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The feasibility of using the Naval Aviation Logistics Data Analysis (NALDA) databases for the Expert System Advisor for Aircraft Maintenance Scheduling (ESAAMS)

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THESIS

THE FEASIBILITY OF USING THE NAVAL AVIATION LOGISTICS DATA ANALYSIS (NALDA) DATABASES FOR THE EXPERT SYSTEM ADVISOR FOR AIRCRAFT MAINTENANCE SCHEDULING (ESAAMS)

by

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December, 1990

Thesis Advisor: Martin J. McCaffrey

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The feasibility of using the Naval Aviation Logistics Data Analysis (NALDA) database as a key element of the Expert System Advisor for Aircraft Maintenance Scheduling (ESAAMS) is examined. A general review of expert systems, knowledge bases, and their development is presented. NALDA databases are examined for accuracy, availability, suitability, and reliability as they pertain to the proposed expert system knowledge base. Appraisal of the NALDA database is based on both analytical and quantitative analysis.

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The Feasibility of Using the Naval Aviation Logistics Data Analysis (NALDA) Databases for the Expert System Advisor for Aircraft Maintenance Scheduling (ESAAMS)

by

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ABSTRACT

The feasibility of using the Naval Aviation Logistics Data Analysis (NALDA) databases as a key element of the Expert System Advisor for Aircraft Maintenance Scheduling (ESAAMS) is examined. A general review of expert systems, knowledge bases, and their development is presented. NALDA databases are examined for accuracy, availability, suitability, and reliability as they pertain to the proposed expert system knowledge base. Appraisal of the NALDA databases is based on both analytical and quantitative analysis.

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ABBREVIATIONS AND ACRONYMS

3-M	Maintenance and Material Management
AEMS	Aircraft Engine Management System
AI	Artificial Intelligence
ANOVA	Analysis of Variance
ASO	Aviation Supply Office
CF	Certainty Factor
CNO	Chief of Naval Operations
DBMS	Database Management System
DSF	Data Services Facility
DSS	Decision Support Systems
EMT	Elapsed Maintenance Time
ESAAMS	Expert System Advisor for Aircraft Maintenance Scheduling
FMSO	Fleet Material Support Office
FOJ	Fleet Oriented Jobs
JCN	Job Control Number
MAL	Malfunction Code
MDS	Maintenance Data System
NADEP	Naval Aviation Depot
NALDA	Naval Aviation Logistics Data Analysis
NAMO	Naval Aviation Maintenance Office
NAMP	Naval Aviation Maintenance Plan
NAMSO	Naval Aviation Maintenance Support Office

NPS	Naval Postgraduate School
PC	Personal Computer
SAF	Support Action Form
SAS	Statistical Analysis System
SCIR	Subsystem Capability Impact Reporting
SRC	Scheduled Removal Component
TDSA	Technical Directive Status Accounting
TRANS	Transaction Code
VIDS/MAF	Visual Information Display/Maintenance Action Form

I. INTRODUCTION

A. BACKGROUND

This thesis is an early step in a long term development project dedicated to producing the personal computer based Expert System Advisor for Aircraft Maintenance Scheduling (ESAAMS). The development of expert systems has rapidly expanded in the last decade. These systems are software programs which solve problems requiring primarily human expertise. It may be both beneficial and cost effective to develop and provide such an expert system to organizational level aviation maintenance managers to advise and assist them with the challenging task of aircraft maintenance discrepancy scheduling. This thesis builds directly upon the earlier work of McCaffrey [Ref. 1], and to a lesser extent upon the works of Chase [Ref. 2] and Allan and McSwain [Ref. 3].

B. OBJECTIVES

The objectives of this thesis are to review the requirements of developing an expert system knowledge base and to determine the suitability, availability, accuracy and reliability of the Naval Aviation Logistics Data Analysis (NALDA) databases as the foundation of unique databases which are essential elements of such an expert system.

The following research questions will be addressed:

- What is an expert system, how is one developed, and how will they assist maintenance managers?
- What is NALDA, where does it obtain its data, and what type of information does it maintain?
- How timely and accurate is the data contained within the various NALDA databases?
- How often will the information retrieved from the NALDA databases need to be updated.
- Will different databases be required to support organizations operating in different geographical locations?
- Can the required data be broken out of the NALDA databases in a format suitable for expert system utilization?

C. METHODOLOGY

Research into expert systems and various aspects of the NALDA system was conducted in literature, by telephone conversation with Mr. Bob Zolio of the Aviation Supply Office (ASO-045401) and members of the NALDA Users Assistance Group, and by a personal unstructured interview with Mr. Gene Woodburn (NAMO-622C).

In addition to this analytical research, a rudimentary quantitative analysis was conducted on a data sample obtained from NALDA's Fleet Oriented Jobs (FOJ) database. The data sample provided various data elements concerning approximately 78,000 individual maintenance actions performed on various systems and sub-systems of Navy and Marine Corps F/A-18 aircraft over a twelve month period ending in August of 1990. Detailed information concerning how the data sample was developed, definitions of the various data elements are contained in chapter VI. A print-out of a small portion of the sample data is contained in Appendix A. Copies of the data sample diskette and printed results of the two analysis of variance (ANOVA) examinations performed will be maintained on file with the author and Professor Martin J. McCaffrey at the Naval Postgraduate School, Monterey, CA. Data manipulation and analysis was conducted on the Naval Postgraduate School (NPS) mainframe computer using the Statistical Analysis System (SAS) program.

Analysis of variance was performed on mean elapsed maintenance time (EMT) computed for various groups. EMT was chosen, based on the author's personal experience, as the most important predictor used in maintenance discrepancy scheduling. An expert system that accurately projects the EMT for a particular maintenance action would allow the maintenance manager to prioritize the discrepancies to be worked upon, to minimize idle time during the repair cycle, and to maximize utilization of his activity's limited repair facilities.

D. THESIS ORGANIZATION

The remaining chapters of the thesis are as follows:

II. EXPERT SYSTEMS. A general description of expert systems, their components, and their development. Emphasis is placed upon the knowledge base and the task of knowledge acquisition as they pertain to the development of the ESAAMS project.

III. NALDA. A general description of the NALDA system, its various databases, and the source of its data.

IV. DATABASE ACCURACY. The accuracy and consistency of the NALDA databases is closely examined.

V. CONCLUSIONS.

II. AN INTRODUCTION TO EXPERT SYSTEMS

A. INTRODUCTION

This chapter serves as an introduction to expert systems, with emphasis on the knowledge base component of an expert system and the knowledge acquisition process as they pertain to the proposed ESAAMS system. The concepts and basic elements of an expert system, how an expert system would benefit aircraft maintenance managers, how expert systems differ from conventional computer programs, the stages in the development of an expert system, a variety of knowledge acquisition techniques, and the topic of knowledge validation will all be discussed.

B. EXPERT SYSTEMS

Although the concept of expert systems has long been a topic within the artificial intelligence (AI) community, the term expert system has only recently gained wide and accepted use. What is an expert system? Dimitris Chorafas defined an expert system as:

> ...software constructs that experts in specific fields enrich with their knowledge. By distilling their expertise into sets of laws and entering them into systems, the experts produce applications programs that help nonexperts solve problems in the experts' fields by responding to program queries. As such, expert systems are artificial intelligence programs that enable a computer to aid you in a decision-making process. The

> knowhow of the human expert is used to instruct the computer how to solve a problem or make a decision. [Ref. 4:pp. 62-63]

Donald Waterman, a prolific writer on the subject, defined expert systems as:

> ...computer programs that manipulate knowledge to solve problems efficiently and effectively in a narrow problem area. Like real human experts, these systems use symbolic logic and heuristics-rules of thumb-to find solutions. And like real experts, they make mistakes but have the capacity to learn from their errors. However, this artificial expertise has some advantages over human expertise: It is permanent, consistent, easy to transfer and document, and cheaper. In sum, by linking the power of computers to the richness of human experience, expert systems enhance the value of expert knowledge by making it readily and widely accessible. [Ref. 5:p. XVII]

Finally, M. A. Bramer defined an expert system simply as:

> ...a computing system which embodies organized knowledge concerning some specific area of human expertise, sufficient to perform as a cost-effective consultant. [Ref. 6:p. 3]

Bramer expanded on his definition by stating that expert systems usually make use of heuristic rules, relating to the specialty in question, which are obtained from subject matter experts and refined through experience.

Heuristic is a term derived from the Greek word "heuriskein", meaning to discover. A heuristic is a rule of thumb, a technique or a simplification that limits or narrows the search procedure.

The earliest acknowledged expert system, DRENDAL, was first developed in the 1965 [Ref. 6:p. 3]. Two other early and comparatively well known expert systems, both developed at the Stanford Research Institute, are MYCIN (a medical diagnostic tool), and PROSPECTOR (a geological exploration tool). Another well known, and more recently developed, expert system is ACE (Automated Cable Expertise), developed by AT&T and in use since 1982. Currently expert systems are widely utilized in many fields and are gaining popularity in the military, manufacturing, banking and service industries. [Ref. 7:p. 69]

Despite their growing use and the positive nature of the definitions above, readers should be aware that expert systems are not the answer to every problem and do have their drawbacks. Expert systems are designed to perform tasks that require cognitive as opposed to physical skills. If the task can only be learned through practicing physical manipulations then it is unlikely that the expert system approach will succeed. [Ref. 5:p. 128] The development of an expert system is an extremely complex and time consuming operation. Extracting expert knowledge is a challenging process. Finally, even with the best experts contributing to their development, knowledge based systems are not 100% reliable. [Ref. 7:p. 74]

C. DIFFERENCES BETWEEN EXPERT SYSTEMS AND CONVENTIONAL PROGRAMS

Valerie Barr of the Pratt Institute writes that:

> In expert systems, unlike other types of programs, we tell the computer what to know, not what to do. When constructing the expert system, we do not provide a set of instructions; rather , we provide knowledge and advice. If we have a step-by-step algorithm for solving the problem at hand, then a "traditional" program is in order. However, if we have no such step-by-step method, then an expert system is in order. [Ref. 8:p.68]

Some readers may confuse an expert system with the more widely known decision support systems (DSS) or database management systems (DBMS). The key difference is that as DSSs have been constructed on the knowledge acquired through DBMS applications, expert systems are built upon the foundation of knowledge gained through the development and implementation of DSSs. [Ref. 4:p. 67] An easy to remember and rudimentary difference between expert systems and DSS or DBMS programs is that while the conventional programs manipulate data, expert systems manipulate knowledge [Ref. 7:p. 67].

D. BENEFITS OF DEVELOPING ESAAMS

McCaffrey determined that the aircraft maintenance discrepancy scheduling domain was acceptable for an expert system solution and that developing an expert system to assist aircraft maintenance managers would be beneficial to the U.S. Navy [Ref. 1:pp. 107-111]. The development of a knowledge base of shared expertise would partially solve the learning curve problem many managers experience when assigned to a squadron possessing aircraft they are not familiar with.

Additionally, expert system development offers one of the few methods available with the potential to achieve significant gains in operational readiness. Because of the large aircraft inventory possessed by the Navy and Marine Corps, a gain of as little as one percent would translate into an additional 50 operationally ready aircraft per day. [Ref. 1, pp. 110-111]

E. COMPONENTS OF AN EXPERT SYSTEM

An expert system consists of three basic components [Ref. 7:pp. 76-77]:

- A knowledge bank (sometimes referred to as an information base or a knowledge base), containing task specific facts and rules. In a rule based expert system, the knowledge base breaks down into the rule base and the working memory (or data base).
- An inference engine, containing problem solving methods and a mechanism for using the knowledge base's information.
- A user interface, which allows the user, the maintenance manager in the case of ESAAMS, to interact with the program.

Frequently, rather than duplicate data already stored in existing databases within the knowledge base, an expert system will be designed to import data from a database when needed. A diagram illustrating the major components of the ESAAMS system, including the NALDA databases, is provided in Figure 1.

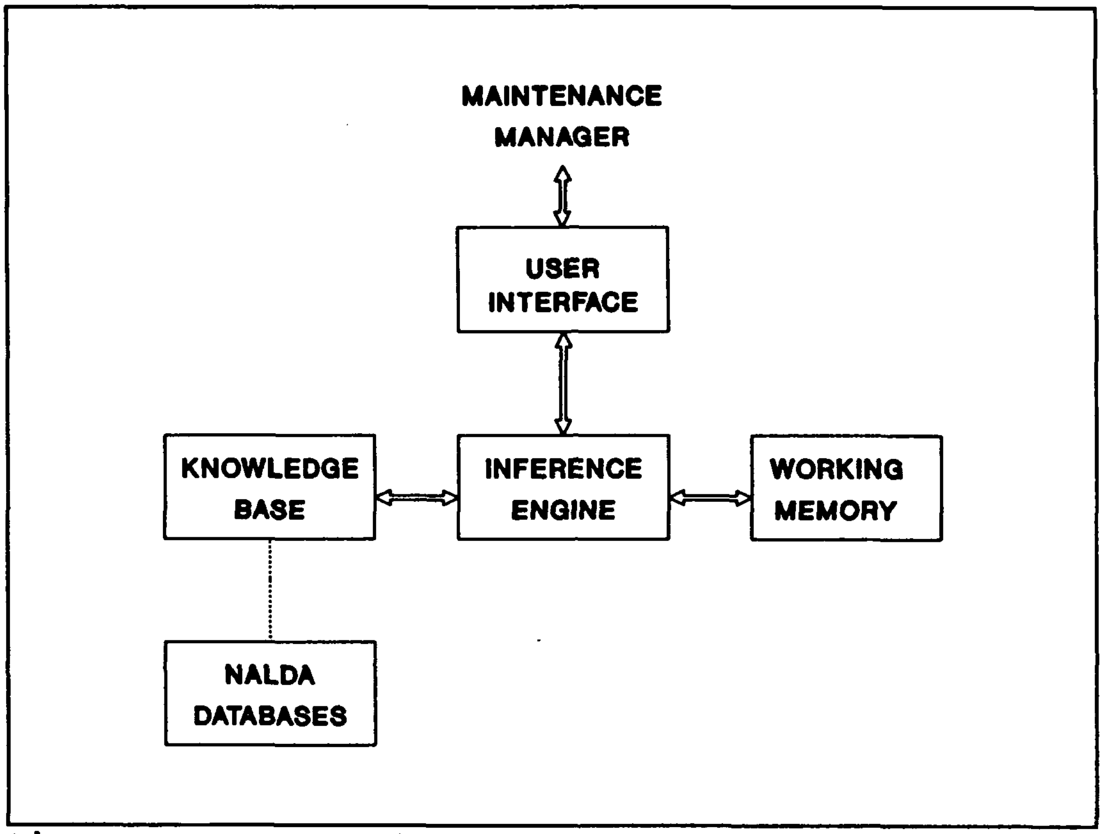

Figure 1 ESAAMS System Components

The two primary components of any expert system, which require the majority of the development effort, are the inference engine and the knowledge base. The function of the inference engine is hypothesis proving. The inference engine is software that implements a search of the rules contained in the knowledge base, looking for matches to the initial information given in the working memory. The inference engine controls the process of invoking rules, deciding how to apply the rules to infer new knowledge and in which order the rules should be applied.

Developers of expert systems today can choose from a number of commercially available expert system shells. An expert system shell is a program containing a working, tested and debugged inference engine and user interface in a framework into which the developer can program the unique knowledge for his particular application into the knowledge base. [Ref. 8:pp. 68-69] The obvious advantage of using an expert system shell is that it allows the developer to concentrate on acquiring and refining the knowledge base instead of the computer code necessary to produce a functioning inference engine.

The knowledge base, sometimes referred to as the knowledge bank in order to avoid confusion with the term "database", is the heart of any expert system. Walters and Nielsen defined a knowledge base as containing:

> ...all the application-specific information. This information can be in the form of simple facts (e.g., data names and values), relationships (e.g., parent-child class memberships), or procedural information (e.g., sequential code for printing a report or drawing a graph). [Ref. 9:p. 5]

The knowledge base contains facts in its working memory, and rules in its rule base. Rules can be thought of as long term information that rarely, if ever, changes. Conversely, facts are short term information that can change quite often. Today, most commercial and experimental expert systems use the IF-THEN rule format. Rules are formatted into two separate parts. The first part of the rule (IF) states some premise or condition. The IF part of the rule may contain more than a single premise and, if so, will contain a clause for each. These are called compound clauses and are linked by conjunctions AND or OR. The second part of the rule (THEN) states a conclusion, consequence, or action that will occur if the conditions of the first part of the rule have been met. [Ref. 7:pp. 77-78] For example:

```
IF   the animal lives in water
AND  the animal breathes water
THEN the animal is a fish, CF 1.0
```

The CF stands for certainty factor, and is sometimes referred to as a confidence factor or rule strength. It is a number between 0 and 1 representing the confidence we have in the validity of our conclusion. A certainty factor is not a probability, it is simply a number that represents the degree of uncertainty you have in a particular rule. Certainty factors are determined by the human experts creating the knowledge base. The certainty factors can be based upon either intelligent estimates, statistical data, or a combination of the two. In rules with compound premise clauses connected by either AND or OR, each clause may have its own certainty factor and the programmer must determine a means to compute a composite certainty factor for the rule. [Ref. 7:pp. 86-88]

F. EXPERT SYSTEM DEVELOPMENT

There are several methods for developing expert systems. This report will summarize a scheme published by Juan J. Ferrada and John M. Holmes. [Ref. 10:pp. 35-41] The development of an expert system can be simplified to four global steps:

- Defining the problem
- Preliminary prototyping
- Developing the expanded prototype
- Delivering the system

1. Defining the Problem

The objectives of this step are to ensure that: the problem to be solved is clearly defined; the project will satisfy a real need; the project is technically feasible; the functions to be carried out are specified; the knowledge base requirements are established; and the available expert system development tools are analyzed.

After the above questions have been answered, a decision must be made whether to use an expert system shell or an AI computer language. Expert systems can be constructed utilizing any number of commercially available expert system shells or AI computer languages. An expert shell has the advantage of containing a substantial amount of AI code and an inference engine that has been tested, debugged and maintained. Building an expert system using an AI computer language provides the expert system developer with greater flexibility while simultaneously tasking him with writing a considerable amount of code.

The final requirement of this initial step is to define the available sources of expert knowledge. A knowledge engineer is the person responsible for gathering and organizing the expert knowledge into an expert system knowledge base. The knowledge engineer must identify the knowledge base requirements as well as the reliability and availability of human experts, databases, spreadsheets, descriptions in text files, graphics and external computer programs. The topic of knowledge acquisition will be discussed in greater detail later in this thesis.

2. Preliminary Prototyping

The principal objective of this step is to quickly demonstrate the technical and economic feasibility of the expert system under development. Preliminary prototype testing should be analyzed to determine how well the interface relates to the knowledge base, how well the inference engine can adapt to the way the knowledge has been introduced to the expert system, how well the knowledge base has been organized by the knowledge engineer, and how well the proposed environment for delivery (PC, minicomputer or mainframe) performs. As recently as 1987 most writers concluded that useful expert systems had to implemented and delivered on minicomputers or mainframes [Ref. 7:p. 74]. Currently personal computers, which are quickly migrating to the 386, the 486 and even more powerful chips, have begun to represent the single largest segment of the expert system business and are the key to the commercial acceptance of expert system technology [Ref. 11:p. 56].

3. Developing the Expanded Prototype

The objective of this step is to develop a system capable of convincing management that it is a useful and potentially valuable tool. The expanded prototype should include an expansion of the knowledge base, sophistication of representation, and links to other systems and programs. The system should be capable of dealing with a variety of exceptions and special cases ignored during earlier prototyping. If the expanded prototype performs well the development of a more extensive delivery system may not be required.

4. Delivering the System

During this phase the developer analyzes the different delivery environments mentioned above and optimizes the program requirements in terms of memory usage or performance.

G. KNOWLEDGE ACQUISITION AND REFINEMENT

Expert systems are powerful and valuable instruments because of the capacity they gain from the knowledge they incorporate. The development of a reliable and accurate knowledge base is the primary goal of any knowledge engineer tasked with developing an expert system. Knowledge acquisition and refinement have historically accounted for a major portion of the overall development expense and time of most expert systems. Knowledge acquisition is defined as:

> ...the transfer of expertise from a human expert to a machine. When the machine, extends its initial knowledge by learning methods, we refer to this as knowledge refinement [Ref. 12:p. 320].

As the demand for expert systems has multiplied, the limited availability of qualified and skilled knowledge engineers has made knowledge acquisition appear to be a major bottleneck in the construction of new expert systems. However, this assumption is based on the dated view that knowledge engineering is a manual craft, depending on the skill of a knowledge engineer who is armed with only a pen, paper and tape recorder. The key to solving this knowledge acquisition bottleneck is to automate some portion of the knowledge engineering tasks. [Ref. 13:p. 49]

Traditionally, knowledge acquisition has been performed by a knowledge engineer who interviews an expert, identifies the components of his knowledge, and builds the expert system knowledge base. The knowledge engineer's task is complicated by the fact that human experts have rarely analyzed their thoughts and the structure of their knowledge, and can rarely provide an overall account of how a decision is made. Traditionally knowledge obtained from any source other than a human expert was discounted when developing an expert system. Frenzel stated, in 1987, that:

> .knowledge comes in many forms. It can be standard textbook knowledge that you can dig out of books, articles, and other references quickly and easily. This knowledge is important, but is usually not the best kind of knowledge for an expert system. The real knowledge will come from individuals who are experts in the subject. [Ref. 7:p. 105]

The traditional interview approach to knowledge acquisition has several shortcomings. One is the afore mentioned shortage of skilled knowledge engineers. Another is the growth in size of expert systems knowledge bases. Early expert systems often used less than 100 rules, and the use of more than 300 rules was rare [Ref. 14:p. 44]. Current state-of-the-art expert systems may contain tens of thousands of rules in their knowledge bases [Ref. 15:p. 15]. McCaffrey estimated the knowledge base of the proposed expert system would contain approximately 1000 to 2000 rules [Ref.1:p. 122]. Clearly automating some or all of the knowledge acquisition process is called for in order to overcome the "knowledge engineering bottleneck."

Parsaye, who defines knowledge acquisition as "the transfer of problem-solving expertise from some knowledge source to a program," identifies three basic approaches to knowledge acquisition currently available [Ref. 13:p.50]:

- interviewing
- learning by interaction
- learning by induction

1. Interviewing

This technique involves the knowledge engineer acquiring knowledge from a human expert through a sequence of interviews and then encoding the acquired knowledge in the expert system's knowledge base. The knowledge engineer plays a central role in this process and his skills largely determine the quality of the information obtained and entered into the knowledge base.

Most readers will recognize that while the interview process is an easy-to-apply and flexible approach, it also contains some serious drawbacks: interviewing is a time consuming and subjective process; often the knowledge engineer, with only a limited amount of subject matter expertise, will not explicitly understand important concepts, resulting in an incomplete or inaccurate knowledge base structure; and directly asking questions of experts risks altering their view of what they actually do. With few, if any, knowledge engineers familiar with the complex task of aircraft maintenance scheduling, these drawbacks will be particularly applicable to the development of the ESAAMS project.

2. Learning by Interaction

This knowledge acquisition technique relies on computer assistance. In essence the human expert interacts directly with a computer program that captures his expert knowledge. This process focuses on specific interactive methodologies and interviewing techniques that help experts clarify the structure of their own thoughts and knowledge. The need for a knowledge engineer can be significantly reduced by utilizing the learning by interaction technique.

3. Learning by Induction

In this knowledge acquisition process a computer program distills knowledge by examining data and examples. The basic concept is to have the program learn to perform a task by analyzing the data documenting the human expert's performance. The primary difficulty with learning by induction is identifying suitable attributes and characteristics on which to perform the induction. The primary advantages of this technique are that dependence on knowledge engineers and human experts is diminished, and knowledge bases containing large numbers of rules can be developed in a short period of time.

4. Summary

All three knowledge acquisition techniques have their advantages and disadvantages. The majority of expert systems currently under development will use all three techniques in the development of their knowledge bases. The one factor all three techniques have in common, and an important source of expert knowledge, is historical data about how an expert actually performed a task. Much of this data is contained in computerized databases, such as the various NALDA databases. A fundamental difficulty with using any of these databases is the obstacle of connecting the AI computer language or the expert shell to various external programs and databases. William Martorelli expands on this challenge:

> For expert systems to be most useful, they should be able to communicate with existing systems and data sources. Today's PC-based (expert system) applications are still often stand-alone entities, or they possess rudimentary links to spreadsheets or PC databases. [Ref. 11:p. 62]

A number of vendors are striving to make their expert system development tools more readily connectable to external programs and data bases. Ken Pedersen synopsized the connection capabilities of 11 commercially available PC-based expert system shells in Reference 16. Readers who desire a more thorough documentation of the connection capabilities of these shells are referred to The PC Expert Systems Shoot-Out, published by Expertise Associates of W. Lafayette, Indiana. In general, many of the shells available on the market today can connect to such popular PC based programs as Lotus 1-2-3 and dBase. Many of the expert system shells, such as VP-Expert, can offer an induction module capable of translating record based examples into production rules. The resulting knowledge base is only as good as the data file on which it is based.

H. KNOWLEDGE VALIDATION

A fundamental question concerning every expert system is how applicable is the expert knowledge acquired for your system? Knowledge base validation is an area of great concern to all knowledge engineers. Validation of the knowledge base should be viewed as an ongoing process built into the development effort. The two primary goals of any software validation effort are to ensure that: (1) the program performs the functions intended, and (2) the program does not perform any intended function that could adversely affect the performance of the entire system. [Ref. 17:p. 287] Parsaye expands on this topic:

> Intuitively the aim of any validation effort is to ensure that the expert system behaves correctly. but what does this mean for systems that produce inexact results? Can we ever be 100% sure the knowledge is correct?
>
> From a philosophical viewpoint the answer is no. Even in traditional programs, you can never be 100% sure about a verification effort in all cases since as the program size grows the size of the verification program will also grow, and at some point the verification system may be more complex and error prone than the program itself. [Ref. 13:p. 59]

Parsaye further states that the two key questions to ask during validation are: (1) How often are mistakes made?, and (2) What is the price to be paid for each mistake?

Parsaye's approach is to compare the performance of the expert system under development against that of a human expert, or even another expert system, on a series of test cases. Because the overall measure of performance obtained under these circumstances would depend largely on the quality of the test cases, it is important to also measure the quality of the test cases. Utilizing a more representative set of test cases will furnish the developer with a more significant set of results.

I. SUMMARY

This chapter has provided the reader with a large amount of information concerning expert systems and their development. The three most significant points to take from this chapter are that:

- With the ready availability of commercially proven shells, the most challenging task facing today's expert system developer is to acquire, develop and validate the applicable knowledge base rules.
- Whichever combination of knowledge acquisition techniques is used, a data base of information concerning past expert performance is required. The quality of the knowledge base developed will depend largely on the accuracy, timeliness and completeness of the information contained in the database.
- Connectability with the NALDA system should be considered when choosing an expert system shell for use on the ESAAMS project. Because NALDA has the capability to download data via floppy diskette in ASCII format, indirect connection through widely available software, such as dBase or Lotus 1-2-3, with many currently available expert system shells is likely. Further research into the direct connection of the NALDA system with an expert system shell is warranted.

III. NALDA

A. INTRODUCTION

This chapter describes the NALDA system, including the source of NALDA's data and the various databases it maintains. The following specific questions will be addressed: What is NALDA? Where does NALDA obtain its data? What type of information is stored in the various NALDA databases? Which database is the most likely source of information for the unique databases which will become essential elements of the ESAAMS system.

B. NALDA DEFINED

The NALDA system, is:

> ...an automated database and information retrieval system for aviation logistics management and technical decision support. Analysis capability is provided through interactive query and batch processing from remote terminals. [Ref. 18:p. I-1]

The principal objective of the NALDA system is to supply a state-of-the-art management information system to assist Naval Aviation maintenance and logistics managers in making improved decisions affecting U.S. Naval Aviation readiness. To accomplish this objective the NALDA system provides a centralized data bank, including remote terminals with maintenance data retrieval and analysis capabilities, that can solve complex integrated logistics support problems for which other available means have consistently proved inadequate. [Ref. 18:p. I-1] Overall management of the NALDA program is conducted by the Naval Air Systems Command, while day-to-day operations are coordinated by the Naval Aviation Maintenance Office (NAMO), located aboard Naval Air Station Patuxent River, Maryland.

C. NALDA DATA SOURCES

NALDA incorporates data from an assortment of different sources including Naval Aviation Depots, the Aviation Supply Office, and the Naval Safety Center [Ref. 18:p. I-1]. The principal source for NALDA data is the monthly Aviation Maintenance and Material Management (3-M) summary produced by the Naval Aviation Maintenance Support Office (NAMSO).

The source for the 3-M summary is the Navy's Maintenance Data System (MDS). The Naval Aviation Maintenance Plan (NAMP), separates the MDS data flow into three cycles [Ref. 19:para. 2.1.3 - 2.1.7]:

- <u>Local Cycle</u>: During this cycle data elements concerning maintenance actions performed are entered onto source documents by technicians at either the organizational or intermediate level.

- <u>Local/central Cycle</u>: During this cycle the completed source documents are screened, corrected, and converted into machine language by a supporting data services facility (DSF).

- <u>Central/external Cycle</u>: During this cycle data from the numerous DSFs are collected and processed by NAMSO, and various reports are issued to originating activities and the chain of command.

1. Local Cycle

The local cycle of the MDS is designed so that each technician, when performing a task, converts a narrative summary of the task into a series of alphanumeric and numeric codes and enters the coded information on to one of two source documents, either a Support Action Form (SAF) or a Visual Information Display System/Maintenance Action Form (VIDS/MAF). Source documents are screened for accuracy and completeness by the technician's work center supervisor, maintenance control supervisor, and the activity's data analyst. These source documents are then collected and transported to a local data services facility (DSF), located aboard either the host air station or deployed ship, where the information is converted to machine record. The DSFs screen the incoming source documents and any questionable data are referred back to the originating activity for verification. The DSF uses the machine records to produce a number of periodic reports summarizing the submitted data. These reports are used to verify the data, for local unit analysis, and for maintenance planning.

2. Local/Central Cycle

After verification, duplicate record files of the information are generated and transmitted to NAMSO, Naval Aviation's central collection facility. At NAMSO the data received is combined with data received from other DSFs.

Machine runs for errors which are detectable by computer are made, and the results of this error analysis are forwarded back to the DSFs and originating activities.

3. Central/External Cycle

In addition to providing periodic 3-M feedback reports to the originating activities, NAMSO provides data and reports to various agencies, including the Chief of Naval Operations (CNO), various systems command field agencies, NALDA, and contractors.

D. NALDA DATABASES

NALDA maintains a number of specialized processing systems and databases. These systems and databases are designed to provide system users with the necessary information to solve problems and to make informed management decisions. [Ref. 18:pp. I-2 to I-3] These databases include:

- Fleet Oriented Jobs (FOJ): contains the most recent eighteen months of selected maintenance, material, readiness, inventory and operations data and are the principal repository of source data in the NALDA system.
- Equipment Condition Analysis (ECA): Provides users with 3-M data and flight data, as far back as 1974.
- Technical Directive Status Accounting (TDSA): Stores, maintains, and disseminates information concerning the incorporation/non-incorporation of Technical Directives. Provides projected and actual man-hour reporting, configuration status of equipment items, and change-kits material accounting.
- Support Action Form (SAF): Contains the most recent eighteen months of support action data.

- Depot oriented Jobs (DOJ): Contains data collected by the Depot Maintenance Data System related to jobs originated by the depots.

- Intermediate Maintenance Activity Analysis (IMA): Contains summary data that facilitates analysis of production data at the intermediate level of maintenance and at individual IMAs for items identified by either a National Stock Number or a part number.

- Utilization (UTIL): Contains the most recent eighteen months of utilization and aircraft flight/flight hour data.

- NALDA/Aircraft Engine Management System (NALDA/AEMS): Contains information derived from the Navy's on-line AEMS.

- Equipment Summary Reports (ESR): Contains current summary information which is identical to the information contained in Aviation 3-M reports.

- Scheduled Removal Component (NEWSRC): Contains data from Scheduled Removal Component (SRC), Assembly Service Record, Module Service Record and History Record forms which are collected at the SRC Central Repository.

E. THE MOST LIKELY SOURCE OF DATA FOR ESAAMS

After interviewing numerous personnel working in the NALDA User Assistance Group, this author determined that the most probable source for the majority of the data needed for the ESAAMS system knowledge base was the FOJ database. Based on this determination, further research and analysis concentrated on the FOJ database. Other specialized databases maintained by NALDA could be utilized, depending upon the information required and the scope of the proposed ESAAMS system.

F. SUMMARY

This chapter has presented the reader with a large amount of information concerning the NALDA system and the databases it maintains. The key point to take from this chapter is that the NALDA databases are Naval Aviation's central repository of logistical and maintenance information. Because they gather historical information from a wide variety of sources throughout the fleet, and because they are uniquely organized to handle ad hoc queries, they are the most likely source of data for the unique databases which will become essential elements of the ESAAMS system.

IV. SUITABILITY AND ACCURACY

A. INTRODUCTION

This chapter evaluates the suitability and accuracy of the NALDA databases as the foundation for the knowledge base of the ESAAMS system. A description of the data sample used in this evaluation process is provided. The following specific research questions are answered: Can the data be broken out in a useful form? How dated is the NALDA data? How accurate is the data? How does geographical location of the originating activities affect the data? How often would a knowledge base founded upon the NALDA databases need to be updated?

B. DATA SAMPLE

A data sample, comprising records of approximately 78,000 individual F/A-18 maintenance actions, was obtained from the NALDA Users Assistance Group. A print-out of a portion of this data sample is attached as Appendix A. The following information was contained in each record: Job Control Number (JCN), Work Unit Code (WUC), Transaction Code (TRANS), Malfunction Code (MAL), and Elapsed Maintenance Time (EMT). Another data element, Maintenance Man-Hours (MMH), was provided in the data sample but was not used in the analysis. A brief description of each data element follows.

1. Job Control Number (JCN)

The JCN is a 9-, 10-, or 11-character alphanumeric code that serves as a base for MDR and Maintenance control procedures. The JCN allows for separate identification of each maintenance action, and provides a link with the maintenance actions performed by the IMA (Intermediate Maintenance Activity) in support of an activity or an O-level (Organizational level) maintenance discrepancy. [Ref. 19:para. 2.1.6.7] The JCN is composed of four parts:

- Organization Code: This is a three-character alphanumeric code that identifies an organization.

- Day: This is the three-character part of the Julian date specifying the day of the year. This is the date the JCN was assigned to a maintenance action and does not necessarily reflect the date on which work was actually started.

- Serial Number: The serial number is either a three character number that runs sequentially from 001 to 999, or a three character alpha/numeric number. This number is normally assigned in sequences as new jobs are initiated.

- Suffix: The JCN suffix is a structured alpha/numeric code added to the basic JCN to identify a sub-assembly or sub-assembly repair action performed independently of the major component repair. The Suffix is used only for I-level (Intermediate level) maintenance functions regardless of where the maintenance is being performed.

2. Work Unit Code (WUC)

The WUC is a one, three, five or seven character numeric or alpha/numeric code. It identifies a system, subsystem, set, major component, repairable subassembly, or part of an end item being worked on. The system code is the first two positions of the WUC, and is used to identify the system within the aircraft/equipment on which work is being performed. These codes are listed in the WUC manual applicable to the type, model, and series of aircraft being maintained. [Ref 19:para. 2.1.6.12]

3. **Transaction Code (TRANS)**

This is a two-character numeric code used to identify the type of data being reported [Ref 19:para. 9.2.4.8]. Examples of commonly used transaction codes include:

- Transaction Code 12: On-Equipment work, including engines, involving non-repairable components/items documented as failed parts.
- Transaction Code 11: On-Equipment work not involving removal of defective or suspected defective components/items.
- Transaction Code 23: Removal and replacement of a defective or suspected defective repairable component from an end item.

Appendix P of reference 19 contains a complete list of these codes with definitions.

4. **Malfunction Description Code (MAL)**

This is a three character numeric code used to describe the malfunction occurring within the item, assembly or sub-assembly [Ref. 19:para. 9.2.4.12]. Examples of common malfunction codes include:

- 782: Defective or damaged tire sidewall, tread, bead, etc.

- 381: Leaking - internal or external.
- 800: No defect - component removed/reinstalled to facilitate other maintenance.
- 814: Cannibalization - lack of replacement material.

A complete list of malfunction codes is contained in Appendix I of reference 19. [Ref. 19:para. 6.2.4.6.5]

5. Elapsed Maintenance Time (EMT)

EMT is defined as the number of clock hours involved in making the repair (in hours and tenths). Although EMT is directly related to job man-hours, it should not be confused with the total man-hours required to complete a job, for example, if four persons worked together for 2.5 hours to make a repair, the total maintenance man-hours expended would be 10.0 and the EMT would be 2.5 hours. [Ref.19:para. 9.2.4.15]

6. Data Sample Acquisition

The data sample provided by NALDA was comprised of the 15 top WUCs for the F/A-18 as determined by numbers of maintenance actions processed in a one year period. All inspection WUCs were mistakenly excluded from the data sample by members of the NALDA staff. This misunderstanding was unknown to the author until the project was near completion. The statistical effect of limiting the data sample to repair actions only, instead of the requested top 15 WUC's, is estimated to be minor. Data elements on every organizational level F/A-18 maintenance action containing one of these 15 WUCs, performed during the twelve month period ending in August of 1990, were included.

The data sample was downloaded from the NALDA system, compressed, and loaded onto a standard 1.2 MB, 5 1/4" floppy disk in ASCII format. Upon receipt, the data was uncompressed using the PKUNZIP program, provided on the diskette, and loaded onto the NPS mainframe computer. Readers interested in obtaining access to the NALDA system are advised to contact the NALDA Users Assistance Group at Autovon 356-4454.

7. Reasoning

Based Upon the author's personal experience and informal interviews with numerous other Aerospace Maintenance Duty Officers, the data elements listed above were selected for two primary reasons:

- The most critical piece of information required for maintenance scheduling is the projected EMT.
- For comparison purposes, maintenance actions were deemed to be identical if they possessed the same WUC, MAL, and TRANS codes.

EMT was selected for analysis because projected EMT is a vital piece of information that is required for efficient maintenance scheduling. In order to maximize their activity's aircraft operational readiness, organizational level maintenance managers seek to effectively manage their limited manpower and material resources. The challenge these managers face several times a day is to wisely schedule repair actions so as to maximize the number of aircraft available to meet the daily flight schedule. Projected EMT is also vital to the effective coordination and management of shared resources, such as hangar bay spots, support equipment and special tools.

Meeting the daily flight schedule requirements with safe, flyable and properly configured aircraft is the number one priority for all organizational level maintenance managers. When an aircraft returns from a mission with one or more discrepancies, the maintenance manager must quickly ascertain the nature of the discrepancies ("up" or "down")[1] and whether or not his activity possesses the capability to repair the aircraft. Assuming that the aircraft can be repaired by the activity, the maintenance manager must then prioritize the discrepancies and determine when to initiate the repair actions. Aircraft with "down" discrepancies that can be quickly repaired (i.e. a short projected EMT) and returned to an "up" status are generally the number one work priority, so as to provide the maximum number of aircraft assets to meet the daily flight schedule. "Up" discrepancies and "down" aircraft with long projected EMT will generally receive a lower work priority, often being scheduled for repair after the flight schedule has been

[1]Up discrepancies are minor problems which do not prevent the aircraft from safely performing its mission. Down discrepancies prevent an aircraft from flying until repaired.

completed. A more detailed description of the maintenance control decision environment is contained in Reference 1.

Several rudimentary statistical analyses were performed upon this data sample. The author recognizes that the sample may not be representative of all of the information contained in the NALDA databases because it: (1) is limited to one aircraft type, (2) is composed of only the most common maintenance actions, and (3) analysis was further limited to those maintenance actions averaging at least 10 occurrences per month. Nevertheless, the analysis did reveal much about the accuracy and consistency of NALDA's FOJ database.

C. NALDA DATA STRUCTURE/FORMAT

As a large relational database, the *NALDA* system can easily retrieve any required information contained in any one of its specific databases. While the computational capabilities of the NALDA system are limited (means and standard deviations can be calculated), the desired data can be easily downloaded in a variety of formats for use on other more powerful computers.

The data sample used in preparing this thesis was assembled and downloaded onto a standard floppy disk in ASCII format. The NALDA User Assistance Group indicated to the author their willingness to provide data samples to support future research. Tasking NAMO to regularly organize and download the NALDA data, by aircraft type, required to develop and maintain the unique databases which will become essential elements of the ESAAMS system will, in the author's opinion, cause only a minor addition to their present workload.

Based upon this author's personal experience every expert likely to be interviewed during the knowledge acquisition phase, particularly senior enlisted maintenance managers, should be thoroughly familiar with the data elements contained in the various NALDA databases. Framing the expert's reasoning in terms of data elements contained in the various NALDA databases should prove to be a time consuming, but not particularly difficult, task. Some items that are significant factors in organizational level aviation maintenance scheduling, such as the availability of qualified technicians and the availability of required support equipment or hangar space, are not contained in any of the NALDA databases.

D. NALDA DATABASE MAINTENANCE

Current NALDA instructions call for the various databases to be updated at least monthly and set a maximum data time lag goal of 60 days. [Ref. 20] During interviews with various members of the NALDA Users Assistance Group it was stated that the time it takes the data concerning a particular maintenance action to flow through the three MDS cycles, through NAMSO, and eventually in to the various NALDA databases rarely exceeds 90 days and currently averages approximately 60 days. [Ref. 21] No documentation was available to support this statement, however these figures of 60 and 90 days corroborate the earlier findings of McCutcheon [Ref. 22:p. 33].

It is important to note that the majority of the maintenance managers interviewed by McCutcheon felt that reports generated from data that was 60-90 days old were of little use to them in their management functions. What most maintenance managers desired was a real-time management information system. [Ref. 22:p. 33] This author knows of no such real-time, or even near real-time, system which will be in place at the organizational level in the foreseeable future.

E. NALDA DATA ACCURACY

With the understanding that the accuracy of a database is directly affected by the quality of data input, this question must be examined from two aspects:

- how accurately is the information transferred from the source documents and entered into the NALDA databases?
- how accurately does the information retrieved from the NALDA databases reflect the maintenance actions actually performed in the fleet?

1. How Accurately is the Information Transferred from the Source Documents and Entered Into the NALDA Databases?

Members of the NALDA Users Assistance Group were confident, during interviews with the author, that the vast majority of keypunch errors were caught and corrected in the local cycle of the MDS system. All members interviewed insisted that the keypunch error rate detected at NAMSO during the local/central cycle averaged less than 1%, although this figure could not be documented. [Ref. 20] The author, based on personal experience, estimates that the claimed 1% keypunch error rate is reasonably accurate.

2. How Accurately does the Information Retrieved from the Various NALDA Databases Reflect the Maintenance Actions Actually Performed by the Fleet Activities?

While investigating this question the author contacted a representative of the Aviation Supply Office (ASO) who deals regularly with the NALDA databases. This representative voiced significant dissatisfaction with the accuracy of the NALDA data. ASO's dissatisfaction is based upon three general points [Ref. 23]:

- Reports generated by the MDS system are used to appraise unit performance. Therefore it is in the originating units interest to "fudge" the data, particularly data elements affecting unit readiness.

- Technicians and maintenance managers see little benefit from the reports generated by the MDS system. This leads to inaccurate, inconsistent and incorrect reporting of maintenance activities.

- Many of the data elements within the MDS system are loosely defined and interpreted, leading individual activities document identical maintenance actions differently.

These three points were echoed in separate interviews with two representatives of the Naval Air Systems Command. [Ref. 24 and Ref. 25]

Although no data is available to document the first point, the author, based upon personal experience, will concede that "data fudging" does occur. The majority of "data fudging" occurs with Subsystem Capability Impact Reporting (SCIR) data elements, which are used to generate readiness statistics. The extent to which SCIR data will be utilized in the knowledge acquisition process for ESAAMS is unknown at this time. SCIR data was not analyzed as part of this thesis.

To validate the other two points a large number of interview summaries, conducted by several representatives of the Navy Fleet Material Support Office (FMSO), concerning the MDS system and NALDA in general, and NALDA's TDSA database in particular, were obtained. This series of interviews was conducted with all levels of the chain of command, ranging from the Systems Command level down to representatives of an air station supply department. Typical of the comments made in many of the interviews were those voiced by a representative of the Commander, Naval Air Forces Atlantic Fleet who viewed the NALDA data as inherently inaccurate, and cited three primary reasons for this inaccuracy [Ref. 26] :

- Part Number entries are unstructured: Because part numbers are assigned by the manufacturer, varying widely in length and combination of alpha and numeric characters, no easy method exists to screen source documents or data records to detect incorrect entries or keypunch errors.

- Code changes: Because many data element codes, particularly Work Unit Codes, are often updated and changed, many data entries are incorrectly made because the technician has memorized the old code and fails to check the manual. Additionally, changing data element codes vastly complicate the task of analyzing and comparing historical data.

- Loose definitions: Definitions of many codes, particularly malfunction codes, are loose. Individual interpretations of which data code is appropriate to a particular maintenance action will have a significant impact on the consistency and accuracy of the databases.

Another problem concerning the accuracy of the NALDA databases was identified by a representative of the Naval Aviation Depot (NADEP) at Norfolk, Virginia. His point was that documentation of repair actions of individual components was inconsistent at most NADEPs, including his own, and virtually non-existent if the item was repaired by the manufacturer or an independent contractor. [Ref. 27] Because this project is not likely to be concerned with the repair history of individual components, and is concentrating on the organizational level, this problem should have little impact on the proposed project.

During another interview with a representative of the NADEP Norfolk A-6 engineering staff, the results of an audit of NALDA's TDSA database with respect to a specific airframes modification (AFC-562) revealed that of 1061 entries, 130 (12%) were incorrect [Ref. 28]. Discrepancies fell into two general categories:

- TDSA showed that the change was not incorporated, but the change actually had been incorporated on the aircraft. (60 discrepancies)
- TDSA showed that the change was incorporated, but the change actually had not been incorporated on the aircraft. (70 discrepancies)

It must be stressed that the deficiencies identified above are largely opinions based on the personal experiences of the interview subjects, and are not conclusive proof that the data contained in the NALDA system is inaccurate. It should also be noted that any deficiencies that may exist in the NALDA databases appear to be largely the result of "user error" throughout the fleet and mismanagement of the MDS program, and are not the fault or specific responsibility of the NALDA managers. Further evidence concerning the accuracy of the NALDA databases will be discussed in later sections of this chapter.

F. THE AFFECT OF GEOGRAPHICAL LOCATION OF ORIGINATING ACTIVITIES ON EMT

To ascertain the effect of the geographic location of the originating activities on EMT, the data records from the sample provided by NAMO were separated, using the organization codes located within the job control number (JCN), into East coast and West cost maintenance actions. The mean EMT for 92 individual maintenance actions for both coasts were compared and the variances analyzed. The following definitions were established:

$$H_0: \mu_{east} = \mu_{west}$$

$$H_1: \mu_{east} \neq \mu_{west}$$

H_0 is the hypothesis we wished to test and is referred to as the null hypothesis. The rejection of H_0 leads to acceptance of the alternative hypothesis, denoted H_1. An example listing of the ANOVA results is contained in Figure 2.[2]

Of the 92 maintenance actions analyzed, 42 (47%) indicated a probability of less than 5% that the two means were equal. Assuming that this is a representative sample, the results indicate that the geographical location of the originating activity does significantly affect the NALDA databases. If we are to use historical EMT data to project EMT, the expert system will need to take this fact into

[2]Complete listings of these ANOVA results will be maintained on file by the author and Professor Martin J. McCaffrey of the Naval Postgraduate School, Monterey California.

Coast	N	Mean EMT
East	122	1.1311
West	342	0.9506

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F
MODEL	1	2.9317	2.9317	16.16	0.0001
ERROR	462	83.7966	0.1814		
CORRECTED TOTAL	463	86.7283	ROOT MSE	R-SQUARE	MEAN EMT
C.V.	42.67		0.4259	0.0338	0.9981

Figure 2 Analysis of variance for: WUC=13C1700, TRANS=23, MAL=782.

consideration. NALDA EMT data will most likely be divided into East and West coast databases.

A closer examination of the complete ANOVA results listings and the example contained in Figure 2 reveals two other interesting factors. First, despite a low statistical probability that the true East and West coast means were equal, many of the sample means differed by 0.25 hours or less. While a variation of 0.25 hours may translate into significant statistical difference between means, from a practical maintenance manager's viewpoint this difference is essentially insignificant for many maintenance actions.

The second factor noted was the wide variation in the frequency of occurrence of identical maintenance actions between the East and West coasts. With both coasts containing roughly the same number of F/A-18 aircraft, the number of identical maintenance actions performed on each coast was expected to be approximately equal. While the majority of maintenance actions analyzed displayed a rough parity in terms of number of maintenance actions performed on both coasts, ratios of two-to-one and three-to-one were common, with the highest ratio noted exceeding twenty-to-one. The example results displayed in Figure 1 show a near three-to-one ratio between the west and east coasts. Neither the East or West coast consistently dominated its counterpart when the frequencies were imbalanced. This inconsistency lends support to the allegations listed above that the definitions of some MDS code elements are loose. If activities performing identical maintenance actions continue to document them differently because of loose code definitions, inconsistencies and inaccuracies in the database will persist.

G. UPDATE FREQUENCY OF AN EXPERT SYSTEM DATABASE, FOUNDED UPON THE NALDA DATABASES

To evaluate how often the knowledge base of the ESAAMS system will require updates from the NALDA databases, the maintenance actions documented in the data sample were grouped by month, using the Julian date component of the JCN. Mean EMTs for each month for each specific maintenance action were compared and the variances analyzed. Months were numbered sequentially, one through twelve, and the mean

EMT for each month was calculated. The null hypothesis, H_0, was defined as follows:

$$H_0: \mu_1 = \mu_2 = \ldots = \mu_{12}$$

H_1, the alternative hypothesis, was defined as at least two of the means not being equal. An example listing of the ANOVA results is contained in Figure 2.[3] Of 105 separate

MONTH	N	MEAN EMT	MONTH	N	MEAN EMT
1	64	1.2703	7	62	1.2581
2	63	1.2603	8	62	1.4241
3	55	1.4418	9	48	1.3792
4	59	1.4559	10	44	1.2000
5	74	1.5216	11	52	1.4596
6	96	1.2614	12	54	1.3981

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F
MODEL	11	7.5551	0.6868	1.33	0.2035
ERROR	721	372.6553	0.5169		
CORRECTED TOTAL	732	380.2103	ROOT MSE	R-SQUARE	MEAN EMT
C.V.	52.8932		0.7189	0.0199	1.3592

Figure 3 Analysis of Variance for: WUC= 62X2100, TRANS=18, MAL=814.

maintenance actions examined , 32 (30%) indicated a probability of less than 5% that the true means of all twelve months were equal. The ANOVA results indicate that

[3]Complete listings of these ANOVA results will be maintained on file by the author and Professor Martin J. McCaffrey of the Naval Postgraduate School, Monterey California.

updates of the knowledge base for at least these 32 maintenance actions will need to be conducted more frequently than once per year. The actual determination of how often to update the databases used to develop and maintain the knowledge base for the proposed expert system will require a more detailed statistical and cost/benefit analysis and is beyond the scope of this report.

It was noted that while small variations (less than .25 hours) between the monthly mean EMTs and the mean EMT for the twelve month period may have been statistically significant for several of the maintenance actions examined, they were again, from a practical user's viewpoint, essentially insignificant for many maintenance actions.

H. SUMMARY

This chapter has presented the reader with a large amount of information concerning the accuracy and consistency of the various NALDA databases and their ability to support the unique databases which will become essential elements of the ESAAMS system. The key points to take from this chapter are:

- Because every expert in Naval Aviation maintenance management is thoroughly familiar with the MDS system, a database, such as those maintained by NALDA, can easily break-out the data required to validate the expert's reasoning.
- The data contained in the various NALDA databases is updated at least monthly, with an average time lag of 60 days between completion of a particular maintenance

action and inclusion of the data in the NALDA system. While real-time, or near real-time, database updates may be desirable, such a system may not be cost effective and is not foreseen to appear at the organizational level in the near future.

- While the accuracy of the transfer of data from source documents, through the three MDS cycles, and into the NALDA databases appears to be very good, the ability of the MDS data elements to accurately reflect the actual maintenance actions being performed in the fleet is in doubt. This doubt is primarily caused by the loose definitions of some of the data elements, leading to inconsistent documentation of identical maintenance actions.

- Geographical location of originating activities, even when generalized to just the east and west coasts, has a substantial affect upon the data elements most likely to affect aircraft maintenance scheduling.

- While a large number of maintenance actions sampled displayed adequate consistency of mean EMT figures throughout a twelve month period, 30% did not. At least this 30%, and perhaps more, will require database updates more often than once per year.

IV. CONCLUSIONS

A. SUMMARY

In chapter II we learned that the task of acquiring the knowledge required to construct a useful and practical expert system is the most difficult step in the entire expert system development process. While a number of knowledge acquisition techniques are available, the growing size of knowledge bases is necessitating a move to automate some portion of the knowledge acquisition process.

A number of expert system shells currently available on the commercial market offer automated knowledge acquisition modules. These modules possess the capability to automatically generate knowledge base rules based upon the data contained in various database files. The key to any automated knowledge acquisition effort is the accuracy of the data contained in the databases and the connectability of the expert system shell used to develop the system.

In Chapters III and IV we examined the NALDA databases in an effort to determine their suitability for use as the foundation for the knowledge base of our proposed expert system. Several weaknesses in the source of NALDA's data, Naval Aviation's MDS system, were identified. Mean EMT was assumed to be the most critical data element for aircraft maintenance discrepancy scheduling maintained by NALDA. Rudimentary statistical analysis revealed that mean EMT: (1) is significantly affected by geographical location, and (2) for a notable percentage of maintenance actions, varies significantly during a twelve month period.

Despite the drawbacks identified above, the NALDA databases are uniquely qualified to serve as the foundation for the knowledge base of our proposed expert system. While the inconsistencies identified among the data may inhibit or preclude the automation of the knowledge acquisition process, it does not make the databases unusable. Many of the inconsistencies, while statistically significant, are insignificant from a practical users point of view.

NALDA is uniquely qualified to provide the information required to serve as the foundation for the EMT database of our proposed expert system for the following reasons:

- As Naval Aviation's central repository of logistical and maintenance data, NALDA is the only conceivable source for much of the data required.

- Every aircraft maintenance expert likely to be interviewed during the knowledge acquisition process will be thoroughly familiar with the data elements contained in the various NALDA databases. These data elements can thus serve as a "common language" when expert reasoning are consolidated.

- The source of much of NALDA's data, the three MDS cycles, are in place and functioning throughout the U.S. Navy. Despite any shortcomings the system may possess, replacing it or duplicating it would be prohibitively expensive.

- The NALDA system is organized to respond to ad hoc data inquiries. Any data required during knowledge acquisition can be quickly retrieved from one or more of the various databases, and downloaded in a variety of communication formats.

B. RECOMMENDATIONS

Based upon the previous discussion, it is submitted that utilizing NALDA as the foundation of a knowledge base of an expert system to be used for aircraft maintenance discrepancy scheduling is feasible. The improved management effectiveness, and potential for improved aircraft operational availability, that such an expert system offers warrant continued research and development efforts.

Areas that warrant further research include:

- Easy access to NALDA terminals would allow maintenance managers to design reports to provide them with the information they feel they need, and provide them with quicker feedback. A feasibility study examining the costs and potential benefits available from placing remote NALDA access terminals in every organizational level maintenance activity should be initiated.

- A comprehensive examination of the factors critical to the success of maintenance managers should be conducted. This examination should seek to identify the specific factors, data elements, and information required for the knowledge base of the proposed expert system.

- A prototype expert system should be constructed to demonstrate the feasibility and benefits available from the use of such a system by maintenance managers. The break-out of NALDA data on a specific aircraft type, and the consolidation of this data into a separate database to be used for the ESAAMS prototype, is required.

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28. Ms. Tricia Lips (NADEPNORVA-32202), interview with Mr. Charles Anderson (FMSO) Naval Aviation Depot, Norfolk Virginia, 29 November 1988.

APPENDIX A.

A. DATA SAMPLE

* WA589326025	5839300	11	800	.9	.3
* WA589310067	5839300	11	800	3.4	1.7
* WA589310033	5839300	18	814	1.8	.9
* WA589317051	5839300	11	800	1.2	.6
* WA589326022	5839300	11	800	4.0	2.0
* AE690097128	5839300	11	811	1.2	.6
* AE690097129	5839300	11	811	1.2	.6
* AE690097130	5839300	11	811	1.2	.6
* AE690097131	5839300	11	811	1.2	.6
* AE690097132	5839300	11	811	1.2	.6
* AE690106810	5839300	11	811	1.6	.8
* AE690106811	5839300	11	811	1.6	.8
* AE690106812	5839300	11	811	1.6	.8
* AE690106813	5839300	11	811	1.6	.8
* AE690097127	5839300	11	811	1.2	.6
* AE690106815	5839300	11	811	1.6	.8
* AE690107028	5839300	11	811	1.9	1.0
* AE690106814	5839300	11	811	1.6	.8
* AE690095038	5839300	11	804	.6	.3
* AE590120266	5839300	11	800	.4	.4
* AE590114064	5839300	11	800	.4	.4
* AE590114102	5839300	11	800	.4	.4
* AE590116188	5839300	23	290	1.1	1.1
* AE590116203	5839300	11	800	.4	.4
* AE590120265	5839300	11	800	.4	.4
* AE690107029	5839300	11	811	1.8	.9
* AE590120836	5839300	18	814	1.0	1.0
* AE690094011	5839300	23	374	1.2	.6
* AE690094015	5839300	11	804	.6	.3
* AE690094016	5839300	18	814	.6	.3
* AE690094017	5839300	11	804	.6	.3
* AE690095035	5839300	11	804	.6	.3
* AE690095036	5839300	11	804	.6	.3
* AE690112091	5839300	11	814	.4	.2
* AE690112091	5839300	18	814	3.0	1.5
* AE690114069	5839300	11	811	1.2	.6
* AE690114070	5839300	11	811	1.2	.6
* AE690114071	5839300	11	811	1.2	.6
* AE690114072	5839300	11	811	1.2	.6
* AE690114074	5839300	11	811	1.2	.6
* AE690114075	5839300	11	811	1.2	.6
* AE690114076	5839300	11	811	1.2	.6
* AE690115004	5839300	11	811	1.2	.6
* AE690115010	5839300	11	811	1.2	.6
* AE690115011	5839300	11	811	1.2	.6

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