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Diagnostic Expert Systems Use In The United States Navy

by

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ABSTRACT

These thesis examines the use of expert systems for equipment diagnostics in the Navy. Diagnostic expert systems have the potential to significantly improve fleet readiness by ensuring quick and efficient repair of downed equipment. This thesis provides a brief explanation of expert systems and a look at their core components. It looks at how the Army, Air Force, and industry are using diagnostic expert systems. It describes several diagnostic expert systems under development in the surface Navy as well as one program that has been fielding these systems for several years. Finally, several conclusions about the Navy's work in this area are presented along with recommendations for further study.

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I. INTRODUCTION

The purpose of this thesis is two fold. First, to increase expert systems awareness within the Navy. Second, to stimulate thought and discussion about the use of such systems in the Navy for trouble-shooting.

A. MOTIVATION

The United States Navy is a technical organization that requires the use of highly sophisticated equipment for the completion of its mission. When a piece of this equipment breaks down, it can significantly affect the safe operation and readiness of fleet units. In some circumstances, such a failure can impact fleet operations as other units are shuffled to replace a unit that is no longer mission capable. It is therefore vital that downed equipment be repaired and brought back on line quickly and correctly. At the same time, the trouble-shooting and repair of this equipment must be done with efficient use of both outside assistance, and limited repair parts. A high level of expertise ensures this efficiency. The more experienced the maintenance force, the more efficient the trouble-shooting and repair of downed equipment.

Expert systems provide a powerful means of capturing and distributing the knowledge of the fleet's experts as well as that of the original designers. Diagnostic expert systems have the potential to significantly improve readiness by ensuring quick repair of equipment while minimizing costs associated with unnecessary replacement of good components, and obtaining outside assistance. Diagnostic expert systems provide a means to, in effect, put a permanent 'tech rep' for appropriate equipment aboard every fleet unit. This makes these systems a potentially valuable resource for the Navy.

B. RESEARCH QUESTIONS

This thesis will examine the use of diagnostic expert systems by the Navy. Primary questions to be addressed are:

- Is the Navy using diagnostic expert systems?
- Which Navy organization or organizations are developing diagnostic expert systems?
- Is the Navy's development of diagnostic expert systems a coordinated effort?

In addition to these primary questions, several related questions will be addressed. These secondary questions include:

- How can the surface Navy benefit from the use of diagnostic expert systems?
- Are Navy personnel aware of expert systems technology and its capabilities?
- Are the Army, Air Force, and industry making use of this technology?

C. RESEARCH METHODOLOGY

The following approach was used to answer these questions. An initial literature review was conducted to gain a general understanding of expert systems. An additional review of professional journals, government reports, and government publications, was then conducted to obtain information and leads on specific projects. This second review included a search through the Defense Technical Information Center's (DTIC) database. This search looked for any reports pertaining to expert systems, fault isolation, equipment diagnostics, and combinations of these items.

These literature reviews led to personal contact with organizations found to be involved with diagnostic expert systems. This contact was made by telephone, electronic mail, and correspondence. Additionally, other organizations which logically might be involved in diagnostic expert systems work, such as program offices, were contacted. This approach provided both an overview of diagnostic expert systems use by the Navy, and an awareness of the difficulties involved in locating information on these systems.

D. OVERVIEW

Chapter II provides a brief explanation of expert systems and a look at their core components. Chapter III looks at how the Army, Air Force, and industry are using diagnostic expert systems. Chapter IV describes several diagnostic expert systems under development by the Navy as well as a program that has been fielding these systems for the past several years. Chapter V discusses potential benefits, problems, and applications of these systems from the author's prospective. Chapter VI briefly summarizes this thesis and presents conclusions and recommendations.

II. WHAT ARE EXPERT SYSTEMS?

Before discussing expert systems currently in development or use, it is necessary to define what an expert system is. This chapter will briefly address the definition, characteristics, and components of an expert system.

A. DEFINITION

What is meant by the term "expert system"? Some authorities in the field have provided the following definitions. Mark Fox (Fox, 1990, p. 8) defines an expert system as a software program that:

> ...emulates the search behavior of human experts in solving a problem.

A more rudimentary definition would be:

> "A computer program using expert knowledge to attain high levels of performance in a narrow problem area" (Waterman, 1986, p. 11)

Perhaps the most encompassing definition is that of the noted author on expert systems, Edward Feigenbaum. He defines expert systems as:

> ... computer programs that couple a collection of knowledge with a procedure that can reason using that knowledge. (Feigenbaum, 1989, p. 6)

The knowledge referred to in these definitions consists of various combinations of facts and heuristics. A fact is a piece of information or data that is widely believed and accepted as being true. A heuristic is best described as a 'rule of thumb.' Heuristics are the distillation of the practical experience gained by an expert over time and vary from one expert to another. Facts are found in text books, technical manuals, and other domain literature, and are readily attainable. In contrast, heuristics are found only in the mind of the expert, take considerable time to develop, and are therefore more difficult to obtain. The task of extracting heuristics from experts and combining them with facts and a reasoning scheme is the job of a knowledge engineer.

B. CHARACTERISTICS

A more instructive method for describing an expert system is to look at its basic characteristics. While expert systems are computer programs, they differ significantly from conventional computer programs. Simply put, the main difference is that expert systems operate on knowledge as opposed to operating on data like conventional programs. Waterman pointed out that expert systems exhibit four general characteristics that distinguish them from conventional computer programs: expertise, symbolic reasoning, depth, and self-knowledge. (Waterman, 1986, p. 25) A brief discussion of each follows.[1]

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[1] For a more detailed discussion see *A Guide To Expert Systems.*, Donald A. Waterman, 1986.

1. Expertise

Expertise refers to the fact that an expert system must perform at or very near the performance of a human expert. It has to be able to develop a correct solution to a problem with at least the same regularity as an expert. Developing a correct solution in and of itself, however, is not sufficient. The expert system must also be able to develop its solution quickly and efficiently, using the same shortcuts an expert would use. A system with 100% accuracy that takes as long or longer than a human expert provides no significant advantage. Another factor of expertise is that the system should be robust. It must be able to handle problems not originally expected or that are on the edge of its domain of knowledge.

2. Symbolic reasoning

A second feature of expert systems is that they use symbolic reasoning. This refers to the fact that, like their human counterparts, expert systems manipulate concepts instead of solving numerical equations. Strings and symbols are used to represent problem concepts such as fluid flows, input voltages, inlet temperature, or material condition. These concepts are then combined with others, reordered, expanded, etc. until a solution is obtained. Expert systems are capable of performing numerical calculations, but the core of their work is the manipulation of concepts.

3. Depth

Depth refers to the fact that expert systems are intended to efficiently solve difficult problems in a very narrow domain. The expert system will have a very substantial level of detailed knowledge about that domain. A large number of complex rules or frames may be needed to store this level of knowledge. It is therefore important that the problem domain be sufficiently narrow in scope. An expert system may only know one subject, but it knows nearly everything about that subject.

4. Self-knowledge

A fourth characteristic is self-knowledge. Self-knowledge refers to the ability of an expert system to look at how it reaches conclusions and to explain its reasoning to the user. The explanation facility most often consists of showing the user the chain of reasoning it used. In a rule based system, for example, a request for an explanation may result in a list of rules that have been activated and the sequence of activation. If an expert system has been supplied with "metaknowledge," (i.e., knowledge about how it reasons) then it will be able to check the validity and accuracy of its conclusions. This is a feature not found in conventional computer programs. Historically, the explanation capability of older systems have been a significant weakness, but considerable efforts are being made to improve how expert systems explain themselves to the user.

C. COMPONENTS

Now that expert systems have been defined and their general characteristics described, it is instructive to look at the component parts of an expert system. Excluding the interfaces for external input/output, an expert system is comprised of three basic pieces. These parts are the knowledge base, the inference engine, and the working memory. (Prerau, 1990, p. 17)

1. Knowledge base

The purpose of the knowledge base is to store the facts and heuristics that comprise the knowledge of the domain expert. (Prerau, 1990, p. 17) A knowledge representation scheme, such as rules or frames, is used to formalize and organize this knowledge.[2] The knowledge base is the core of an expert system.

2. Inference engine

The second major component of an expert system is the inference engine. The inference engine provides control of the system. It combines the knowledge stored in the knowledge base with acquired information stored in the working memory,

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[2] For a complete explanation of knowledge representation schemes, refer to *Developing and Managing Expert Systems.*, David S. Prerau, 1990, or *A Guide to Expert Systems.*, Donald A. Waterman, 1986.

to derive new information with which to work. (Prerau, 1990, p. 17) Another description of its function is that it contains the problem solving paradigm that organizes and controls the steps taken to solve the problem. (Feigenbaum, 1989, p. 35) The two most commonly used paradigms for controlling where the reasoning process starts and how it proceeds are known as forward and backward chaining.[3] The inference engine is the brain of the expert system.

3. Working memory

The third component of an expert system is the working memory. The working memory is a repository for information the system has received from the outside environment and that the system has derived from its current session. (Prerau, 1990, p. 17) The knowledge in the working memory is transitory in nature, whereas that in the knowledge base is static and for the most part permanent.

4. Operations

A simplified explanation of how the three components of an expert system work together is as follows. The inference engine searches the knowledge base, in accordance with its reasoning scheme, for a rule that matches the facts stored in the working memory. If a matching rule is found, it is fired and the facts in working memory are added to, deleted,

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[3] For an explanation of forward and backward chaining, see The Rise of the Expert Company., Edward Feigenbaum, Pamela McCorduck, and H. Penny Nii, 1989.

or modified. This cycle is repeated until a final solution is reached, or the system's domain knowledge has been exhausted.

D. SUMMARY

This chapter has examined the definition, characteristics, and components of expert systems. Expert systems are computer programs that emulate the performance of a human expert in a specific domain. These programs exhibit the characteristics of expertise, symbolic reasoning, depth, and self-knowledge. A knowledge base, inference engine, and working memory are the basic components of all expert systems. With this background in place, the following chapter will examine diagnostic expert system applications used by the Army, Air Force, and by industry.

III. ARMY, AIR FORCE, AND INDUSTRY DIAGNOSTIC EXPERT SYSTEMS

Before examining the Navy's use of diagnostic expert systems, it is instructive to look at how the Army, Air Force, and industry are employing these systems. Both the Army and Air Force have at least one diagnostic expert system in operational use. Industry has hundreds of such systems. Only a few will be discussed here.

A. U.S. ARMY

1. Pulse Radar Intelligent Diagnostic Environment (PRIDE)

PRIDE is a diagnostic expert system that aids in the maintenance of the Pulse Acquisition Radar(PAR) of a HAWK missile battery. PRIDE was developed in order to provide a trouble-shooting tool for the PAR, to sustain the training level of the soldiers assigned to PAR maintenance, and to capture the expertise of the Army's experts and make it available to any soldier working on the radar.(Carnegie, 1990,p.1)

PRIDE's knowledge base contains information on:

- 214 failures
- 192 tests
- three test procedures
- four questions

- four rules
- 97 repairs (Carnegie, 1990,p.5)

It is designed to run on personal computers running the DOS operating system and has been deployed on GRID laptop computers.

Pride was originally developed at the Army's Ordinance Missile and Munitions Center and School (OMMCS) in the late 1980s. The initial prototype was a rule based system built with the M.1 shell from Teknowledge. The system was fielded for evaluation. Feedback from the field indicated that a diagnostic expert system was feasible, but that this prototype system had some problems. One problem was a poor user interface. A second problem, with potentially greater repercussions, was the system contained too many rules to be successfully maintained.(Knutilla, 1991) The changing of one rule can effect many others. If the knowledge base contains a very large number of rules, it becomes difficult, if not impossible, to predict the effects of changing a rule on the rest of the knowldge base.

The Army decided to rebuild the system in order to eliminate these problems. Carnegie Group Incorporated was contracted to reimplement PRIDE. Development of the new system began in April 1990 and was completed in October of that year. Carnegie developed the system using their TEST-BENCH development tool which uses frames for knowledge representation. The knowledge incorporated into PRIDE was provided by subject matter experts from OMMCS.(Carnegie, 1990, p.1)

After the development work was completed, PRIDE was sent to several Army ordinance companies for evaluation. One of these companies, the 188th Ordinance Company from FT. Bragg, took PRIDE to Saudi Arabia during Operations Desert Shield and Desert Storm. Since the HAWK batteries in Saudi Arabia were not allowed to radiate, the full diagnostic capabilities of PRIDE were not put to a test in a combat environment.(Harper,1991) However, PRIDE was used quite extensively for training while deployed to the desert. Faults would be induced to the PAR by senior technicians and junior soldiers would isolate these faults using PRIDE. PRIDE is now in its third version and is in use with four of the Army's ordinance companies.(Harper,1991)

2. Other systems

The success of PRIDE has led to systems being developed for other components of the HAWK missile system. One such system is the High Power Radar Intelligent Diagnostic Environment (HIPRIDE).(Harper,1991) In addition, the Army is also pursuing a diagnostic expert system for the M1A1 Abrahms tank. Carnegie Group has been awarded a contract to develop this system. This new system will be integrated into the

Army's Unit Level Logistic System and will include an integrated electronic technical manual. (Gilbertson,1991)

B. U.S. AIR FORCE

The Air Force also began development of at least one diagnostic expert system in the late 1980s. This system was called the Expert Missile Maintenance Aid or EMMA and was intended as a feasibility study. The ultimate goal of the study was to develop an expert system to assist novice munitions technicians isolate faults to the lowest replacable unit (LRU). This system would be faster than human experts using automated test equipment, or ATE.(Mullins,1990) Other goals included showing that an expert system could reduce testing time by more effectively ordering tests, and demonstrating the ability of an expert system to enhance the technicians understanding of the tests through its explanation facility.(Huebner,1990,p.5)

EMMA was initially a two phase project. The first phase, involving field level diagnostics, ran from September 1986 to July 1987. A second phase, involving depot level diagnostics, ran from August 1987 to April 1989. Two systems were developed for the first phase. Raytheon built a system to diagnose the AIM-7F Sparrow missile and Rockwell developed a system for the GBU-15 Modular Glide Bomb. Both of these systems underwent successful evaluations. The GBU-15 system, in particular, resulted in a seventy four percent reduction in the fault isolation time of an all up round, and a forty percent reduction for rounds in the stand alone configuration. Both Raytheon and Rockwell built expanded versions of these initial systems for the depot level maintenance phase with similar results. (Mullins,1990)

The GBU-15 EMMA was fielded for a one year period at Seymour Johnson Air Force Base from July 1989 to July 1990. During this period the system underwent a progressive series of modifications based on feedback from the technicians using it. At the end of this period, the Air Force and the contractor concluded that EMMA was a viable technology for aiding Air Force technicians. Specifically, it was found that EMMA reduced life cycle cost of the GBU-15 by:

- reducing the number of diagnostic tests needing to be run;
- reducing fault isolation time by isolating to the Lowest Replacable Unit (LRU) faster than human experts;
- being available 24 hours a day as a source of expertise;
- reducing depot level work load by reducing the occurrences of 'Return Test OK' situations. (Huebner,1990, p.5)

Responsibility for the GBU-15 EMMA was transferred to the Commodities Directorate of the Air Force Logistics Command in early 1991. During Operation Desert Storm the system was introduced to the Gulf theater by an airman assigned there who had previously worked on the development of EMMA and had a copy of the program. After being introduced, the program saw considerable use as employment of the GBU-15 increased. EMMA is available to maintenance units upon request, but due to the low number of units employing the GBU-15, is currently only used by four units. (Hadley,1992)

C. INDUSTRY

Industry has made considerable use of diagnostic expert systems. Such systems have been used to diagnose car components (such as engines and air conditioners), computer networks, telephone switch exchanges, and diesel locomotives. Although a significant number of these systems are in use, it is difficult to find detailed information on specific systems in the computer literature. As one executive of a company marketing expert system development software stated:

> "Secrecy and company private clauses keep most developers quiet regarding their systems." (Eskew, 1991)

It would appear that many companies have decided that the use of diagnostic expert systems gives them a competitive advantage.

Figure 3-1 summarizes a few of the many industrial applications of diagnostic expert systems found.

D. SUMMARY

This chapter has looked at how the Army, Air Force, and industry have made use of diagnostic expert systems. At least one system was found for both the Army, and the Air Force.

INDUSTRIAL DIAGNOSTIC EXPERT SYSTEMS		
SYSTEM NAME	SYSTEM FUNCTION	COMPANY
Predictor Help Desk Diagnostic Support System	Assist help desk operators trouble-shoot problems with the Predictor soft-ware package	U.S. West
Service Bay Diag-nostic System (SB-DS)	Assist mechanics in trouble-shooting FORD automobiles.	Ford
Automotive Comput-er-base Expert (ACE)	Diagnose faults in electric/hydraulic derricks.	Alabama Power Com-pany
NETHELP	Diagnose breakdowns in a package track-ing network.	Federal Express
Metermen's Assis-tant	Diagnose faults in electric revenue meters.	Pacific Gas and Electric
COOKER	Monitor and diag-nose problems with sterilizer cookers.	Campbell's Soup Company

Figure 3-1

The success of the PRIDE program has encouraged the Army to develop additional systems. Although it is likely that the Air Force has other programs in operation or development, only one, EMMA, was found. A number of operational diagnostic expert systems were found to be in use by industry. This is an indication of the high degree of acceptance by industry of this technology. The Navy's use of diagnostic expert systems will be addressed in the following chapter.

IV. EXPERT DIAGNOSTIC SYSTEMS IN THE NAVY

As has been shown, the Army, Air Force, and industry are all using diagnostic expert systems. To what extent is the Navy using diagnostic expert systems? Although behind industry, from this investigation it appears that the Navy is ahead of both the Air Force and the Army in the use of expert systems for equipment diagnostics and maintenance. Over the past several years, the Navy has developed a number of diagnostic systems. Unfortunately not all have been successful. It continues to develop additional systems. The following sections will discuss several Navy expert systems.

A. PROJECT EXPERT

Project Expert was started in the late 1980s to demonstrate that an expert system could be used as a maintenance advisor for a surface ship sonar.(Holland, 1989, p. 40) To describe Project Expert, it is necessary to first look at the Fault Isolation System shell and then examine the product of Project Expert, the Technician Assister System.

1. Fault Isolation System (FIS) Shell

In the mid 1980s, the Naval Research Laboratory (NRL) believed there were two major problems associated with using the emerging expert systems technology for diagnostic systems. The first problem concerned the large number of systems or machines that could potentially benefit from a diagnostic expert system. As an expert system uses a knowledge base that is domain specific, a unique expert system would have to be built for each application. The second problem was the fact that for many of the applicable systems or machines there was no significant expertise to incorporate into an expert system. This is particularly true of new machines. It would therefore appear to be infeasible to develop a large number of diagnostic expert systems. (DeJong, 1990, p. 770)

As a possible solution to these problems, NRL developed the Fault Isolation System shell or FIS. FIS is a model based expert system shell(DeJong, 1990, p. 770) created specifically for use in diagnostics. This means that instead of human expertise, the knowledge base contains a model of a properly functioning system. A diagnostic system built with FIS will compare its stored model to the conditions existing in an incorrectly functioning piece of equipment and isolate the fault by using first principles. The information for the model can be gleaned from the systems technical specifications and drawings. FIS can therefore be used to create expert systems where no significant expertise has been developed. FIS was designed to be as general as possible so as to be useful for a large number of applications.

FIS is currently being used at the Naval Aviation Engineering Center (NAEC) to generate program sets for automated test equipment. It was also used by the Naval

Oceanographic and Atmospheric Research Laboratory (NOARL) to develop the Technician Assister System to be discussed in the next section. NRL still supports FIS, but is not actively maintaining the program. Updates are only made if requested. (Molnar,1992).

2. Technician Assister System

One of the first uses of the FIS shell was the Technician Assister System (TAS). This was the end product of Project Expert. The purpose of TAS was to prove that improved fault isolation could be achieved, through expert systems, for equipment not having extensive built in fault isolation capabilities. (Holland, 1989, p. 40)

TAS was a combined effort of NOARL and NRL and was designed to diagnose faults in Unit 26 of the AN/SQS-53 surface ship sonar system. Unit 26 is a signal processor that uses twelve channels for processing the left, right, and center beams of the sonar signal. It contains 100 replacable modules.

The knowledge engineers created TAS's knowledge base from schematics and technical manuals. As the development proceeded, the number of rules quickly exceeded expectations. In order to compensate for this steadily growing knowledge base, the developers decided to use a divide and conquer approach. The knowledge base was divided into several smaller knowledge bases, each covering a segment of Unit 26 or a particular class of problems. These knowledge bases are called upon as needed by a supervisory expert system.(Molnar-,1990, pp. 1-2)

The project was canceled in late 1989. Reasons for the project's cancellation include:

- The knowledge base was too large. It exceeded 7000 rules and continued to grow. This was far above any number previously tried by the developers. (Hammond,1991)
- The system did not appear deployable. It required the computing power of a VAX computer to run and could not be ported to a PC.(Weldon,1991)
- The program was only 40 percent complete after several years and several hundred thousand dollars worth of effort.(Weldon,1991)

Although TAS was canceled, it was not a complete failure. It did demonstrate that a model based diagnostic expert system was technically achievable. (Romalewski, 1991) (Molnar, 1991)

B. AN/USH-32 EXPERT SYSTEM MAINTENANCE ADVISOR

The cancellation of the Technician Assister System was not the end of work on diagnostic expert systems by NOARL. In conjunction with the Naval Sea Combat System Engineering Station, Norfolk, NOARL has developing a new expert system diagnostic aid. This system is to be used to diagnose problems in the AN/USH-32 Signal Data Recorder-Reproducer. The AN/USH-32 is a component of the AN/SQR-19 Tactical Towed Array Sonar System.(Hammond,1991) This piece of equipment was selected because it is a stand alone unit that is not as complex as Unit 26 of the AN/SQS-53B used before. It has been designed from the start to run on a standard PC. The Maintenance Advisor also incorporates technical drawings, tables and procedures that the technician may reference during a diagnostic session. (Romalewski,1991)

As of November 1991, the Expert Systems Maintenance Advisor was 80% percent complete and undergoing evaluations. (Hammond,1991) It is expected to be operational in the early part of 1992. (Romalewski, 1991) NOARL is already looking to begin a new project.

C. PHALANX INTEGRATED DIAGNOSTIC SYSTEM (IDS)

The MK-15 Close In Weapon System (CIWS), or Phalanx, is an automatic radar controlled 20mm gatling gun that serves as a surface ship's last defense against anti-ship missiles. In situations involving sea skimming missiles, CIWS may be the only weapon capable of reacting to such a threat. It is vital to the defense of a ship that its CIWS mounts are maintained at a high degree of readiness.

1. Phalanx Maintenance Problems

Over the years it has been in service, Phalanx has demonstrated some significant maintenance problems. Various weapon inspections have indicated low operational readiness of the Phalanx system. This is primarily the result of inadequate experience and training on the system. In addition, even well trained and experienced sailors have had a difficult time maintaining this highly complex piece of equipment.(Joyce, 1991) Some indications of the difficulty in maintaining the Phalanx system are cited below:

- Greater than 1000 fault isolation paths exist(GE Aerospace,1991);
- For each path there are approximately 15 decisions/15 actions the sailor must make or perform(GE Aerospace, 1991);
- A no failure evident(NFE) rate exceeding 20 percent on parts swapped out and sent to depots has been documented.(GE Ordnance, 1989, p. 8);
- The mean time to repair(MTTR) is greater than five hours. (GE Ordnance, 1989, p. 8);
- The fault isolation success rate is less than 70 percent.(GE Aerospace, 1991);

2. Integrated Diagnostic System

In order to reduce the maintenance problems of the MK-15 CIWS, the Naval Ordinance Station, Louisville has developed a diagnostic expert system to assist fleet sailors. It is called the Integrated Diagnostic System(IDS). IDS was first proposed by General Electric in 1987. In 1989 GE demonstrated a prototype system that diagnosed problems in the mount servo subsystem of a Block 1 Baseline 0 MK-15. This prototype demonstrated a significant reduction in MTTR. As a result, approval was given to go-ahead with full scale development. A full scale version for the Block 1 Baseline 0 system entered beta testing at eight sites in May 1991. (Phalanx Program Office,1991)

a. *IDS Goals/Benefits*

Several specific goals were set for the Integrated Diagnostic System. They include:

- A fault isolation success rate greater than 90 percent
- A reduced no failure evident rate
- A reduction in sailor actions by 50 percent
- A reduction in sailor decisions by 50 percent
- A reduced MTTR(Phalanx Program Office, 1991)

It is interesting to note that the reduction in MTTR was expected to come, in part, from a reduction in administrative delays. IDS speeds up the fault isolation process. As a result sailors are less likely to make fatigue related errors and will not be as frequently interrupted by meals or coffee breaks, which often happens with the longer manual fault isolation process. There will also not be a delay caused by waiting for an outside expert to arrive. The experts knowledge will already be on board in the form of IDS's knowledge base.

b. *IDS results to date*

Results from the testing of IDS have been very positive. In tests conducted by GE in May 1991, IDS located

1114 out of 1223 faults inserted into a Phalanx system. This is a success rate of 91 percent.(GE Aerospace, 1991)

Feedback from the fleet has also been positive. IDS is considered to be user friendly, a reliable tool, and a diagnostic time saver.(Phalanx Program Office,1991) In one case IDS located a fault in one hour that two weeks of manual fault isolation had failed to find. (Joyce,1991) As one individual put it:

> "IDS has successfully fault isolated problems on the day of installation when manual trouble shooting had failed." (Haberzetle,1991)

Beta testing for the Phalanx Block 1 Baseline 0 IDS is expected to be completed by May 1992. If found to be successful it will be deployed fleet wide. IDS versions for later models of the MK-15 are already in development. The Naval Ordnance Station, Louisville will be tasked with supporting and maintaining the IDS knowledge base.

D. NAVAL SEA SUPPORT CENTER EXPERT SYSTEMS PROGRAM

A highly successful use of diagnostic expert systems is the Expert Systems program run by the Naval Sea Support Center's Atlantic and Pacific detachments. This program has put a growing number of 'Expert on a Floppy' diagnostic expert systems into the fleet.

1. Background

Among other missions, the Naval Sea Support Center is tasked with direct fleet support. Its mission in this area is to:

> "Promote fleet readiness and maintenance self-sufficiency in ship board systems and equipments." (NAVSEACENLANT, 1991)

This is done by providing the fleet with diagnostic advice and training through technical assist visits, message traffic, etc.

During the 1980s, the Naval Sea Support Center, Atlantic(NAVSEACENLANT) found itself facing significant obstacles to the performance of its mission. (Branham, 1991) These obstacles included:

- Decreasing funds for fleet maintenance and training;
- Increased demand for its services. (33% increase from FY89 to FY90 and 100% from FY90 to FY91);
- A fixed or decreasing work force (NAVSEACENLANT, 1991).

Faced with these problems, NAVSEACENLANT began to explore the possible use of AI technology to reproduce their expertise. (Branham, 1991) In 1987 work was begun on a diagnostic expert system prototype for the 75-85 ton R-12 Air Conditioning plant used on numerous ships. This expert system took approximately 1760 man hours to develop and test at a cost of $53,000. The system was developed and is maintained in house by NAVSEACENLANT personnel. An affordability analysis based on 441 R-12 units installed aboard 204 ships or installations indicated a 12 to 1 return on investment. The system demonstrated a 96 percent diagnostic success rate during an evaluation taking place over six months on 33 ships. (NAVSEA, 1991)

With these results, NAVSEACENLANT began to receive funding from NAVSEA C91 and the surface type commanders. (Hickey,1992) The Expert Systems Program, as it is called on the East Coast, and the Maintenance Expert System Program as it is known on the West Coast, had begun.

2. Program Objectives

The Naval Sea Support Center's purpose in developing these expert systems is to:

> ...provide fleet and shore personnel, engaged in the operation and maintenance of Naval systems and equipments, with an affordable stand alone tool to enhance their ability to maintain operational readiness and attain maintenance self-sufficiency. (NAVSEACENLANT, 1991)

The goals of both the Commander, Naval Surface Force, U.S. Pacific Fleet and the Commander, Naval Surface Force, U.S. Atlantic Fleet for this program are stated in their implementing instructions as follows:

> The primary goal of ES [Expert Systems Program] is to enhance operational readiness and on board knowledge level. Secondary goals are to reduce dependence on technical representatives for troubleshooting and repair recommendations and increase the effectiveness of PMS

[Preventive Maintenance System] on selected equipments.(COMNAVSURFLANT, 1991)

3. Program Description

The Expert Systems Program is managed by the Atlantic and Pacific detachments of the Naval Sea Support Center. As appropriate applications for the use of expert systems are identified, NAVSEACENLANT/NAVSEACENPAC knowledge engineers, in conjunction with the resident equipment experts, begin developing the new system. The cost of developing new systems has been reduced to approximately $43,000 per system, further enhancing their affordability. Once developed, ("Experts on a Floppy" as they are called) they are distributed on each coast by the appropriate detachment. Both detachments have complete distribution and training systems. A representative will deliver the system and perform the initial installation. Normally this is on a PC that is located in the ship's Engineering Department. This installer will also conduct training to ensure that the users are familiar with system operation. Updates are sent out periodically. The demand for these "Experts on a Floppy" and their updates has been high enough that NAVSEACENLANT has purchased a disk duplicator to keep up with it. (Branham, 1992)

Ships can obtain copies of these systems by contacting NAVSEACENLANT or NAVSEACENPAC. Figure 5.1 shows those systems currently available. Figure 5.2 lists equipment for which systems are to be developed in fiscal year 1992. (NAVSEACENPAC,1992)

EXPERT SYSTEMS PROGRAMS IN USE

ES NAME	EQUIPMENT	SHIP CLASS
BOILER	150psi AUX STEAM BOILER	LKA-113
CENT200	R-114 200 TON A/C PLANT	CG-47
CENT150	R-114 150 TON A/C PLANT	DD-963
CLUTCH	CLUTCH FRICTION SYNCRO W/BRAKE, MODEL SQ500B	DD-963/DDG-993
CRANE	CVN-68 CLASS B&A CRANE	CVN-68
DYNALEC	TELEPHONE SWITCHBOARD	DD-963/VARIOUS
EOAIR	R-12 75-85 TON A/C PLANT	FFG-7/FF-1052/ AFS-1/LST-1179/LPD-4/ AE-21/23/ LSD-41/AGF-11/ DDG-2
EOEVAPS	EVAPORATOR	CG-47
EVAP963	EVAPORATOR	DD-963
HPIR2010	3000psi HPAC	DD-963
HPIR2011	3000psi HPAC	CG-47
HPIR207	3000psi HPAC	FFG-7

Figure 5-1

Expert Systems Scheduled for FY-92 Development	
400 Hz Power	Controllable Pitch Propeller
LM 2500 Controls	Mk 92 FCS DSOT
B&A Crane for LSD/LPD	Power Distribution
Gas Turbine Generator	Anchor Windlass
SSGTG Controls	Auxiliary Boiler for LSD-41/44
Evaporator for FFG-7	363 Ton R-114 A/C for CVs
R-114 A/C for SSN-688	300 Ton R-114 A/C for CVs
125 Ton A/C for DDGs	O2N2 Producer LGSB
Refrigeration for DDG-993	

Figure 5-2

4. Expert System Advantages

The Naval Sea Systems Command (NAVSEA) has identified several advantages to using expert systems. Direct advantages for NAVSEA include:

- an effective training tool in a reduced funding environment;
- controlled maintenance cost through standard repair recommendations;
- historical documentation of failures for engineering design/maintenance changes;
- Preventive Maintenance System (PMS) compatibility;
- improved fleet readiness and self-sufficiency (NAVSEACENPAC, 1991).

Advantages identified for the fleet from the use of these systems include:

- enhanced ability to maintain equipment;
- standard problem/repair statements;
- earlier determination of organizational level repairs resulting in fewer catastrophic failures;
- increased maintenance self-sufficiency;
- increased operational readiness (NAVSEACENPAC, 1991).

5. Expert System Maintenance

The knowledge base of an expert system will require modification throughout the system life cycle. This may be due to any of several factors. The equipment itself may be modified; the rules or regulations may be changed; there may be enhancement or bugs that warrant change. Maintenance of expert systems is therefore a critical concern. The Naval Sea Support Center has implemented a program, similar to that for the PMS system, to maintain its expert systems. Under this program, fleet users send feedback reports to NAVSEACENLANT or NAVSEACENPAC. These reports are reviewed, and if appropriate, changes are made. Updates to the systems are distributed on a semi-annual basis. If a feedback message concerns a safety issue, however, immediate changes are made and distributed. (Branham, 1992) This maintenance is performed by NAVSEACEN-LANT/NAVSEACENPAC personnel.

6. Feedback on the Expert Systems Program

The response from the fleet to the expert systems distributed by the Naval Sea Support Center has been very positive. Comments to NAVSEACENLANT on the original R-12 diagnostic system included:

> "Cuts troubleshooting to one eighth the time." (USS MOINESTER)
>
> "Would like to have other systems." (USS BOWEN)

One auxiliaries officer reported that the two expert systems on his ship had led to a competition between the computer and the sailors. The sailors in his division would combine their expertise in order to figure out the problem. They would then check their solution to that of the computer. The officer considered this competition to be a good way to introduce the system. It was further stated that the expert systems were used constantly for troubleshooting when log book readings could not be explained. (Rivera, 1991)

Further indication of the success of the program is the attention it is receiving at higher levels. NAVSEA C56, has directed his life cycle managers to learn more about expert systems. Interest at the flag officer level is also evident. OP-043 has all the expert systems installed on his computer. Additionally, several of the systems have been installed at the Surface Warfare Officer School Command (SWOSCOLCOM) for demonstration purposes. (Branham, 1992)

E. SUMMARY

This chapter has examined several Navy diagnostic expert system projects. Three of these projects developed individual systems. Two of these systems, the AN/USH-32 Expert System Maintenance Advisor, and the Phalanx Integrated Diagnostic System, are currently undergoing testing. Both appear to be headed for deployment. One of the three projects was canceled after problems with the size of the knowledge base and the computing platform developed. The fourth project examined was the Naval Sea Support Center's Expert System Program. This program has already developed and deployed several diagnostic expert systems to the fleet. The Center's Atlantic and Pacific detachments continue to develop additional systems. This search for Navy diagnostic expert systems was limited to the surface warfare community. As a result, no examples from the submarine and aviation communities have been presented.

Having seen some of the ways the Navy is using diagnostic expert systems, the following chapter will address potential benefits, problems, and applications of this technology.

V. POTENTIAL BENEFITS, PROBLEMS, AND APPLICATIONS

Previous chapters have discussed ways in which industry, the Army, Air Force, and Navy have made use of diagnostic expert systems. This chapter will address what the author sees as potential benefits of, problems with, and applications for diagnostic expert systems in the Navy. This examination is made from the perspective of a surface line officer.

A. BENEFITS

The use of diagnostic expert systems provides several benefits to the Navy, some of which have already been alluded to in previous chapters. The most important of these benefits are reduced mean time to repair, efficient use of spare parts, increased knowledge and training, and greater maintenance self-reliance. Each of these benefits is significant when taken individually. More importantly, these benefits add up to improved fleet readiness.

1. Reduced Mean Time To Repair(MTTR)

The use of diagnostic expert systems reduces the time needed to repair equipment in several ways. First, the diagnostic process itself is faster. With its heuristics, the expert system skips unnecessary tests that take time to perform yet provide no information relevant to the problem. Additionally, using an expert system, makes flipping back and forth in a technical manual between diagrams, descriptions, and procedures unnecessary. With the latest tendency to embed expert systems, electronic technical manuals can be integrated with the expert system to provide rapid recall of any information needed. Also, less time is spent trying to find the correct technical manual to use.

A second way diagnostic expert systems reduce repair time is by making more accurate diagnoses. Because the expert system is based on the knowledge of a domain expert, there is a higher probability that the problem will be correctly identified and repaired the first time. This saves the time frequently spent on making incorrect repairs and starting over again. This time savings can be considerable, especially if the repairs require significant disassembly and/or draining of a system.

Yet another way diagnostic expert systems reduce repair time is by eliminating the need to wait for outside assistance. If the problem is such that an expert is required, his or her knowledge is already on board in the form of the expert system. No time is wasted waiting for the expert to arrive or waiting for a reply to a message. Even if the expert system cannot solve the problem and outside assistance is still required, it can save time. It can reduce the number of possibilities the outside expert needs to consider upon his arrival and speed up the fault isolation process.

2. Efficient Use of Repair Parts

Another way diagnostic expert systems benefit the Navy is through more efficient use of scarce repair parts. This can be especially critical to a deployed unit with limited parts storage. This benefit accrues in two ways. First, since expert systems normally provide more accurate diagnosis, fewer parts are wasted taking incorrect action. Second, the use of expert systems can reduce, if not eliminate, the frequent diagnostic practice of swapping out components until the problem disappears. This practice takes valuable repair parts out of circulation, and overloads intermediate maintenance activities and depots with high NFE rates. It quite often also results in the destruction of the new parts. This happens when a suspected component, such as a circuit board, is mistakenly believed to be the problem, but is really only a symptom. The still undiscovered fault may cause the new component to fail. Thus diagnostic expert systems offer the potential to drastically reduce two of the major causes of repair part wastage. At the same time they may help reduce some of the load on repair activities.

3. Knowledge and Training

Another significant benefit is an increased level of knowledge and training. As sailors work with the expert system, they are in effect working with an expert. From this association they gain an expert's insight into the equipment's design and operation. Instead of needing years of hands on work to gain this insight, the sailors get it as soon as they start working with the program. This means sailors obtain a higher level of knowledge, to which they can add, earlier in their careers.

With regard to the subject of training, the expert system does not have to be used solely on actual problems. Sailors can use the system to test their own knowledge and skills. Given a hypothetical failure, sailors may attempt to determine the cause using their own knowledge and technical manuals. Their solutions are then compared with that of the expert system. If there are differences between the two solutions, the expert system's explanation capability may be used to explain the reasoning process of the experts. This interaction teaches the sailors more effective ways to trouble shoot the equipment. This form of interactive training can be both fun and competitive. It can encourage sailors to learn even more. Also, the training provided by the expert system is available on a twenty-four hour basis, so sailors can train whenever they want.

4. Capture Navy Expertise

Still another benefit is the capture of the Navy's valuable expertise. This an increasingly important benefit as Navy manpower is reduced through early outs, early retirement, and normal attrition. As these sailors leave the service, they take with them a great deal of hard won trouble-shooting experience with Navy equipment. Expert systems allow the Navy to capture this expertise. It then becomes permanent corporate knowledge that can be passed down to younger, less experienced sailors.

5. Maintenance Self-Reliance

The final major benefit of using diagnostic expert systems is an increased self-reliance of individual units. This benefit was alluded to earlier as one of the ways MTTR is reduced. For a ship in her homeport, having to rely on outside assistance to isolate a failure is at the most inconvenient and embarrassing. If the assistance is not locally available, it can be brought in with little or no impact on the ship's operations. For a ship underway or deployed, however, that same reliance immediately affects ship operations. Important missions may have to be interrupted or terminated, and port calls canceled in order for the ship to pick up the technical assist team. If an equipment failure renders the ship no longer mission capable, any delay to await outside assistance impacts other units as well. Other ships will have their schedules and operations changed in order to fill the gap. Diagnostic expert systems offer the potential to significantly reduce this reliance. To the extent of systems covered by expert systems, each ship would have on board its own set of "tech reps" that are always on call.

6. Summary

The benefits of reduced MTTR, more efficient use of parts, increased knowledge and training, capture of Navy expertise, and increased self-reliance combine to significantly improve fleet readiness. Improvements in MTTR mean more operational systems on line. They also allow more time to be spent on operational training. Efficient use of parts effectively increases the number of available spares without taking money and resources away from operations, training, or personnel. Improved self-reliance means more units are fully capable and fleet operations are less susceptible to logistic interruptions. This improvement in readiness can be achieved relatively inexpensively, by using expert systems to work smarter, instead of building new systems or buying more spare parts, etc.

B. POTENTIAL PROBLEMS

As previously discussed, the use of diagnostic expert systems can provide valuable benefits to the Navy. These benefits, however, do not come without some possible problems. While it is believed most of these problems are ones of perception, they must be addressed if expert systems are to be successfully employed.

1. Systems Not Taken Seriously

The first problem to be addressed is the possibility that the expert system will not be seriously used. The probability and seriousness of this problem depends on the way the system is introduced. If the system is described with frequent references to Artificial Intelligence (AI) it may be considered nothing more than an experiment. For many, AI is still the stuff of science fiction like HAL 9000 in 2001 A Space Odyssey or DATA on Star Trek. If the expert system is delivered with insufficient training or command attention then it can become nothing more than an interesting toy that is not fully utilized. In either case, the system is not seen as a valuable tool and just takes up space on its computer's hard drive. Both of these problems can be avoided if the expert system is properly introduced with sufficient training. Command attention and interest also helps ensure the system is taken seriously.

2. Man-Machine Competition

A rather serious problem can arise if expert systems are incorrectly perceived as a means to replace people. This problem is two fold. First, it could lead to attempts to save money by reducing the number of experts at shore facilities. Reducing the amount of time these people spend assisting ships does not make them extraneous, as that time can now be put toward other important uses such as designing better systems and procedures, or providing additional training. The fact is these personnel are already in too short of supply.

Attempts to save money may also include reducing manpower aboard ships. This leads to the second part of the problem, morale. If sailors think they can be replaced by a computer program they will be reluctant to use it. They will not be as motivated to take pride in their work, to excel, or to learn. The result is poor morale, sloppy work, and problems instead of benefits. This problem can be avoided if it is re-enforced that an expert system is a tool just like a piece of test equipment. They are to be used by people not replace them. A software program cannot do physical work or replace the common sense and ingenuity of the fleet sailor, but it can help make his or her job easier.

3. Over Dependence on Expert Systems

Finally, the potential to become overly dependent on expert systems poses a serious problem. Ironically, this would be as a result of their success. As expert systems become more accepted and their capabilities improved, it will become tempting to allow them to perform all fault isolation. Why should a sailor learn about fault isolation if the expert system does it just as well, but faster? If sailors do not need to know fault isolation, then maybe they need to only be taught the minimum basics in schools. If this trend were allowed to develop and continue, expert systems could potentially degrade fleet capabilities instead of increasing them. The answer to the previous question is that expert systems are not perfect and may not cover every contingency for a given system. Also, we will never get to the point of having an expert diagnostic tool for every system aboard a ship. It is therefore important for sailors to be highly trained and to know how to trouble shoot, and to use and interpret maintenance manuals and other test equipment.

4. Summary

Several potential problems with the use of diagnostic expert systems have been discussed. It is possible for expert systems to be seen as toys or experiments and not as powerful tools. It is also possible that these systems could be considered as suitable replacements for human technicians resulting in inappropriate manpower cuts. Finally, it is quite possible to become overly dependent on these systems and neglect needed training. While possible, these problems are unlikely if the implementation of expert systems is properly planned and controlled.

C. POTENTIAL USES

There is an almost unlimited number of potential applications for diagnostic expert systems. A few of these are discussed in the following paragraphs.

1. Gun Mounts

Naval gun mounts, such as the MK45 5"/54 LWGM, are extremely complicated pieces of equipment. A mix of mechanical, hydraulic, and electronic components, it is often difficult to isolate a fault that is not readily apparent. Fault isolation and repair is made even more time consuming as a result of having to drain hydraulic lines and reservoirs to access many of the various valve blocks, seals, and pressure switches.

Diagnostic expert systems are particularly applicable for these systems for several reasons. The requirement to drain/refill the system would be reduced because the initial diagnoses would more often be accurate. Also, many checks requiring such action could be eliminated by the expert system as not being relevant to the problem at hand. Expert systems would also tie together the disparate types of knowledge, such as hydraulics and electronics, that sailors maintaining these mounts need. This could be particularly helpful since it is not uncommon for the maintainers to never have had formal training in these complimentary fields. A final argument is that there are a sufficient number of installations to ensure a good return on the investment into expert systems. The MK45, for example, is used on numerous ship classes from destroyers to amphibious assault ships.

As mentioned previously, one such expert system is in testing for the MK15 CIWS. Missile launching systems would also be an appropriate application for diagnostic expert systems for the reasons stated previously.

2. Radars

The individual radars of a ship's sensor suite are also appropriate applications for diagnostic expert systems. A cursory look at their circuit diagrams illustrates the complexity of trouble shooting these systems. In contrast to the difficulty of swapping out components of a gun mount, it is very simple to swap out circuit cards. This simplicity makes these systems very susceptible to fault isolation becoming maintenance diagnoses by part swapping. Expert systems can be used to quickly isolate the problem to a single card or group of cards to be replaced. Additionally, expert systems can be used to continue to work on a transitory problem that has temporarily gone into hiding. This is something that cannot normally be done with manual fault isolation. As with gun mounts, duplication of particular radar systems throughout the fleet should provide a good return on investment.

3. Electronic Engineering Officer of the Watch

A system could be built that automatically receives the data monitored by the Engineering Officer of the Watch (EOOW) of a gas turbine powered ship. The system would use its expertise to warn the EOOW of potential casualties, whose indications might be missed during normal operations, before they occur. In the event of an actual casualty, the system would identify it. Quite often, many of the possible casualties have nearly identical symptoms, frequently leading to misdiagnoses. An expert system could also serve to train new EOOWs. It would be a backup system only. Responsibility for the safe operation of the propulsion plant would still rest with the EOOW. This system would, however, help EOOWs by confirming their diagnoses or warning them of cascading casualties.

4. LM2500 Marine Gas Turbine Engine

The LM2500 is a complex mix of electronic and mechanical components. It is often difficult to determine if a casuality is caused by a mechanical failure or electronic fault. Additionally, many casualities have nearly identical symptoms. A diagnostic expert system would make the task of isolating casualities easier and faster. Two sub-systems could be developed. The first would be for the electronics and the second for the mechanical components. The central expert system would narrow the cause to either a mechanical or electronic problem and call on the appropriate sub-system. Applicable expertise can be found inside the Navy at such places as the Gas Turbine EOOW school, and GSE/GSM training courses. The use of these engines on the FFG-7, DD-963, CG-47, and DDG-51 class ships would ensure a high return on investment for such a system.

5. Gas Turbine Generators (GTGs)

Like the LM2500s, these are complex electronic and mechanical systems. The same arguments for the LM2500 apply to GTGs. Two systems would have to be developed. One system for the prime mover, and a second for the generator itself. In use on the same classes of ships as the LM2500, the return on investment would be acceptable.

6. Naval Tactical Data System (NTDS) Consoles

These are multi-function electronic display consoles. Being electronic systems they contain a large number of circuit boards and other components that can easily be swapped out. This encourages swapping parts out to isolate problems. Being multi-function consoles, it is not unheard of for parts of a operating console being used to isolate problems in a second console. A third console would take on the duties of the first console. This practice can result in two downed consoles. This equipment is also subject to transitory faults that can be tracked down by using an expert system after they disappear. Again, the potential return on investment would be high as various versions of these consoles are used on just about every surface combatant.

D. SUMMARY

This chapter has presented what the author feels are the potential benefits, problems, and applications of diagnostic expert systems. The potential benefits include reduced MTTR, efficient use of repair parts, improved knowledge and training, the capture of Navy expertise, and increased maintenance self-reliance. The sum of these benefits is improved fleet readiness.

These systems not being taken seriously, competition between man and machine, and over dependence on these systems, are some of the potential problems. None of these problems should prove to be insurmountable. They do, however, indicate the need for well planned implementation of these systems.

Gun mounts, radars, and various other shipboard electronics and machinery are all potential applications for diagnostic expert systems technology.

Having looked at these benefits, problems, and applications, the following chapter will summarize this paper and present the author's conclusions and recommendations.

VI. CONCLUSIONS AND RECOMMENDATIONS

This thesis has examined the use and development of diagnostic expert systems by the Navy. This examination began by first defining expert systems, their characteristics, and their components. A brief examination was then made of how these systems are being used by the Army, Air Force, and industry. Several Navy systems from the surface warfare community were then described. Finally, potential benefits, problems, and applications of diagnostic expert systems for the surface Navy were presented from the author's perspective as a surface line officer.

The research for this paper was affected by several factors. First, due to time constraints, the author concentrated the search for Navy systems to the surface warfare community. Secondly, the author's unfamiliarity with the Army and Air Force's acquisition, and research and development organizations hampered a detailed search for diagnostic expert system applications in these services. Although not exhaustive, this research leads to several conclusions and recommendations.

A. CONCLUSIONS

The information presented in this paper and the problems experienced in obtaining it allow several broad conclusions to be drawn.

1. Is The Navy Using Diagnostic Expert Systems?

Contrary to the author's initial belief, the Navy is using diagnostic expert systems. This use has progressed the farthest in the area of Hull, Mechanical and Electrical (HM&E) systems. The Naval Sea Support Center has been developing and using expert systems since 1987. A complete program has been created to develop new systems and maintain those already in use. Use of expert systems has not advanced as far in the area of weapons systems and sensor maintenance. Work in this area has been limited to a few systems intended to study the potential of expert systems for diagnostics. Fortunately, two of these systems, the AN/USH-32 Expert Maintenance Advisor, and the Phalanx Integrated Diagnostic System, appear headed for operational use. Although it appears the Navy is embracing this technology, it is still far behind civilian industry.

2. Which Navy Organizations Are Developing Diagnostic Expert Systems?

Numerous organizations are developing diagnostic expert systems within the Navy. Some of these organizations include the Naval Research Laboratory, the Naval Ordanance

Station, Louisville, and the Naval Sea Support Center. There is not one central organization developing these systems, but rather, several.

3. Is The Navy's Development Of These Systems Coordinated?

There is no coordinating Navy organization responsible for the collection and dissemination of information on these projects, or charting the direction in which the Navy should proceed in this field. The developers of each of the Navy's diagnostic expert systems discussed were unaware of each others work. The normal answer to the question of "Do you know of any other systems being developed?" was "No". The closest thing to a coordinating organization is a Condition Based Maintenance (CBM) working group. This group includes representatives from OP-03,OP-043, the type commanders, Naval Sea Support Center, and the life cycle managers, reliability and maintenance, and logistics groups of the Naval Sea System Command. The goal of this group is to move the Navy toward a Condition Based Maintenance philosophy that includes the use of expert systems. (Branham, 1992)

This uncoordinated development means that independent developers are not able to benefit from lessons learned by other projects. It can also lead to duplication of significant effort.

4. How Does The Surface Navy Benefit From These Systems?

There appears to be no statistical data being collected nor assesment being made of the impact of diagnostic expert systems. There was no data found on changes in the number of requests for technical assitance, parts usage, number of CASREPS, or man hours saved by expert systems. Several sources stated that only anecdotal data on the success of fielded systems was available. As a result of this lack of data, only one real cost analysis for a diagnostic expert system was located. Without such data and analysis no concrete evidence can be presented to support the conclusion that diagnostic expert systems provide worthwhile benefits to the Navy.

5. Are Navy Personnel Aware Of Expert System Technology?

One of the major difficulties encountered in conducting research for this thesis was a lack of awareness about expert systems. It was not unusual to be directed to an organization's ADP department if a specific person was not requested, and even these computer specialists often knew nothing about expert systems. This lack of awareness is also evident in the fleet. Despite a COMNAVSURFPAC letter implementing the Maintenance Expert System program, NAVSEACENPAC has to take the lead in informing units about these systems and encouraging their use. (Santos,1991) This lack of awareness stems in part from the scarcity of literature on

Navy diagnostic expert systems. Very few Navy reports on diagnostic expert systems were found and most of those dealt with theoretical work on knowledge representation, modelling, or reasoning. Diagnostic expert systems will not be used if the people who need to be using them are unaware they exist.

6. Are The Army, Air Force, And Industry Making Use of This Technology?

The Army, Air Force, and industry are all using diagnostic expert systems. Both the Army and the Air Force have at least one system operationally deployed. Industry is making considerable use of these systems, with numerous industrial applications found. These applications ranged from electronic equipment to automobile maintenance. Industry appears to be several years ahead of the military in the acceptance of this technology.

B. RECOMMENDATIONS

The following paragraphs contain recommendations for further work with diagnostic expert systems. As will be seen, many of these suggestions can be performed by NPS students as thesis projects.

1. Include Diagnostic Expert Systems As Part Of The Acquisition Process

The development of a diagnostic expert system for a new piece of equipment should be included in the acquisition process as part of the specifications. What better initial experts exist then the equipment designers and engineers? Requiring an expert system for complex diagnostic decisions to be included with the delivery of new equipment captures this valuable expertise and transfers it to all of the future maintainers. This is also the logical place to absorb the cost of development. These systems are part of the logistical support of a new piece of equipment. The initial knowledge base would grow as practical fleet experience is obtained.

2. Create A Central Database On Diagnostic Expert System Development

A central database of all Navy expert systems research and development would provide several benefits. First, by making available lessons learned from previous projects, costly mistakes can be avoided by other development teams. Expert systems developers would be able to benefit from the experience gained in building systems similar to their own. Second, a central listing of completed systems and systems under development would prevent duplication of effort. If an organization believes it has found an expert system application, it can check to see if it has already been done, and with what results. Finally, such a central database would make it easier for people interested in expert systems to find out what the Navy is doing in this field.

The initial set up of such a database would be an excellent multi-student thesis. It would involve an extensive and formal survey of the Navy to find all past and present expert system projects. A database would then need to be designed and implemented. This database could be made available on the Naval Postgraduate School mainframe computer through the Defense Data Network or as a computer bulletin board. After set up, the database could be maintained, with funding from an outside command, by a NPS staff member. This maintenance could probably be performed as a collateral duty.

3. Collect Data On The Impact Of Diagnostic Expert Systems

Data needs to be collected on the impact of diagnostic expert systems on fleet readiness and maintenance. Some items to be tracked include reduction in MTTR, reduction in the NFE rate, reduction in technical assist visits, and the associated costs saved. This would also make a good thesis topic for NPS students.

4. Conduct Cost/Benefit Analysis For Systems In Use

This recommendation is related to the previous one. Many of the diagnostic expert systems currently in use by the Navy have not undergone formal cost benefit analysis. Without such analysis, the worth of these systems can not be convincingly proved.

5. Determine User Views On Diagnostic Expert Systems

Several diagnostic expert systems are now in use in the fleet with more following. How do the sailors using these systems feel about them? Do they like them? Are they intimidated by them? What suggestions do they have for future systems? How do the supervisors feel about expert systems? How do both groups feel the systems should be used? The answer to these and other questions would help designers select appropriate applications, and design them better. They would also help in developing appropriate strategies for introducing future expert systems. Additionally, such questions promote thought about expert systems in general. Again, this is a potential thesis topic for NPS students.

6. Spread The Word About Expert Systems

The Navy is making use of numerous expert systems for various purposes yet there is very little literature available on these systems. The fleet needs to be informed of this technology and its benefits through such literature as *Surface Warfare Magazine, Naval Aviation News, All Hands*, and *Proceedings*. This would spur interest inside the Navy and provide impetus for new applications and improvements. The Navy should share its experiences with other federal agencies through *Government Computer News* and *Federal Computer Weekly*. No matter how good expert system technology is, if no one but developers and academicians know about it, it will not see wide spread acceptance.

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