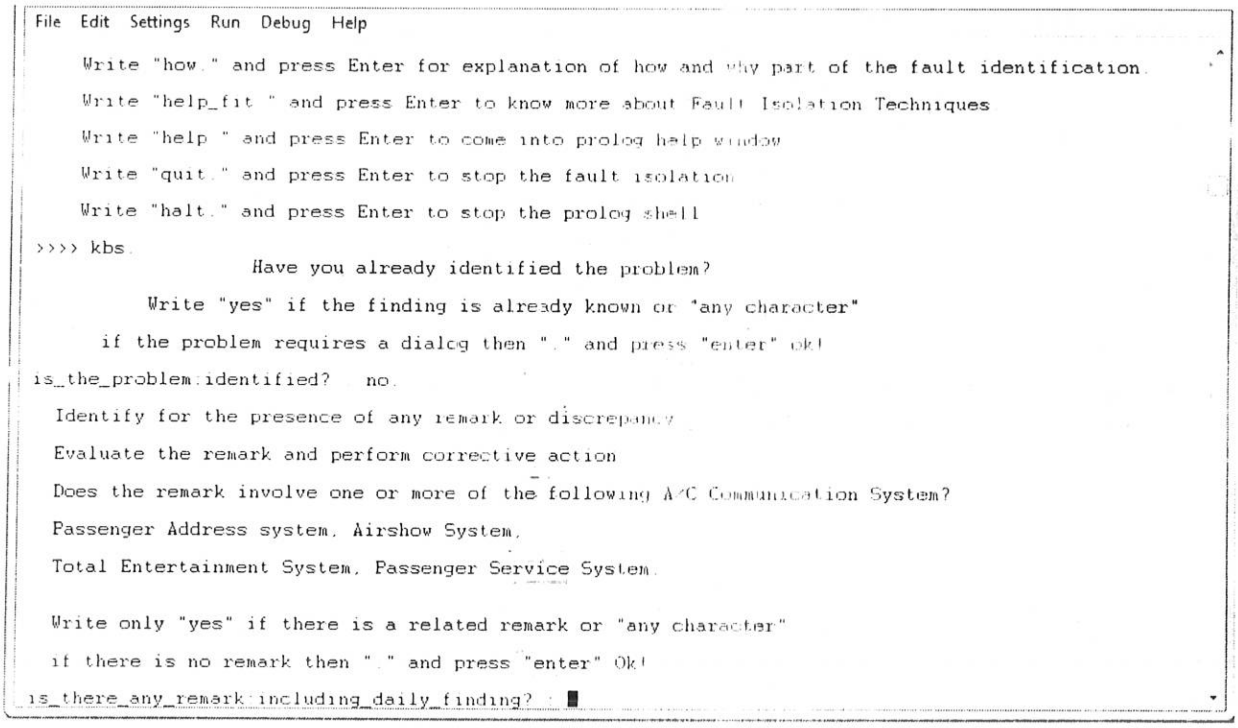


Figure 4.6 remark identification dialogs

The knowledge based system already has facts and rules in its knowledge base. The user observes carefully for each dialog so as to respond accordingly. When the system gets full information about the cause of a certain problem, it will provide the fault isolated and the recommended actions to be taken to rectify the problem as shown in figure 4.7.

The user communicates with the system by responding to the logically organized questions and finally reaches isolation to the possible cause of the fault and its recommended actions which needs to be taken to resolve the problem. As shown in figure 4.7 after the fault isolation and recommended actions are suggested the cause of the problem is also stated as "The finding is: ife cooling duct clogged".

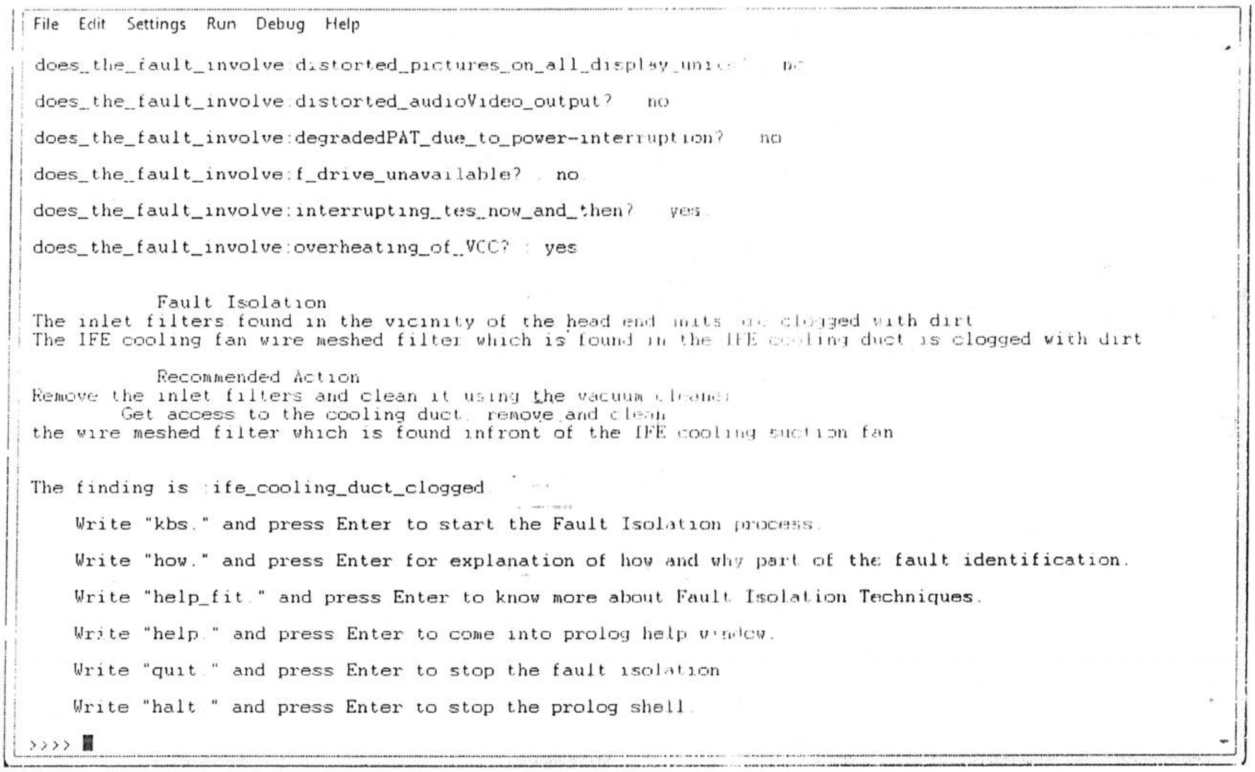


Fig 4.7 Dialog between the user and the system on fault isolation and recommended actions for inlet filters and IFE fan filters clogged with dirt.

The user can also see how the knowledge based system has reached to this conclusion by entering "how" to the prompt. Figure 4.8 shows how the knowledge based system is reaching to the fault isolation and recommended actions when PAT is degraded due to clogged wire meshed filter with dirt in the IFE cooling suction duct.

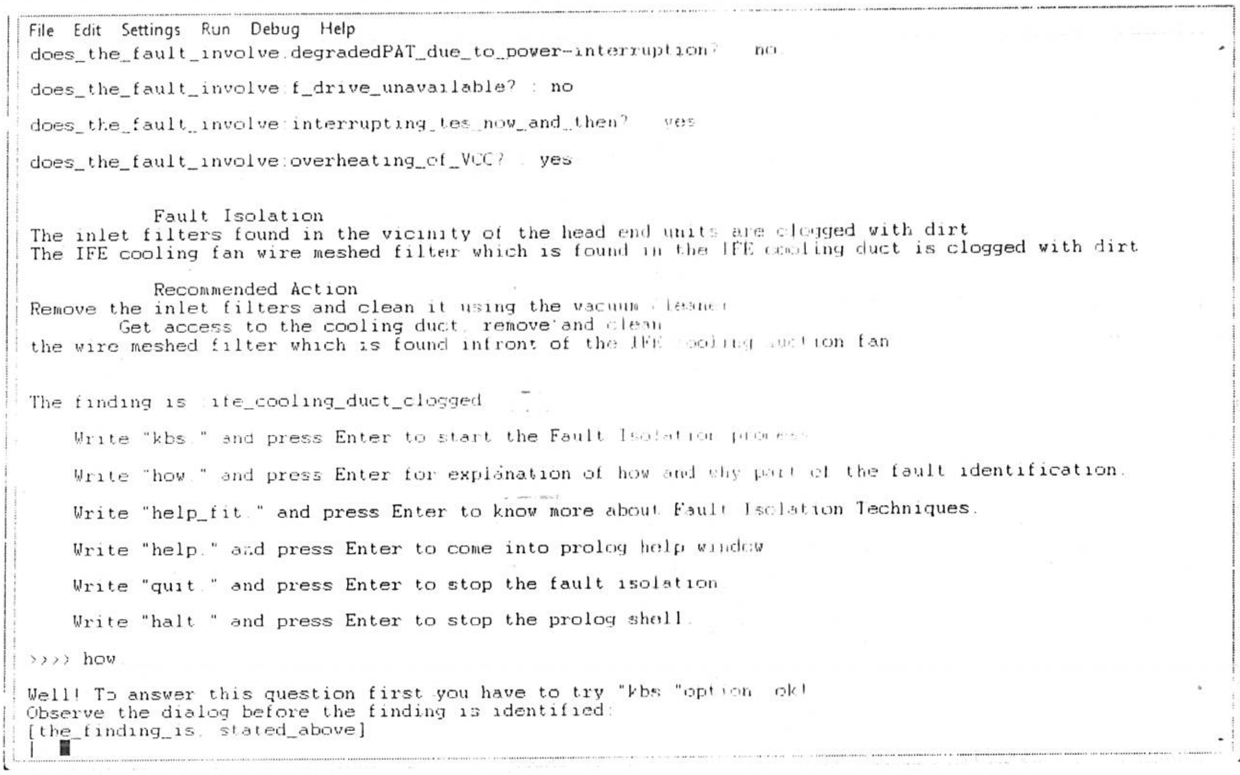


Figure 4.8 Explanation on the how part of the dialog.

The other functionality of the menu is "help_fit" which explains about the benefit of efficient fault isolation technique using the knowledge based system as illustrated in figure 4.9.

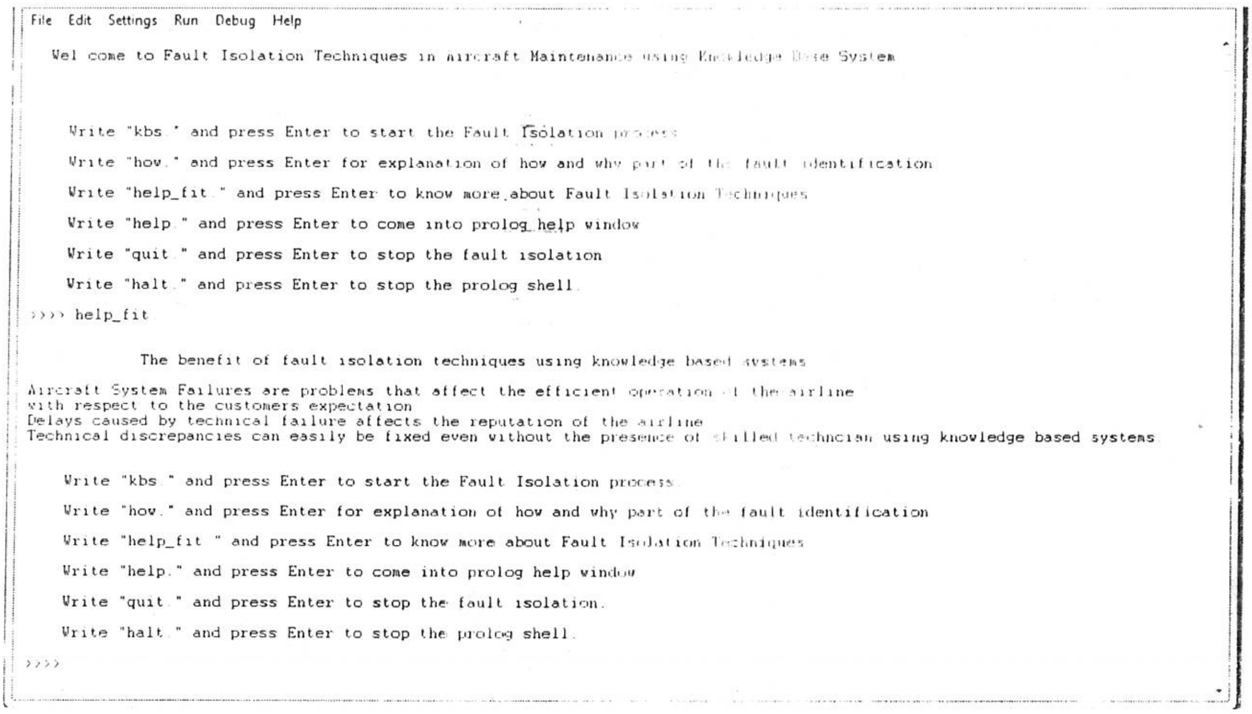


Figure 4.9 A display that shows the help_fit function

The "help" menu is used to get full documents concerning the knowledge based system software tool called SWI prolog.

The "quit" menu stops the fault isolation process and the "halt" menu exits from the prolog program in which it can serve as a close option to the knowledge based system.

4.3 Testing and Evaluation

A data set is prepared in the prototype development based on the records of maintenance resume book from March 1/2008 to June 30/2009. The one year and three months of the resume book contains above 13000 records which are entered every day in each working shift. The resume book is prepared to be recorded in an Excel file and has main attributes of date, shift, Id number of the technician, aircraft registration number, log book remarks and the corrective actions performed as illustrated in figure 4.10.

AIRCRAFT MAINTENANCE RESUME BOOK FROM MARCH 2008 TO JUNE 2009

Date	shift	ID NO	A/C	log book remark	Corrective action taken (Include Chapter for corrective action for any cabin / Maintenance log book remark)
11/9/2008	E	15153	ALN	NO REMARK	
11/9/2008	E	13133	ALP	MOST OF ECONOMY SEATS INDIVIDUAL ENT SYSTEM	REPLACED CFS AND OPERATIONALLY CHECKED.
				INOP.	PER AMM 23-32-00
				VIDEO ANNOUNCEMENT IS INOP.	REPLACED CFS AND OPERATIONALLY CHECKED.
				THROGH OUT THE FLIGHT IFE SYSTEM WAS IN	PER AMM 23-32-00
				DEGRADED MODE.PLEASE TAKE THE NECESSARY	
				ACTION.	
12/9/2008	N	16039	AME	ON SEAT #12LJ -CALL LIGHT HOLDER DAMAGED	HOLER REPLACED
				ON SEAT# 38F -DAMAGED HARNESS &PCU	HARNESS REPLACED
				FROM SEAT #11HFD DOSEN'T INTER IN TO TEST MODE	PSUD PWR CABLES RECONNECTED
				ALL BURNT LAMOS REPLACED.(DAILY)	
12/9/2008	N	16039	AMU	NO REMARK	
12/9/2008	N	16148	AKF	NO REMARK	
12/9/2008	N	16039	ALC	PROJECTOR #2 FAILED	LAMP REPLACED 33-22-00
12/9/2008	N	16148	AMT	NO REMARK.(DAILY MONITOR #5 FLICKERS.	SCU RESETTED AND CHECKED OK
12/9/2008	O	15843	AMF	VTR # 2 INOP	VTR HEAD CLEANED & CHKD OK PER ATA 23-32-17
				ON SEAT #28 DFH ALL READING LIGHTS ARE INOP(THREE	POWER RESET & CKD OK PER ATA 23-34-09

Figure 4.10 Sample of the aircraft maintenance resume book

The prototype of the knowledge based system make reasoning by using the basic facts and/or middle level solutions as preconditions to come up with the final solution of previously occurred problems. However some aircraft system problems may require additional or other facts and conditions to fix their problems. Therefore it is the limitation of the prototype as it involves only the basic facts.

The knowledge base system design has included providing recommended actions for already isolated and identified aircraft system faults without going through a dialog with the user. The testing and evaluation of the prototype is carried out by providing outstanding and frequently occurring aircraft system problems to the human experts of experienced aircraft technicians.

A data set of 150 aircraft system problems with outstanding remarks, frequently occurring defects, remarks that require unit replacements and stayed for a long period of time are selected from the resume book records. A total of 50 questions that can represent major remarks of the resume book are prepared for testing the accuracy of the knowledge based system as indicated in table 4.1. The questions are divided into power related, communication failures and problems that require unit replacement to simplify the evaluation process.

The number of questions on each type of aircraft system problems is decided based on the proportion of the solutions provided for the problems encountered. The validity of the prototype is checked by comparing the problem solving approach of the knowledge based system with experienced technicians having good avionics skiii. The result of the comparison shows that the designed knowledge based system has a very close fault isolation and problem solving approach to the experts in the aircraft maintenance. The comparison has revealed 86% accuracy in solving major problems that have been organized from previous resume book records as indicated in table 4.1. The sample fault isolation methods are attached in the appendix I. One major problem of the prototype is it doesn't give possible solutions for those problems which are out of the rule.

Moreover most of outstanding aircraft system problems are solved by consulting the available maintenance documents and team works. Therefore there was a problem in comparing the results of these experts and the knowledge based system as solutions suggested by the experts for each question were not exactly accurate. So the integration of cases to the knowledge base is required.

Types of aircraft system problems	Total number of problems selected for testing	Number of same solutions by the KBS and human experts	The accuracy of the KBS in %
Power related problems	10	8	80
Communication failures	15	13	87
Unit/equipment failure	25	22	88
Total	**50**	**43**	**86**

Table 4.1 Testing the accuracy of the knowledge based system

The finding of the study indicates that the fault isolation system in aircraft maintenance can be effectively facilitated by using knowledge based system to retain the tacit knowledge obtained from individuals and team works with respect to the available documents.

The testing phase of this study has also revealed that efficient maintenance practices are achieved through team work and discussions about the problem of the aircraft system among technicians.

The knowledge representation of the prototype with rule based techniques requires to exhaustive input of facts and relationship of facts. However the relation between symptom and source of failure of a certain aircraft system is indefinite. Therefore the application of the knowledge based system demands partial similarity matching techniques and the integration of learning tools like neural network to create a general pattern for matching with new aircraft system failures.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The presence of stiff competition in the aviation industry provides both challenges and opportunities for airline operators. The challenges involve the availability of many airline operators that compete in providing better service for the passengers and cargo services. The delay of scheduled flights dissatisfies customers at large and causes other airlines to exploit the situation in their favor. Most of the delays caused by technical failures should be minimized as long as the airline is committed to satisfy the customers. The other challenge Ethiopian Airlines still facing is the loss of skilled man power in the major airline operations. The research has revealed that significant amount of experienced aircraft technicians have resigned from the airline and join to rival airlines. It is very difficult to cope up with these challenges as long as customer satisfaction is concerned.

Despite some of the challenges mentioned above the airline needs to exploit the opportunities of the situation by merging and having a code sharing agreement with world class airlines, introduction of information technology products and taking considerable amount of market share. The introduction of latest information technology products supports airline activities with respect to the competition of the aviation industry and customer satisfaction.

Aircraft maintenance takes center stage on both the challenges and opportunities of the aviation industry. It plays an important role in providing an airworthy aircraft that meets flight schedules on time. This airworthiness can only be achieved by having efficient and skilled aircraft technicians.

In this research the applicability of knowledge based system is proved as a useful approach for facilitating the fault isolation and detection technique for technicians in aircraft maintenance. The airline has long been dependant on training aircraft technicians in its training school for filling the void left by skilled technicians.

Apart from training it is believed that this research will initiate the airline to use more advanced knowledge based systems to facilitate aircraft maintenance activities especially in fault isolation approaches of aircraft system failures. Fault isolation and detection in aircraft maintenance using knowledge based system helps to minimize the delay of scheduled flights due to technical failures.

Different maintenance personnel have the affinity of specialty in some skills of aircraft systems. The fault isolations of chronic aircraft system problems require multidisciplinary knowledge of technicians. The presence of teamwork in diagnosing aircraft system problems has a significant advantage in filling the gaps created by technicians with different skills. However the lack of proper and exact way of recording the maintenance activities that affects the knowledge acquisition process was the other problem observed in this study. The knowledge based system development faced the problems stated above in obtaining a fully complete knowledge from single individuals and properly retained maintenance records suitable for further analysis of the records.

The fault isolation and diagnosis nature of the study allows employing a backward chaining inference of the rule based system. The rule based knowledge representation technique is structured after the modeling of the domain knowledge is carried out using decision trees. The accuracy of the knowledge based system developed using the techniques are 86%.

To come up with a practical knowledge based system, cooperation of the technicians' explanation on how the problem of a certain aircraft system is solved and proper recording of outstanding maintenance activities in the resume book should be practiced in a better and advanced way. Moreover the system needs to update its knowledge base when new facts are introduced, besides creating generalized patterns for identifying aircraft system faults.

5.2 Recommendations

Based on the findings of this research, the following recommendations are suggested for further work to improve the functionality of the prototype and develop a full-fledged fault isolation system in aircraft maintenance.

- To come up with a practical system, the knowledge based system should be expanded to include more knowledge by a thorough extraction of the facts, procedures and rules for fault isolation in aircraft maintenance. Therefore participating large number of skilled aircraft technicians at different departments and consulting the various documents and manuals is required to develop a full-fledged knowledge based system.

- The prototype developed in this research has used a rule based knowledge representation technique to reason out the solution of a certain problem. However other researchers need to integrate the use of learning tools like neural networks as a potential problem solving technique in aircraft maintenance activities.

- The knowledge based system does not hold all the necessary rules and is not self learning at this stage. But, attempt should be given for further work to develop self learning system that can match a case even though there is no exact rule in the knowledge base.

- The airline is expected to support the study by allocating budget, providing training and encouraging experts in cooperating with the system and improving the recording of maintenance activities in such a way that it is suitable for adopting knowledge based system development.

- In this research, attempt has been made to assess the applicability of knowledge based system in facilitating the fault isolation techniques in areas of the specific aircraft communication systems that includes passenger address system, airshow system, computerized total entertainment and passenger service system.

Besides passenger entertainment and service system, it is open for interested researchers to consider also other aircraft systems like electrical power system, pressurization and air conditioning system, flight control system, hydraulic and pneumatic system, landing gear system.

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fault_isolation(pat_cfs_communication):-nl,nl.

write(' Fault Isolation '),nl,

write('The communication between PAT and CFS has failed due to'),nl,

write('defective CFS, PAT or the ethernet connection of PAT/CFS and terminator may be defective').

Some of the Recommended Action Statements

recommended_action(system_power):-nl,nl,

write(' Recommended Action '),nl,

write('Confirm the presence of pop out CB and '),nl,

write('Make sure the electrical power control panel is not interchanged with other aircrafts,'),nl,

write('assure the ADB power and master IFE switch to on position').

recommended_action(pat_cfs_communication):-nl,nl,

write(' Recommended Action '),nl,

write('Properly connect the ethernet cables from PAT to CFS and check their terminator'),nl,

write('Replace the CFS if there is short ground time'),nl,

write('Load OPS to both CFS and PAT if there is sufficient ground time').

recommended_action(reboot_onProcess):-nl,nl,

write('Recommended Action '),nl,

write('The PAT and CFS are resetting and wait until successfully rebooted,'),nl,

write('If the problem persists recycle the master power').

recommended_action(adb_power):-nl,nl,

write(' Recommended Action '),nl,

write('Switch on the ADB power and observe the condition of the DPCU'),nl,nl.

ple of Questions for Interview

-300 Total Entertainment and Service System

ft System Power

If there is no power to the IFE system that includes the display units and DPCUs, What could be the probable faults, provided that there is aircraft system power. ADB and Master switches are in "ON" position?

The passenger service and entertainment system interrupts now and then. The VCC area temperature indicator rises to show that there is overheat and PAT is in degraded mode. What kind of actions could you take to solve this problem?

unication System Questions

What could be the probable cause for a DPCU that displays "COMF" Communication Failure and its recommended practices from your experience?

PAT degraded and the IFE system is in DVO mode. The network drive is unavailable. What could be the probable cause and corrective actions for this problem from your experience?

What is the probable cause and its corrective actions if the audio is becoming noisy along he seat groups?

Suppose the reading and call lights of economy class seats are messed up, what are the ossible causes and corrective actions for this problem?

The IFE database which is updated every month is unable to be updated on the seat pplications. The fault involves that the video announcement is disabled. Suggest the robable cause and corrective actions from your experience.

that require Unit Replacement

nere is no audio in the seat entertainment systems and video announcement, the airshow also inoperative. Suggest the probable cause and corrective actions from your perience.

ring OPS loading to the core of IFE system components (PAT and CFS), the software unable to be loaded fully and there are pop out error messages. What could be the ses and corrective actions?

DPCU displays "FA" and the display units are blank. What are the causes and rective actions of the failure?