2

AN EXPERT SYSTEM FOR LEARNING THE NATIONAL ELECTRIC CODE

THESIS

Jeffrey M. Liddle
Captain, USAF

AFIT/GEM/LSM/89S-12

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

89 12 28 071

(2)

AFIT/GEM/LSM/89S-12

AN EXPERT SYSTEM FOR LEARNING
THE NATIONAL ELECTRIC CODE

THESIS

Jeffrey M. Liddle
Captain, USAF

AFIT/GEM/LSM/89S-12

Approved for public release; distribution unlimited

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information is contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GEM/LSM/89S-12

AN EXPERT SYSTEM FOR LEARNING THE NATIONAL ELECTRIC CODE

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering Management

Jeffrey M. Liddle, B.S.

Captain, USAF

September 1989

Preface

The purpose of this research was to provide a better method for training with and using the National Electric Code. This was accomplished by applying hypertext and expert system technology to the code.

Hypertext provides a quick, yet structured approach to viewing the code. It gives the user virtually instant access to the large quantities of text contained in the code. The expert system provides the expertise in electrical design requirements. By asking the user a series of exercises and linking the user to the code rules via hypertext, the user gains a better understanding of the National Electric Code and electrical design requirements.

Several individuals have provided a great deal of assistance in building the expert system and writing the thesis. I would like to specifically thank my thesis advisor, Lt Col James Holt. His efforts and comments kept me focused throughout the research. Meredith Le Clair and Scott Crabtree from Knowledge Garden were instrumental in clearing major hurdles on the expert system design. A word of thanks is also owed to Gregory P. Bierals for his expertise and insight on the National Electric Code.

Finally, I would like to thank my wife Amy for being there when I was tired and supporting me when I needed it the most.

Captain Jeffrey M. Liddle

Table of Contents

		Page
Preface	. . . .	ii
List of Figures	. . . .	v
Abstract	. . . .	vi
I.	Introduction	1
	Overview	1
	Background on the National Electric Code	1
	Statement of the Problem	4
	Hypertext Definition	5
	Expert System Definition	5
	Research Questions	5
	Scope and Limitations	6
	Assumptions	6
II.	Expert Computer Systems	8
	Overview	8
	Expert Computer System Categories . .	10
	Components of an Expert Computer System	11
	Knowledge Acquisition	11
	Knowledge Base	11
	Inference System	13
	User Interface	14
	Expert Computer System Classification .	15
	PC-Based Expert Computer System . . .	15
	Expert Computer System Shells . .	17
	Hypertext	20
	Combining Expert Systems and Hypertext	21
	Existing Computerization of the NEC .	22
	Summary	23
III.	Methodology	24
	Overview	24
	Four-Part Development Process	24
	Problem Identification	24
	Development Tool Selection	27
	Prototyping and System Building .	32
	Testing and Validation	34
	Summary	38

	Page
IV. Results and Other Findings	39
Overview	39
Expert System Software	39
NEC Automation	40
Hypertext Function	41
Expert System Training Function .	43
Validation	45
Limitations	48
Summary	49
V. Summary, Conclusions, and Recommendations .	51
Summary	51
Conclusions	51
Research Question 1	51
Conclusion 1	51
Research Question 2	52
Conclusion 2	52
Research Question 3	52
Conclusion 3	52
Research Question 4	53
Conclusion 4	53
Research Question 5	53
Conclusion 5	53
Recommendations for Future Research .	53
Appendix A: Subjective Questions for Testing and Validating the Prototype Expert System	56
Appendix B: Objective Testing Measures	57
Appendix C: Knowledge Sources	58
Appendix D: Request for Program	59
Appendix E: KnowledgePro Program	60
Appendix F: List of Individuals Tested	79
Bibliography	80
Vita	82

List of Figures

Figure		Page
1.	Major Divisions of Artificial Intelligence .	9
2.	Basic Structure of an Expert System	12

AFIT/GEM/LSM/89S-12

Abstract

The purpose of this research was to apply hypertext and expert system technology to the National Electric Code to assist with learning and using the code. Presently there is no formalized training available on learning the code. Also, using the code is awkward and cumbersome at best because of the code's large quantity of text.

Hypertext brings to the expert system a very quick and efficient way of viewing and moving through the code. The user controls the direction taken based on the selection of a hypertext path. The expert system, through a series of exercises, provides the training needed to learn the code rules and electrical design procedures. Hypertext provides the link between the exercises and the code rules to assist in answering the exercises. This process strengthens the user's knowledge of code rules and standard electrical design procedures.

The expert system was developed using the expert system shell KnowledgePro by Knowledge Garden. The prototype expert system provides complete access to chapter 2 of the National Electric Code and a series of learning exercises. The system was tested to determine; how useful the system is, how it can be integrated into the traditional engineering and computer environment, and how user-friendly the system is.

Four different groups of individuals were tested to achieve a cross-section of information. Test results clearly indicate that the system is useful, user-friendly, and that the prototype should be expanded to include the entire code.

AN EXPERT SYSTEM FOR LEARNING THE NATIONAL ELECTRIC CODE

I. Introduction

Overview

Within the United States Air Force, Civil Engineering has responsibility for all facility design projects. The Civil Engineering design branch consists of four departments; architecture, civil engineering, mechanical engineering, and electrical engineering. The Electrical Engineering Department has responsibility for all electrical power and distribution system designs.

Electrical designs are principally guided by Chapter 16 of Air Force Manual (AFM) 88-15 and the National Electric Code (NEC). AFM 88-15 provides design criteria and standards specifically for the Air Force. Chapter 16, titled Electrical, is based on and is derived from the National Electric Code. In some cases, the Air Force standards are more stringent than the NEC.

Background on the National Electric Code

The National Electric Code is, "a nationally accepted set of guidelines for the safe installation of all electrical equipment" (15:XV). It is the driving force behind all electrical power designs. The NEC is published by the National Fire Protection Association and is updated every three years. It is considered a minimum set of rules to follow in the safe design of electrical systems. Some agencies, such as the Air Force, have adopted more stringent rules. The important phrases to remember from the definition are 'nationally accepted' and 'safe installation'. Nationally accepted, means all areas of society have accepted the NEC as the minimum guideline to follow. Consequently, the National Electric Code is used extensively by courts of law, insurance companies, engineering firms, and all levels of Government.

Safety is extremely important when working with or around electrical equipment. The NEC provides safe practices to follow when installing and working with electrical equipment. Noncompliance with the National Electric Code can be costly, often resulting in fires, personal injury, and loss of life. In addition to the safety aspect, when noncompliance is detected, authorities will require redesign and new construction of the work. This results in additional design and construction costs.

There are a number of problems associated with the use of the National Electric Code.

1. There is no formal training available on the use of the NEC itself. While there are a few universities throughout the United States which offer National Electric Code review seminars, the seminars are geared for those already knowledgeable in the

code. The seminars review changes to the NEC based on each three year update. They are not designed to cover the NEC by itself as a code book. Quite often, what information is received at the seminars is forgotten back in the work environment. Existing Air Force training in electrical power design requires knowledge in the use of the NEC. The Air Force Institute of Technology sponsored short course in electrical power design requires some knowledge of the NEC prior to attendance (18). The electrical power design course does not have enough time or available resources to teach the code rules and design rules concurrently.

2. The type of training that is available is on-the-job training. However this requires an expert present most if not all of the time. There are some Electrical Engineering Departments with only 1 or 2 engineers assigned, neither of which maybe experts.

3. The code book is structured into chapters and sections and contains a large number of rules. Mr. Richard Winters from HQ AFLC/DEE stated that "by the year 2000, the codebook may be too large for anyone to carry" (20). Information needed for a particular design problem or to answer a question, most likely is contained in different chapters and many different

sections. This makes using the National Electric Code awkward and cumbersome.

4. Once the section or sections are located, the contents are open to interpretation as to whether the information applies to the problem in question. The National Electric Code is simply stated, a rule book. The user must determine which rules apply to their problem. The novice electrical engineer requires the assistance of an expert to make this determination.

Statement of the Problem

How can electrical engineers use the National Electric Code effectively and learn/train with it at the same time without having an expert present all the time? The goal is to provide quick and easy access throughout the entire code and a training method available to the user in the work environment. Hypertext, in conjunction with expert system technology from the artificial intelligence arena, may provide the solution to the stated problem. Applying hypertext and expert system technology to the National Electric Code attempts to fill the void left at the work environment and could become a training tool that does not require an 'expert' present at all times.

Hypertext Definition

"Hypertext is a generic term for a type of application in which 'live' or 'sensitive' areas of a screen (called buttons) can be used to control direction or 'branching' within a program" (4:136). This allows for real-world knowledge to be logically linked together in a straightforward way (11:97). The expert computer system user has more control over the direction the program takes providing quick and easy access of information.

Expert System Definition

An expert system is a "computer program which emulates human expertise by applying techniques of logical inference to a knowledge base" (11:2). It does what a panel of experts would do for you (3:25). Professor Edward Feigenbaum of Stanford University, one of the leading researchers in artificial intelligence, defines an expert system as:

> an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. (9:5)

Research Questions

The following questions must be answered in order to solve the specific problem.

1. How can an expert computer systems, be developed for learning the National Electric Code?

2. What parts of the National Electric Code can be inserted into an expert system?

3. How could an expert system combined with hypertext help an electrical engineer use and train with the NEC?

4. Where and when will the expert computer system be used?

5. How will the expert computer system be evaluated?

Scope and Limitations

The scope of the thesis is to develop a prototype expert computer system to assist in using and learning the National Electric Code. The intent is to demonstrate the feasibility of using an expert computer system in conjunction with the NEC. Since the quantity of text within the National Electric Code is quite large, one of the nine chapters in the NEC will be selected for encoding onto the expert computer system.

Assumptions

The researcher made the following assumptions to better define the expert system requirements:

1. The NEC expert system is designed for Air Force Civil Engineering use but could be used by anyone desiring to use it.

2. The prototype system shall be freely copyable to all who wish to use it.

3. The software requires an MS-DOS operating system.

II. Expert Computer Systems

Overview

There has been a tremendous growth in the computer industry that seems to drive itself by each new major innovation. Innovations such as: high-level languages, solid-state logic, compatible machine ranges, disk storage, time-sharing, virtual machine architectures, large scale integration and solid-state memory, text processing, personal computers, artificial intelligence, and successful packaged software have fueled growth in the past (11:1).

Expert systems is a division of a large growth area called artificial intelligence (AI) and may be defined as:

> A part of computer science, concerned with design of computer systems which exhibit human intelligence: understanding language, learning new information, reasoning, and solving problems. (2:17)

Figure 1 shows the major divisions within AI. From Figure 1, we can think of expert computer systems as a subset of AI technology in general (4:3). Among the divisions of artificial intelligence, expert systems have emerged as the most practical application of the techniques developed in artificial intelligence research (11:1).

Expert system development began in the late 1970's and early 1980's and is rapidly expanding. "We have had

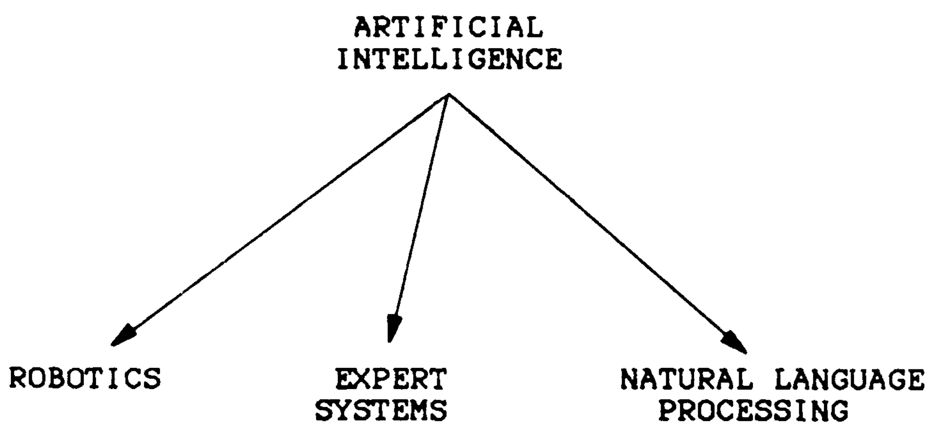

Figure 1. Major Divisions of Artificial Intelligence (4:4)

the era of the spreadsheet, word processor, and currently, the data base; next, it is argued, we will have the era of the expert system" (6:1). A trend began during the 1980's, showing increased use of expert systems to address the large volume of nontechnical problems involving decisions or assessments (1:6).

Expert computer systems have successfully progressed out of the academic world and into the business world. In the past, expert system applications were limited to large corporations, however, this is changing due to the availability of expert system development tools (17:40). "Companies should be asking how expert systems might prove beneficial in their business" (3:28).

Expert Computer System Categories

Most expert computer systems are categorized in one of three ways: rule-based systems, frame-based systems, and blackboard systems (1:10). Rule based systems, or "production systems" are the most common in use. The rules are called "IF-THEN" and are found in the form of IF X, THEN Y. "Frame-based systems store factual knowledge in frames, where frames resemble miniature data bases which are hierarchically ordered" (1:11). Frame-based systems are usually of the form "WHEN-THEN". Blackboard systems, defined by Michael Ham in his article, "Playing by the rules", is described by Mary K. Allen in her Doctoral Dissertation as:

> taking its knowledge from several knowledge sources embodied as separate data bases and calls in the information it needs with appropriate subroutines. Each knowledge system acts like a separate system and conclusions are sent to a shared data base (the blackboard) that can be viewed and accessed by any data base. (1:14)

The advantage of blackboard systems is one source uses the conclusions drawn by the other sources (1:14).

Components of an Expert Computer System

The basic structure of an expert system is shown in Figure 2. The structure contains four parts; knowledge acquisition, knowledge base, inference system, and a user interface.

Knowledge Acquisition. "Knowledge acquisition facilities are used to transfer the knowledge from the human expert or other information source into a form that can be used by the expert system" (13:5). Knowledge acquisition facilities are also referred to as tools.

Knowledge Base. The knowledge base is an organized body of information in computer memory (11:2). It is where the information required to emulate human expertise is stored (11:88). A knowledge base does not contain simple statements or facts, but contains rules for carrying out tasks. It is the foundation of the expert computer system. Knowledge bases may be unlimited in size and complexity. Real-world knowledge may be thought of as:

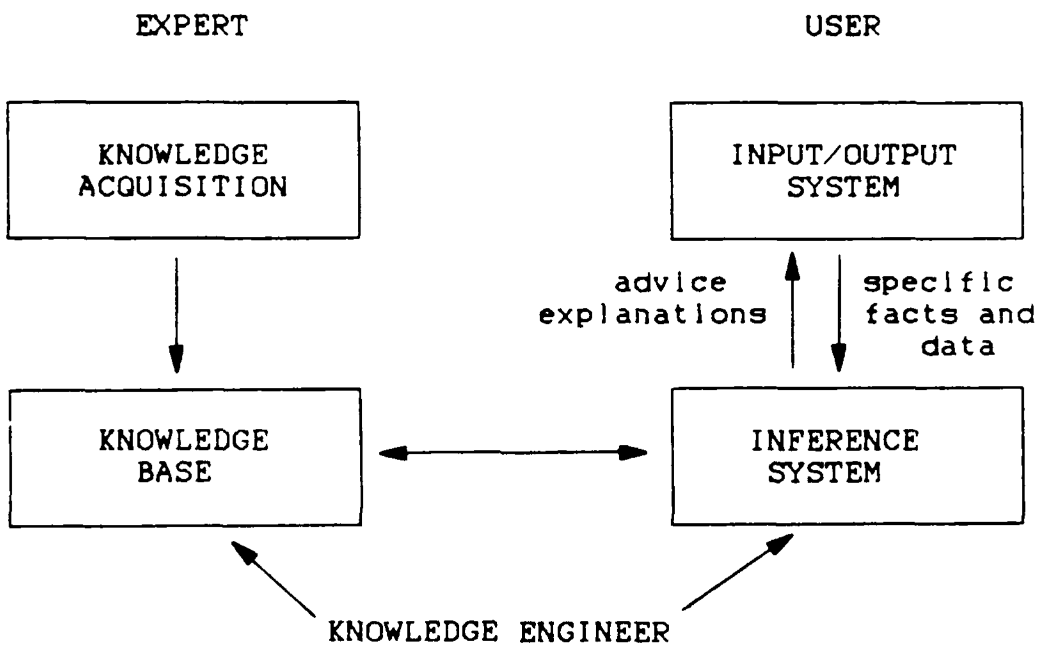

Figure 2
Basic Structure of an Expert System (13:6)

a subtle collection of rules, procedures and relationships, as well as simpler facts or assertions, which must be represented and structured in such a way that it can be conveniently stored in computer memory and accessed by user programs. (11:88)

Inference System. The inference system or inference engine, operates on the knowledge base and applies the laws of logical inference to make further statements (11:89). The inference engine is independent of the knowledge base. The rules within the knowledge base may change and not affect the inference engine. The style or number of rules does not affect the way the inference engine carries out its task (6:10). The inference engine is considered the heart of the expert computer system, but does not necessarily contain large lines of code. The inference engine guides and controls the search through the knowledge base by one of three methods: forward chaining, backward chaining, or a combination of the two.

The decision to use any of the three methods should be based on the problem being solved. "Forward chaining builds up from the available facts about a situation to deduce conclusions" (11:9). In forward chaining, the inference engine compares information supplied by the user with the "IF" portion of the rule based knowledge base. If the comparison yields a match, the rule "fires", or more descriptively, is activated as a known fact and is added to the user supplied information.

"Forward chaining is appropriate where the possible conclusions cannot be pre-specified" (11:9). Backward chaining is just the opposite of forward chaining. Backward chaining starts with a conclusion or goal and tries to see if the conditions which would make the conclusion true can be satisfied (11:9). It is appropriate for use when desired conclusions can be specified in the beginning. Examples are medical diagnosis and diagnosing equipment faults. Determining which method to use is not cut-and-dried, but may be stated as follows:

> If the problem involves significantly more conclusions than facts, forward chaining is preferred; if the problem involves significantly more facts than conclusions, backward chaining is probably more appropriate. (4:35)

User Interface. User interface may be defined as the method in which the expert computer system interacts with the user (9:98). Another way of saying user interface is to say user friendly. User interface is made up of tools which allow for varying degrees of interaction. Most expert computer systems include at least one or more of the following tools; explanation facilities, graphic display of the reasoning process, on-line help systems, trace facilities, and case management and batch processing facilities. Some interfaces are built for specific users in mind, while others are more generic in nature. Selection menus may be incorporated into the user interface depending on the number of applications the expert computer system can handle (6:23).

Expert Computer System Classification

Expert computer systems can be either large or small. Large systems are generally processed in LISP on computers with specially designed architecture or on large computers and may contain 500 to several thousand rules (9:92). LISP is a programing language which is very appropriate for artificial intelligence programs and expert computer systems. LISP stands for list processing language. Small expert computer systems contain less than 500 rules and usually run on micro or personal computers (PC) (9:232). They are generally referred to as PC-based expert computer systems. This thesis will focus on the small or PC-based expert computer system.

PC-Based Expert Computer System

As mentioned earlier, expert computer systems have progressed out of the academic world and into the business world. This is fueled in part by PC-based expert computer systems bringing artificial intelligence into mainstream corporate America (4:3). The arrival of high-powered personal computers brings with them the large computational ability required by artificial intelligence and expert systems for use in the business and engineering environment (10).

PC-based expert systems are a set of computer programs which emulate human expertise by applying the techniques of logical inference to a knowledge base and run on a personal computer. This is significant because, even at the PC level, expert computer systems can predict, diagnose, solve problems, plan, and provide aid in making many decision-making processes that require human expertise (4:4). The same reasons that made PC's so popular have made PC-based expert computer systems popular. Factors such as desktop computing capability, versatility, ease of use, and portability make it popular with users (4:5). "The advantage of a PC-based system is you can get a hold of it, get it into your company, use it in applications you're interested in, and determine if that is the direction you want to take" (4:5). Costs have dropped substantially for PC-based systems and with increased use, better tools and interfaces have simplified the building process (4:5).

PC-based expert computer systems have a wide range of applications. Certain kinds of tasks performed by experts lend themselves to PC-based expert computer systems technology better than others (4:11). There are four general areas for PC-based expert computer systems applications:

--intelligent information retrieval or manipulation
--diagnosis and problem-solving
--prediction and forecasting
--instruction or training (4:11)

A good way to determine the feasibility of developing and building a PC-based expert computer system is to find out whether or not the knowledge needed to solve the particular problem can be expressed in a set of "IF...THEN" rules which are understandable to the user (4:11).

Software developers are following the trend toward PC-based expert systems. They are offering a host of tools or shells that make the entire building process as easy as many common PC applications (4:13-14). It is apparent that:

> The emphasis from vendors today is on ease of use, access to commonly stored data, facilitating the knowledge acquisition process, and incorporating graphics, windows, menus, and natural-language features. (4:14)

Expert Computer System Shells. Expert system shells combine two parts of an expert system, the inference engine and user interface, into one software package (3:25). Some are very specific in design and others are general. Expert computer system shells may have a wide range of development aids and must therefore be flexible to meet the widest possible range of requirements (12:99). Programming time and effort are saved by expert computer system shells. Expert system shells reduce the tasks of capturing and structuring knowledge and expertise (4:5).

This makes the expert system technology available to nonprogrammers (4:51). A good analogy is:

> Using a shell to build an expert system is analogous to using word processing, spreadsheet, or database software for individualized needs. Few of us would even dream of writing our own word-processing software when so many commercial packages are available. (4:51)

Because the expert system shell may be specific in design, "the choice of a shell may often be a compromise between the user's requirements and the shell's capabilities" (12:99). The following list defines a number of important features that may be included in the expert computer system shell.

* program development and checking facilities (for example; windowing and error reporting)

* provision of floating-point and double-precision arithmetic facilities

* provision of transcendental and other scientific functions

* ability to call libraries of subroutines

* general file handling facilities

* ability to communicate with external databases

* provisions of file security and back-up

* ability to call operating system commands

* graphics capability with operator interaction

* communication with external equipment and computing systems

* ability to link with programs written in other languages

* production of fast compact code and sophisticated editing facilities (12:100)

As the knowledge base increases in size, speed of response also becomes important. Not all of the features can be included in every shell. It depends on the requirements and needs for the use of the shell. Expert computer system shells "dictates the nature of the tasks which people who use it must carry out, and the talents they need" (11:90). It places the emphasis of work on the acquisition and organization of knowledge (11:90). This new work is called "knowledge engineering" and those who do it are called knowledge engineers. Knowledge engineers must:

> have the ability, training, and experience to elicit knowledge from the domain experts, to structure it appropriately in the knowledge base, and to design the whole system so that it can arrive at required solutions quickly and effectively. (11:91)

In their book, Mind Over Machine, Dreyfus and Dreyfus talk about knowledge engineering as interviewing leading experts in various fields to find out how they make judgments at the core of their expertise (8:101). In his book, A Guide to Expert Systems, Donald Waterman defines knowledge engineering as "the process of building an expert system" (19,5). Knowledge engineering involves an interaction between the expert system builder and the human experts in the problem area. "The knowledge engineer 'extracts' from the human experts their procedures, strategies, and rules of thumb for problem solving, and builds this knowledge into the expert system"

(19,5). The result of this process is a program that solves a problem in the same manner that a human expert would.

Hypertext. "Hypertext is a generic term for a type of application in which 'live' or 'sensitive' areas of the screen can be used to control direction or 'branching' within a program" (4:136). It gives the user the opportunity to control the execution of a program without simply responding to questions that lead to predetermined pathways (4:137). By highlighting key words within the expert computer system, the user will have greater control during each expert system consultation. Hypertext gives "the end user more information about the questions being asked and the statements being made" (16:I-2). An example of hypertext might be:

> Welcome to the _automated_ NEC.
>
> topic 'automated'
> Automated in this case means using an _expert system_ combined with _hypertext_ to help in your search through the code rules.
>
> topic 'expert system'
> An expert system is a computer program that is designed to solve a problem or give advice in response to questioning by the user.
>
> topic 'hypertext'
> Hypertext allows the user to direct the flow of information based on the user's need.

The above example shows three hypertext words or phrases that could be a part of a larger expert system. When the user reads the statement, "Welcome to the _automated_ NEC.", they have the choice of sending themselves to a definition of automated or continuing with the expert system consultation. If the user decides to hypertext to the definition of automated, they will find additional hypertext words within the definition of automated. This is an example of how hypertext can be stringed together. The user decides which direction the expert system should take them.

Hypertext facilitates wider ranges of user expertise, from a novice to the expert. "It can offer explicit information to less knowledgeable users while not encumbering the more advanced users of the system with superfluous text" (4:207).

Combining Expert Systems and Hypertext. Expert systems, by themselves, do not give the user control over the system (16:I-3). Additional information or clarification is not available to the user. As long as the questions are answered the same, the user is sent along the exact same path. Hypertext systems that focus only on displaying messages have the opposite problem. Although they allow the user to control the system, the only control the designer has is in setting up the hypertext (16:I-3).

Real communication is achieved by combining hypertext and expert systems (16:I-3). Hypertext can be located even within a specific question that the expert system is asking. The user has better control of the desired answer based on their movement within the expert system. At the same time, both the expert system designer and the user have control of the system based on the direction their hypertext response takes them. The use of hypertext will allow for fast and controlled movement throughout the expert system based on the users' needs and experience level. Chapter III will expand on the above statements and discuss the specific approach or methodology for building the expert computer system.

Existing Computerization of the NEC

Computerizing the National Electric Code is not a new idea. Gregory P. Bierals, president of Electrical Design Institute, states that users of the NEC are looking for an automated reference to the code by subject (5). Quite often, electrical engineers find themselves paging through the code looking for all the sections that may pertain to a specific subject. This is a very time consuming effort.

David L. Lemaster, P.E., of Future Systems, Richmond, Virginia, has computerized a number of National Electrical Code tables. His program is called the Electrical Reference Data Base. E.K. Greenwald from Madison, Wisconsin has a program called, NEC Tables, which also contains NEC table information. Both of these applications, and there are undoubtedly others like them, provide NEC table information only. This is not to say that they are not beneficial, but they are not linked to any other part of the National Electric Code.

Applying hypertext and expert system technology together, is an attempt to extend the computerization of the National Electric Code. Hypertext provides the link between the hundreds of sections and tables located within the code and to the expert system exercises. Together, they should provide a useful tool that will help engineers to learn and use the National Electric Code.

Summary

Chapter II discussed many key definitions and issues regarding expert computer systems and hypertext. Expert computer systems are a subset of artificial intelligence technology. Today, they are one of the leading practical applications of artificial intelligence techniques. Expert computer systems are usually categorized as; rule-based, frame-based, or blackboard systems, the most common being rule-based.

Hypertext allows the user real communication within the expert computer system. It gives the user more information about the questions and answers. This facilitates wide ranges of user expertise, from novice to expert.

Expert systems combined with hypertext is good way to solve the 4 identified problems from Chapter I.

III. Methodology

Overview

This research will show that improved use of and training on the National Electric Code is possible by applying hypertext and expert system technology to the code. The goal is to make AI tools work for the engineer. This approach is taken based on two underlying fundamental problems. One, there is literally no training available on the use of the NEC. Two, because of the code's structure and large size, it is very cumbersome and awkward to use.

Four-Part Development Process

It is important to have a systematic approach when applying expert system technology to allow for efficient use of time and resources. A development plan will make the entire development process more manageable and will be better able to judge the overall effectiveness of the results (4:16). The four parts to the process are:

1. Problem and identification
2. Development tool selection
3. Prototyping and system building
4. Testing, validation, and maintenance (4:16)

Problem Identification. Identifying an appropriate problem is an important first step when developing an expert computer system (4:57). Heavy computational type problems are not suitable for expert system development. Situations that require cognitive expertise are suitable for expert system development (4:57). "Expert systems are particularly good at solving problems involving diagnosis, classification, analysis, or teaching skills" (4:57). As noted in Chapter I, there is virtually no training available on the National Electric Code. On-the-Job training is limited and inconsistent at best. Integrating expert system technology with hypertext to the National Electric Code appears to be an appropriate solution to the problem.

Along with identifying an appropriate problem, you must also precisely formulate or define the problem (4:58). What is it that you want the expert computer system to specifically accomplish? This is directly tied to the problem identification. It is possible that the expert system can solve part of the problem but not all of the problem. Is this acceptable or not? The expert system developer must keep the specific problem in focus at all times.

The desired problem solution is two-fold. First, quick and easy access to all areas of the NEC is needed to aid in its use. The National Electric Code is basically a large rule book with numerous exceptions for each rule. Most rules reference other applicable chapters and articles throughout the code. A typical example follows:

Article 210-5. Color Code for Branch Circuits.

(b) Equipment Grounding Conductor. The equipment grounding conductor of a branch circuit shall be identified by a continuous green color or a continuous green color with one or more yellow stripes unless it is bare.

Exception No. 1: As permitted in Section 250-57(b), Exceptions No. 1 and 3 and Section 310-12(b), Exceptions No. 1 and 2. (15,66)

This example cites references in different sections within chapter 2 and also chapter 3 which confuses the access to the information. An expert system approach in conjunction with hypertext seems logical here. In this case, an expert system could define each step of the way and automatically send the user to the exceptions if appropriate.

Second, electrical design problem solving, with code references, would aid in learning the code. To assist the engineer in learning the rules of the code, the expert system could ask a series of questions that include hypertext code references to the specific NEC sections that contain the answer. This way the engineer begins to learn the electrical design principals and becomes more familiar with the code.

Common sense applies here on the size of the problem compared to the solution. Donald Waterman, in his book titled, A Guide to Expert Systems, states that one of the three characteristics that make the use of expert systems appropriate is proper scope. Waterman goes on to state that "one of the most dangerous pitfalls in expert system building is choosing a problem that is too broad or general to be handled adequately" (19:133). It is much simpler to start small and work up (4:59). Most problems can be broken down into self contained parts, yet still yield acceptable results. The National Electric Code is separated into nine chapters. For this research, one chapter from the NEC will be selected as a test basis for the entire code.

Development Tool Selection. The expert system developer must recognize three points; which tool is most appropriate for the expert system goal, which fits within the existing resources, and which one the developer understands (4:75).

Five criteria have been identified which are important from both a user and developer perspective.

1. Fit the tool to the problem
2. Effectiveness of the developer interface
3. Effectiveness and friendliness of the user interface
4. Integration capability with existing programs and databases
5. Run-time licensing for delivered systems

(4:75-76)

The most important of the five criteria is fitting the tool to the problem. For rule-based tools, the knowledge must be "procedural" in nature or easily expressed in rules (4:77). Does the knowledge seem to fit to the form of IF...THEN rules. For inductive tools, the knowledge must be in the form of examples that represent past practices or events (4:77). This tool should be used if the overall structure of the knowledge is unknown. For hybrid tools, the need for both rule-based and inductive techniques should be required (4:77). Greater flexibility is another reason for using hybrid tools. Electrical design requirements are fairly well structured and the National Electric Code is well formatted. This suggests that the proper expert system tool for this research effort is a rule-based or hybrid system.

The developer's interface must be easy to use yet be flexible enough to allow future growth (4:78). The tool must be well documented and provide some form of training. Both can be in the form of reference materials, on-line help, and tutorials (4:78). Since this is a PC-based tool, the developer must have the means readily available to themselves for fixing problems. Reference material provides information on the total system and shows useful examples. On-line help provides information on the system's commands and is designed to 'jog' the developers memory during system development (4:78). Tutorials may provide the most benefit because they step the developer through a demonstration of the tool at work with an example problem. The inexperienced developer will rely on the tutorial to acquire the skills for system development while the experienced developer will use the reference manual.

The expert system tool should have some form of editor for entering knowledge. The editor should be familiar to the developer or easy enough to learn by themselves. It should be powerful enough to handle the problem to be solved. To save development time, the editor should allow for quick movement back and forth between testing and debugging the system (4:79).

The ability of the expert system shell or tool to visually display the logic of the system and the knowledge is important (4:80). This helps in developing and debugging the expert system. As the knowledge base grows it becomes easier to get lost in the data. A common way of displaying the data is by a decision tree. The tree shows a hierarchical arrangement of the key words which represent interactions between key words of the system.

Depending on what type of problem the expert system is to solve, graphics-handling capability may be important. It can provide a polished, professional look to the system (4:81). Windowing is a powerful graphics tool that provides visualization of relationships (4:81).

The third criteria for expert system shell or tool selection is effectiveness and friendliness of the user interface. This is critical for the success of the expert computer system because no matter how well written the system is, if it is not 'user friendly' the system will not be successful. Most PC-based expert systems use a question/answer format during a consultation (4:82). How the user is allowed to respond during a consultation determines the degree of user friendliness and effectiveness. Four common input formats are:

--Typed response with ENTER key to accept
--Light bar controlled by cursor keys with enter key to accept
--Command list on-screen with function keys for input
--Mouse interface for selecting graphical options (4:82)

The most efficient user interface is the one with the fewest key strokes. "The more 'visual' the choice, the easier the system will be to use" (4:82).

The output format or how the system communicates to the user is also important. The user must understand what the expert system is asking or trying to tell in it's output. Five popular methods for output communication are:

--Simple text on screen
--Natural-language translations
--Windows for embedded/hidden text or graphics
--Hypertext for nonlinear information retrieval
--Tailored/selected report generation (4:83)

In many cases, a combination of methods is incorporated into the expert system for ease of use.

Integration capability with existing programs and databases is the fourth criteria in development tool selection. This allows for a wider scale of development and adoption of expert system technology at the PC level (4:85). In some instances, different software programs can be "piggy-backed" together extending the range of applications. An expert system may function as an 'intelligent' front end to an existing spreadsheet or database program (4:85). If this is a requirement to solve your problem, you must make sure the existing program and the choice of expert system tool is compatible. Most tools can access files in ASCII, Lotus 1-2-3, and dBASE formats.

The final criteria for development tool selection is run-time licensing for delivered systems. After the expert system program is completed and running, a number of users may wish to use the program but not add to it. Run-time programs of the expert system is a limited version of the complete expert system software. It allows users to consult an expert system program, but not build a new expert system or change the existing one in any way. This is extremely important if the expert system developer anticipates a large number of users. Without the run-time licensing, every potential user would be required to purchase the expert system software to use the expert system.

The choice of expert system development tool or shell must match the requirements and needs of the problem to the criteria outlined above. The best match available will allow for an easier development of the expert system and provide the best possible solution to the problem.

Prototyping and System Building. This step "involves developing a working knowledge base and an effective user interface" (4:161).

Prototyping is important for large knowledge base problems and offers four major advantages to building the entire expert system from the start.

> 1. A prototype enables the developer to judge whether the system is feasible. Being unable to get the system to perform well on a subset of the intended problem suggests that the system will not be capable of handling the entire problem. A prototype thus provides the opportunity to 'prove the concept,' or test the validity of an expert systems solution to the problem. The developer may discover after running the prototype that the problem at hand may really be illsuited for an expert systems approach.
>
> 2. A prototype allows the developer to test the suitability of the development tool that has been selected. Testing even an incomplete system may reveal that the knowledge representation scheme, the control or inference mechanisms of the tool, or its user-interface capabilities may be inadequate for the problem at hand. The prototype will also suggest the speed with which the completed system will run; a small system whose run-time is unacceptable indicates that the completed version will be even slower and that a different tool, or at least a different organization of the knowledge, may be required.
>
> 3. A prototype will suggest the amount of time required to build the whole system, an estimate that is essential for determining a cost/benefit ratio. As a result of the prototyping experience, developers may discover that their initial time estimate was either too optimistic or too pessimistic.
>
> 4. If developers need to gain support of a supervisor before building an expert system, one means of doing so is to present the supervisor with a working prototype of the system. To suggest the potential of a fully developed system, a prototype often makes a more convincing argument than even a cogent and well-prepared verbal or written presentation of the concept. (4:161-162)

Two avenues of approach for building a prototype expert system are to restrict the number of recommendations or restrict the number of factors (4:162). Recommendations are the results of the expert system and factors are the inputs to the expert system. For this research effort, a combination of restrictions are incorporated based on the reduction of the National Electric Code use, from nine chapters to one chapter.

Once the concept and use of prototyping is agreed upon, the acquisition of knowledge follows. The expertise or knowledge may exist in many forms (4:164). Typically, knowledge comes from human experts which may include the developer themselves or from printed material. The act of acquiring the knowledge is defined as knowledge engineering. Knowledge engineering is not an easy task. Although human experts may know a great deal about the subject matter, conveying the information to the expert system developer is often difficult. It is the knowledge engineers task to get the correct information from the experts.

Two types of information that the knowledge engineer should strive for are the results or recommendations of the expert system and the factors that distinguish the results from each other (4:164). Once the knowledge is obtained, the relationships need to be established using the acquired factors and results. This is accomplished using rules, induction methods, or some combination of both.

Finally, the user interface is developed. The key idea is ease of use, yet sophisticated enough to solve the problem. Four guidelines to follow are:

1. Keep the screen as sparse as possible
2. Require as few keystrokes as possible
3. Use graphics whenever possible
4. Use windows or hypertext (4:195)

Hypertext accommodates users of different levels of sophistication (4:207). The user has control of the expert system direction based on his or her needs.

The user interface should be able to interpret all forms of user supplied information. If the user supplied information is inappropriate, the expert system must be responsive and explain the error. If the expert system is unable to respond to valid user supplied information, it should default to a predetermined statement explaining why no answer was provided.

Expert system documentation should be provided that follows three categories:

-ease of finding information
-ease of understanding the information
-task sufficiency of the information (14:43)

Testing and Validation. The testing and validation stage should demonstrate that the newly developed system has accomplished it's desired goals. "There is an overall shift from 'proof-of-concept' of the system to its 'performance'" (4:221). Without testing and validating, the research looses a great deal of credibility.

Four different groups of users are used for testing and validating the use of the expert system. They are:

1. Electrical engineering instructors from the School of Civil Engineering, AFIT, Wright-patterson AFB Ohio.

2. Electrical engineers assigned to HQ AFLC, Wright-Patterson AFB Ohio.

3. Electrical engineers assigned to the 2750th Civil Engineering Unit, Wright-Patterson AFB Ohio.

4. Graduate of Engineering Management students with an electrical engineering background, School of Systems and Logistics, AFIT, Wright-Patterson AFB Ohio.

The intent of the testing phase is to find out how the expert system performs when used by an expert. Its focus will be on answering three questions about the expert system itself.

1. How useful is the system?

2. How easily can it be integrated into traditional computer and engineering environments?

3. How can it be made as user-friendly as possible? (4:222)

To answer the above questions, the four specified groups will be tested with the prototype expert system and asked a series of questions regarding six specific criteria for testing and validation. The six criteria for testing and validating are: accuracy, completeness, reliability and consistency, effective reasoning, user-friendliness, and run-time efficiency. See appendix A for a summarization of the specific questions asked.

Accuracy is important to insure that the answers received from the expert computer system are the same as if received from a human expert in most cases. The goal can not be 100 percent accuracy, because problems arise where there is hidden or unknown information not available to the expert computer system but is available to the human expert. The intent of the expert system is to guide and provide a tool for understanding, not replace.

Completeness, which is related to accuracy, is a function of the expert system size and complexity. Completeness should be defined at the beginning of the development process and then measured against the developed system (4:223).

"The best way to test and validate an expert system for reliability and consistency is to simply measure it against a real expert" (4:224). If similar advice is given by both the human expert and the expert system, the expert system is considered reliable (4:224). If the process is repeated, and the same advice under the same circumstances is given, the expert system is considered consistent (4:224).

Effective reasoning is important to ensure the expert system follows the correct logical path to the answer. This may be accomplished using rule-base testing or decision tree testing. Rule-base testing involves looking at the set of rules to determine if the relationships show correct procedural knowledge. Decision tree testing is much the same but shows the logic in a tree diagram format (4:225).

User friendliness is a key factor in the success of the expert system. The information represented should be clear and understandable.

> No matter how accurate, complete, reliable, and consistent the system may seem from the developer's perspective, it may still be of little use to the user if it cannot convey its knowledge or expertise effectively. (4:226-227)

Two types of testing are subjective and objective. Subjective testing involves asking the user a set of questions after consultation with the expert system (4:227). Those used for this research are listed in Appendix A. Objective testing involves observing the user during a consultation on a number of measurable factors. The objective factors are listed in Appendix B.

The final criteria for testing and validating is run-time efficiency. Even the most accurate, complete, reliable, and friendly system may not be used if the system is considered too slow or the system does not communicate well with external programs (4:228). This may be a function of the expert system itself or of the hardware the expert system runs on.

Summary

Chapter III discusses the methodology used to solve the proposed problem of use and training on the National Electrical Code. This involves the use of hypertext and expert system shell technology to 'automate' the code. A four part development process is outlined and explained. Part one is problem identification. The problem should be well defined and resources identified before building the expert computer system. The next step is selecting the development tool for building the system. The requirements of the problem should be matched to the abilities of the tool. Step three is prototyping and system building. This step involves narrowing the scope to test the feasibility of using hypertext and expert system technology and then actually building the system. The final part, testing and validation, checks the system for accuracy and completeness. Without this phase, the system lacks credibility.

IV. Results and Other Findings

Overview

After a suitable problem has been identified and the solution method decided upon, the final step requires building and testing the expert computer system. Knowledge sources for the expert system knowledge base are located in Appendix E. Chapter IV discusses how the solution methodology was followed in building the expert system and the evaluation of test results. See appendix F for requesting the program software.

Expert System Software

The expert system software chosen for this research was KnowledgePro by Knowledge Garden, Inc. KnowledgePro is a PC-based expert computer system shell, meaning that the inference engine and user interface are combined into one software package. Using an expert system shell allows the researcher to concentrate on knowledge representation and solving the defined problem as opposed to programing the software. KnowledgePro combines expert system shell technology with hypertext communication capabilities that best suits the problem solution.

KnowledgePro meets all five criteria outlined in chapter III for expert system tools. It fits the defined problem because it is a rule-based expert system.

The developer interface is not difficult to learn. KnowledgePro is well documented, comes with tutorial software, and provides on-line help. It represents information through on-screen windows which may be adjusted in size by the developer.

KnowledgePro accepts all four types of user interface capability that was outlined in chapter III; typed response, light bar control(hypertext), function keys, and mouse interface.

Integration with external programs and files can be programed with KnowledgePro. This is a critical point when considering the external file length of the NEC text. Chapter 2 of the NEC has a text file length of 300 kilobytes (k) which is too large for one computer file.

Finally, KnowledgePro comes with a run-time license agreement. This allows for a large number of expert system users, without the requirement to purchase the development software.

NEC Automation

This research attempts to show that applying hypertext and expert system technology to the code provides assistance to electrical engineers on training with and using the NEC. A prototype expert system was developed using the KnowledgePro expert system shell software with hypertext capability to test the feasibility of automating the code.

Chapter 2 of the NEC was selected as the knowledge base for this research because the chapter contains many of the fundamental rules associated with electric power design. It also can be thought of as a complete unit of information in and of itself when separated from the rest of the code. The expert system is listed in Appendix D.

Hypertext Function. Hypertext is a formidable solution tool for solving the problem of awkward and cumbersome searches of the NEC. Chapter 2 of the NEC is divided into articles and sections, with each having distinct numbers associated with them. Each number associated with the chapters, articles, and sections is defined as a hypertext 'button' and can be activated by the user at their discretion. By providing a series of menus that are linked together via hypertext, the user is now able to direct themselves throughout the code in which ever direction they wish to take. Hypertext provides quick access between chapter 2, the articles of chapter 2, and all the sections under each article. Whenever a section references another section or another article, the user can hypertext right to that section or article and does not have to physically go back through the menus. The menus are provided as a starting point and are used for direction. This is the same process that a human expert would go through in searching through the code.

Hypertext provides two major advantages when compared to manually flipping the code pages. The speed of response is extremely quick and the program remembers your path irregardless of how many times you hypertext to different sections or articles.

Hypertext is not restricted to numbered references. The program contains a number of hypertext words and phrases. These are used to supply more information about a subject that a novice might require, but at the same time allowing the expert to continue on, unheeded by redundant explanations. An example from the program follows:

> Topic 200-1 Scope
>
> This article provides requirements for: (1) identification of terminals; (2) #mgrounded conductors#m in premises wiring systems; and (3) identification of grounded conductors.
>
> Topic 200-2 General
> Etc, Etc.
>
> Topic Grounded Conductor
>
> Grounded conductor means a system or circuit conductor that is intentionally grounded.

In the above example, a user might find themselves reading the information contained in section 200-1. The #m before and after the phrase 'grounded conductor' is the hypertext code and would send the user to the definition of grounded conductor, if the user desires.

During early development of the program, the expert system computer code and the NEC text were contained in one computer file. This became a major problem as the file size grew. Once the file size reached approximately 200 kilobytes in size, the KnowledgePro application software disallowed any further processing. It became apparent that the problem was the large quantity of NEC text and not the expert system computer code. With the help of the software engineers at Knowledge Garden, a search technique was devised that allowed the separation of expert system computer code and NEC text to reside in separate files. The search routine allows for unlimited text file size or more realistically, is limited to the available memory of the hard disk drive. Presently, the expert system computer code is 75 kilobytes in length and the NEC text files are 300 kilobytes long.

The National Electric Code contains a number of tables in addition to the many sections of text. Hypertext can also be used to view the tables in the same manner as the code sections. The user has the option of viewing the code sections or viewing the tables. In addition to taking either of these two separate paths, if a section of the code references a table, the user can hypertext themselves directly to the table, and is not required to back up or go down the string of menus associated with the articles and chapters.

Expert System Training Function. Hypertext provides ease of use when viewing the code. To assist electrical engineers in training with the code, seven sample exercises were developed based on NEC data and standard electrical power design requirements.

Each of the exercises asks the user one or more questions regarding an electrical power design problem. Six of the seven questions were designed to test the user's knowledge of National Electric Code rules. The expert system provides the appropriate response based on the user's input to the question. Each question has the code reference shown, either by section number, table number, or both. Hypertext provides the link between the question and the code reference. This provides a source of information to answer the question, builds up the user's confidence, and strengthens their ability to use the code book. An example of a question is:

> What is the maximum allowed load (in amperes) of a receptacle rated 20 amperes, REF 210.21(b)(2) REF Table 210-21(b)(2)?

In the above example, the user could hypertext to either of the two references, obtain the answer, and then hypertext back. In the event the user believes they know the answer without referencing the code but answers incorrectly, the expert system indicates the error. The hypertext references remain so the user can review why their answer was incorrect.

The seventh exercise is an electrical design problem similar to what an electrical engineer would encounter on the job. The expert system asks the user a series of questions relative to some design problem the user may have. Based on the user's answers, the expert system helps design the system and provide the correct design requirements from the information supplied.

Again, to help the user answer the questions posed by the expert system, NEC references are provided. The user can hypertext to the reference, get the necessary information. and then hypertext back. The expert system performs all the necessary mathematical calculations required by the exercise.

The seven exercises are only examples of what the expert system can do. Any number and style of exercises are possible with the system. The expert system could be custom built to suit a particular engineer's needs or office functions. This provides greater flexibility of use. Expert system documentation is provided showing which keys are active on the computer keyboard.

Validation

To determine the validity of the expert system, a series of questions designed to test the performance of the system were given to four different groups of users. Appendix C lists the individuals tested. The questions were designed to show if the system is useful, can be integrated into the engineering environment, and is user-friendly. Positive responses would indicate that the system has validity and does in fact solve the problem.

All individuals indicated that the expert system was useful and beneficial. The speed of response was considered extremely fast, much faster than using the code book by hand. The linking of many different sections of the code and then being able to return to the starting place was specifically mentioned as a great benefit. The code references provided with each exercise were most beneficial. The first six exercises that test the user's knowledge of the code were answered incorrectly the majority of the time. Most answers to the exercises were not known and hypertext references saved everyone.

The testing brought out a possible problem when trying to integrate the system into the engineering and computer environment. Half of the individuals tested used IBM compatible PC's with the system running fine. However, the majority of computers used by Civil Engineering are Wang computers. The other individuals tested used Wang computers. All of the Wang computers used during the test had MS-DOS emulation software installed. One of the Wang PC's had a color matching problem with the expert system software that blackened the function menu screen and rendered the hypertext color scheme useless. The possible problem was that the MS-DOS emulation software was outdated. The other Wang PC performed fine. This should not greatly effect integration into the engineering and computer environment as long as computer software is kept up to date.

The responses to the user-friendly questions were quite varied, as one would expect. The term user-friendly is an individual perception. The overall consensus was that the system was very user-friendly, but at the same time a number of excellent comments were received on possible improvements. The F3 and F4 function keys are heavily used for hypertext movement but are somewhat awkward to use. These keys are required by the application software and can not be changed. With repeated use they should become less awkward to use.

When the user is answering questions within the exercise portion of the system, the responses are entered into the system by hitting the return key. However, the return key is never explained in the key stroke menu. Outside the exercise portion of the system the return key exits the user from the system and should not be used. A better explanation of when to use the return key is required. At the same time, the expert system is looking for numeric answers only. Whenever alpha-numeric answers are provided, for example, 200 feet as opposed to just 200, an incorrect answer is given. An explanation is needed as to how the user should respond to the exercises. Changes have been made to the expert system explaining when to use the return key and what type of answers are required.

The color differentiation between paragraph headings and exception number headings was considered beneficial, but the individuals tested did not know what the meaning of the different colors was. This brought out a general consensus that it would be appropriate to have a general explanation of the system on the opening screen with all the different features explained at once. This idea was incorporated into the expert system.

<u>Limitations</u>. The expert system does have limitations. The following list of limitations were brought out during development and testing of the expert system.

1. The number of external files that the expert system can access is virtually unlimited, which is extremely important for future work. However, the size of each external file does affect the response time of the hypertext function. As long as each external file is kept at or below 100 kilobytes, the response time is acceptable. Beyond 100 kilobytes, the response time begins to slow down. Presently, all external files are below 100 kilobytes in length.
2. Wang personal computers generally work fine with the expert system. However, some of the older models with outdated software do show problems with color matching that can render the expert system unusable.

3. Monochrome screens (single color) can be used with the expert system, but the hypertext number or phrase is shown with an underline instead of in inverse video. This could be a point of confusion for some users. KnowledgePro can be configured for use with monochrome screens.

4. Software modifications are required within the KnowledgePro software in the event that a user does not have a hard drive or the user can not free up enough disk space on their c: drive. Working with floppy disk drives, as opposed to a hard disk drive, will work , but the access time will be considerably slower.

5. A somewhat annoying but minor inconvenience is the format of the numerical answers given by the expert system. Presently, eight decimal places are shown with every answer, but rarely are more than two ever required for this type of engineering work.

Summary

Chapter IV presented the results and other findings from building and testing the expert system. The expert system shell called KnowledgePro was selected largely because of its hypertext capabilities which is central to the solution of the problem. Hypertext was the solution method used to make the NEC less awkward and cumbersome to use. The expert system capability provided the training and learning of the code through a series of exercises. KnowledgePro's ability to access external files was a major hurdle because of the large quantity of text involved.

The system was tested to find out how useful it was, how user-friendly it was, and how easily it can be integrated into the engineering and computer environment. The test results brought out many positive improvements that were incorporated into the expert system.

V. Summary, Conclusions, and Recommendations

Summary

This research has shown that it is possible to develop a prototype expert system with hypertext capabilities that improves the use of and training on the National Electric Code. Hypertext brings to the expert system a very quick and efficient way of viewing and moving through the code. The expert system, through the use of exercises, provides the training needed to learn the code rules and electrical design rules.

The expert system solves all four identified problems with using the National Electric Code. It provides training to the electrical engineer, eliminates the need for an expert to be present all of the time, finds information quickly, and directs the search to relevant sections of the code providing a higher degree of confidence for the selected code rules.

Conclusions

The conclusions discussed here are directly related to the research questions developed in Chapter I.

Research Question 1: How can an expert system be developed for learning the National Electric Code?

Conclusion 1: The thesis research outlines a four-part development plan that provides a systematic approach to developing an expert system. The development plan provides a more efficient and manageable process. The 4 parts include: problem identification, development tool selection, prototyping and system building, testing, validation, and maintenance.

Research Question 2: What parts of the National Electric Code can be inserted into an expert system?

Conclusion 2: The majority of the NEC contains text and table information broken down by chapters, articles and sections. It was important for the expert system to contain all of this information in order to be as complete as possible. Virtually all of the NEC can be inserted into the expert system because of the accessing external file capabilities of the software. The National Electric Code does contain some graphics and diagrams which are not addressed in this research effort.

Research Question 3: How could an expert system combined with hypertext help an electrical engineer use and train with the NEC?

Conclusion 3: This system is designed to provide two services to the engineer. One, is to make the code more usable through hypertext. The code is so large that it is very awkward and cumbersome to use. Hypertext greatly speeds up the search process and adds a sense of order to the code's massive size. Second, there is virtually no training on use of the code. The expert system provides a series of questions designed to test the engineer's knowledge of the code rules and electrical design principals. The user becomes a better engineer as they learn the structure and rules of the code and how the code applies to electrical design principals.

Research Question 4: Where and when will the expert system be used?

Conclusion 4: The expert system is generic in nature and could be easily modified to meet any user's needs and requirements. Therefore it can be used in any electrical engineering office or any other office that requires the use of the NEC. The training exercises are ideal for use when first learning the NEC and are an excellent tool for the training environment.

Research Question 5: How will the expert system be evaluated?

Conclusion 5: To validate the system and ensure that the defined problem is solved, a series of objective and subjective questions were given to four groups of potential users. Their comments and suggestions were used to improve and validate the effectiveness of the system.

Recommendations for Future Research

This is the first attempted use of applying expert system technology to electrical engineering. Other uses are limited only by the creativity of the system designer.

A. This expert system is a prototype system containing chapter 2 of the NEC. Since the expert system has proved feasible, the next step is to include the entire code and make the expert system complete.

B. The exercise portion of the expert system could be greatly expanded by adding more design type exercises. This type of exercise gives two-for-one in benefits. First, the user gets training on the code rules through the hypertext code references in each exercise. Second, the user can learn many of the electrical design principals and how the code applies to them.

C. Exercises similar to exercise 7 could be expanded to get the most use out of the power of expert system technology. The expert system could be structured so that the system knows what the user is after. It could select the appropriate table or search out the solution without the user having to request it.

D. The KnowledgePro software (for an additional fee) has a graphics package available that could be used to include the pictures and diagrams found throughout the code. After including all nine chapters, this would make the expert system truly complete.

E. The majority of computers used within Civil Engineering are produced by Wang and the assumption is that these computers are going to be with CE for the near future. It should be investigated whether or not Wang produces an acceptable expert system package and incorporate the package onto the Wang system. Both PC and main-frame systems should be investigated.

Appendix A: Subjective Questions for Testing and Validating the Prototype Expert System

1. Did you have any problems installing the KnowledgePro Runtime software into your computer?

2. Did you have any problems loading the NEC expert system disk or NEC text files disk into your computer?

3. Are the instructions adequate for bringing up the opening menu on the expert system.

4. Is the opening menu on the expert system self explanatory or would you like to see more information?

5. Are the NEC sections presented in a likable manner? If not, what changes would you like to see made?

6. Is the speed of the hypertext response fast, adequate, or to slow?

7. If you are using a color monitor, do you think that the colored headings and paragraph markings help in distinguishing the information on a full page?

8. Are the windows of code to large or just right? If to large, how much smaller would you like to see them?

9. When using the electrical design training section, are the questions self explanatory, too basic, or too difficult to understand?

10. After working the sample "design" exercise through by hand did you get the same answer as the expert system? If you did not, do you know why not?

11. When using the sample design exercise, did you find the hypertext code references helpful in understanding and solving the problem.

12. If you had an expanded version of the expert system that included the entire code and a number of the required design procedures that you normally encounter in your design work, would you find the expert system beneficial for helping you accomplish your work, help you or others train in design work, or not of beneficial use?

13. Are there any final comments you would like to make about using the expert system?

Appendix B: Objective Testing Measures

1. Did the user require any assistance during their consultation?

2. What is the average response time when using hypertext?

3. What were the average number of keystrokes required to get a response?

4. How many times did the user activate the help menu?

5. What was the perceived impression of the user during the consultation?

6. What type of computer was used by each user?

7. Did each user have a personal computer at their desk or at least immediate access to one?

8. Did the user verify the expert system's answers to the design procedures with their own copy of the NEC or from their own prior knowledge?

Appendix C: Knowledge Sources

Knowledge sources for the expert system knowledge base were:

1. Captain Michael H. Ufnal, Electrical Engineering Instructor, School of Civil Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH.

2. Gregory P. Bierals, President of Electrical Design Institute, Davie FL.

3. National Electrical Code book, 1987 edition.

4. Air Force Manual 88-15, Criteria and Standards for Air Force Construction, 1986 edition.

Appendix D: Request for Programs

The following address should be used for copies of the expert system software.

AFIT/LSM
Air Force Institute of Technology
Wright-Patterson AFB OH 45433-6583

Attn: Lt Col James R. Holt

Appendix E: KnowledgePro Program

The following text contains the source code for the KnowledgePro expert system. The format is the same as it appears on the software with the exception of the thesis page numbers.

```
Say ('Welcome to the #mautomated#m NEC.
Words or phrases, highlighted in gray for color monitors
or underlined for monochrome monitors use hypertext and
can be selected by pressing F# and viewed by pressing F4!

What area are you interested in?

     National Electric Code #mchapters#m

     National Electric Code #mtables#m

          Electrical Design #mtraining#m

                   Software #minstructions#m').

topic 'automated'.
say ('Automated, in this case means, using an #mexpert
system#m with #mhypertext#m capabilities on the National
Electric Code to help in your review and search of the
code.').
end.   (*automated*)

     topic 'expert system'.
     say ('An expert system is a computer program that is
     designed to solve a problem or give advice in
     response to questioning by the user.  It uses
     knowledge and inference procedures to solve problems
     that are difficult enough to require significant
     human expertise for their solution.').
     end.   (*expert system*)

     topic 'hypertext'.
     say ('Hypertext allows for real communication between
     the user and the expert system.  Highlighted words,
     when keyed on by the F4 function key will link the
     user with the information about the highlighted word.
     When finished, the user is sent back to the
     hypertexted word to continue.').
     end.   (*hypertext*)

topic 'chapters'.
say ('What chapter of the NEC would you like to review?
```

```
     Chapter   1  General
     Chapter   #m2#m  Wiring Design and Protection
     Chapter   3  Wiring Methods and Materials
     Chapter   4  Equipment for General Use
     Chapter   5  Special Occupancies
     Chapter   6  Special Equipment
     Chapter   7  Special Conditions
     Chapter   8  Communication Systems
     Chapter   9  Tables and Examples').
end.   (*chapters*)

topic '2'.
say ('What Article of Chapter 2 would you like?

     #m200#m  Use and Identification of Grounded
     Conductors
     #m210#m  Branch Circuits
     #m215#m  Feeders
     #m220#m  Branch-Circuit and Feeder Calculations
     #m225#m  Outside Branch Circuits and Feeders
     #m230#m  Services
     #m240#m  Overcurrent Protection
     #m250#m  Grounding
     #m280#m  Surge Arresters').
end.   (*2*)

topic '200'.
say ('What Section of Article 200 would you like?

     #m200.1#m    Scope
     #m200.2#m    General
     #m200.3#m    Connection to Grounded Systems
     #m200.6#m    Means of Identifying Grounded Conductors
     #m200.7#m    Use of White or Natural Gray Color
     #m200.9#m    Means of Identification of Terminals
     #m200.10#m   Identification of Terminals
     #m200.11#m   Polarity of Connections').
end.   (*200*)

topic '210'.
say ('What Section of Article 210 would you like?

     A.  General Provisions
     #m210.1#m    Scope
     #m210.2#m    Other Articles for Specific-Purpose
     Branch Circuits
     #m210.3#m    Classifications
     #m210.4#m    Multiwire Branch Circuits
     #m210.5#m    Color Code for Branch Circuits
     #m210.6#m    Branch Circuit Voltage Limitations
     #m210.7#m    Receptacles and Cord Connections
```

```
     #m210.8#m   Ground-Fault Circuit-Interrupter
     Protection for Personnel
     #m210.9#m   Circuits Derived from Autotransformers
     #m210.10#m  Ungrounded Conductors Tapped from
     Grounded Systems

     B.  Branch-Circuit Rating
     #m210.19#m  Conductors--Minimum Ampacity and Size
     #m210.20#m  Overcurrent Protection
     #m210.21#m  Outlet Devices
     #m210.22#m  Maximum Loads
     #m210.23#m  Permissible Loads
     #m210.24#m  Branch-Circuit Requirements--Summary


     C.  Required Outlets
     #m210.50#m  General
     #m210.52#m  Dwelling Unit Receptacle Outlets
     #m210.60#m  Guest Rooms
     #m210.62#m  Show Windows
     #m210.63#m  Rooftop Heating, Air-Conditioning, and
     Refrigeration Equipment Outlet
     #m210.70#m  Lighting Outlets Required').
end.   (*210*)

topic '215'.
say ('What Section of Article 215 would you like?

     #m215.1#m   Scope
     #m215.2#m   Minimum Rating and Size
     #m215.3#m   Overcurrent Protection
     #m215.4#m   Feeders with Common Neutral
     #m215.5#m   Diagrams of Feeders
     #m215.6#m   Feeder Conductor Grounding Means
     #m215.7#m   Ungrounded Conductors Tapped from
     Grounded Systems
     #m215.8#m   Means of Identifying Conductor with the
     Higher Voltage to Ground
     #m215.9#m   Ground-Fault Protection for Personnel').
end.   (*215*)

topic '220'.
say ('What Section of Article 220 would you like?

     A.  General
     #m220.1#m   Scope
     #m220.2#m   Voltages
     #m220.3#m   Computations of Branch Circuits
     #m220.4#m   Branch Circuits Required

     B.  Feeders
```

```
       #m220.10#m  General
       #m220.11#m  General Lighting
       #m220.12#m  Show-Window Lighting
       #m220.13#m  Receptacle Loads--Nondwelling Units
       #m220.14#m  Motors
       #m220.15#m  Fixed Electric Space Heating
       #m220.16#m  Small Appliance and Laundry
       Loads--Dwelling Unit
       #m220.17#m  Appliance Load--Dwelling Unit(s)
       #m220.18#m  Electric Clothes Dryers--Dwelling Unit(s)
       #m220.19#m  Electric Ranges and Other Cooking
       Appliances--Dwelling Unit(s)
       #m220.20#m  Kitchen Equipment--Other than Dwelling
       Unit(s)
       #m220.21#m  Noncoincident Loads
       #m220.22#m  Feeder Neutral Load

       C.  Optional Calculations for Computing Feeder and
       Service Loads
       #m220.30#m  Optional Calculation--Dwelling Unit
       #m220.31#m  Optional Calculation for Additional Loads
       in Existing Dwelling Unit
       #m220.32#m  Optional Calculation--Multifamily
       Dwelling
       #m220.33#m  Optional Calculation--Two Dwelling Units
       #m220.34#m  Optional Method--Schools
       #m220.35#m  Optional Calculations for Additional
       Loads to Existing Installations

       D.  Method for Computing Farm Loads
       #m220.40#m  Farm Loads--Buildings and Other Loads
       #m220.41#m  Farm Loads--Total').
end.   (*220*)

topic '225'.
say ('What Section of Article 225 would you like?

       #m225.1#m   Scope
       #m225.2#m   Other Articles
       #m225.3#m   Calculation of Load
       #m225.4#m   Conductor Covering
       #m225.5#m   Size of Conductors
       #m225.6#m   Minimum Size of Conductor
       #m225.7#m   Lighting Equipment Installed Outdoors
       #m225.8#m   Disconnects
       #m225.9#m   Overcurrent Protection
       #m225.10#m  Wiring on Buildings
       #m225.11#m  Circuit Exits and Entrances
       #m225.12#m  Open-Conductor Supports
       #m225.13#m  Festoon Supports
       #m225.14#m  Open-Conductor Spacings
```

```
     #m225.15#m  Supports Over Buildings
     #m225.16#m  Point of Attachment to Buildings
     #m225.17#m  Means of Attachment to Buildings
     #m225.18#m  Clearance from Ground
     #m225.19#m  Clearances from Buildings for Conductors
     Not Over 600 Volts, Nominal
     #m225.20#m  Mechanical Protection of Conductors
     #m225.21#m  Multiconductor Cables on Exterior
     Surfaces of Buildings
     #m225.22#m  Raceways on Exterior Surfaces of
     Buildings
     #m225.23#m  Underground Circuits
     #m225.24#m  Outdoor Lampholders
     #m225.25#m  Location of Outdoor Lamps
     #m225.26#m  Live Vegetation').
end.   (*225*)

topic '230'.
say ('What Section of Article 230 would you like?

     #m230.1#m   Scope

     A.  General
     #m230.2#m   Number of Services
     #m230.3#m   One Building or Other Structure Not to be
     Supplied Through Another
     #m230.6#m   Conductors Considered Outside of Building
     #m230.7#m   Other Conductors in Raceway or Cable
     #m230.8#m   Raceway Seal
     #m230.9#m   Clearance from Building Openings

     B.  Overhead Service-Drop Conductors
     #m230.21#m  Overhead Supply
     #m230.22#m  Insulation or Covering
     #m230.23#m  Size and Rating
     #m230.24#m  Clearances
     #m230.26#m  Point of Attachment
     #m230.27#m  Means of Attachment
     #m230.28#m  Service Masts as Supports
     #m230.29#m  Supports Over Buildings

     C.  Underground Service-Lateral Conductors
     #m230.30#m  Insulation
     #m230.31#m  Size and Rating
     #m230.32#m  Protection Against Damage

     D.  Service-Entrance Conductors
     #m230.40#m  Number of Service-Entrance Conductor Sets
     #m230.41#m  Insulation of Service-Entrance Conductors
     #m230.42#m  Size and Rating
```

#m230.43#m Wiring Methods for 600 Volts, Nominal, or Less
#m230.46#m Unspliced Conductors
#m230.49#m Protection Against Damage--Underground
#m230.50#m Protection of Open Conductors and Cables Against Damage--Aboveground
#m230.51#m Mounting Supports
#m230.52#m Individual Conductors Entering Buildings or Other Structures
#m230.53#m Raceways to Drain
#m230.54#m Connections at Service Head
#m230.55#m Termination at Service Equipment
#m230.56#m Service-Entrance Conductor with the Higher Voltage-to-Ground

E. Service Equipment--General
#m230.62#m Service Equipment--Enclosed or Guarded
#m230.63#m Grounding and Bonding
#m230.64#m Working Space
#m230.65#m Available Short-Circuit Current

F. Service Equipment--Disconnecting Means
#m230.70#m General
#m230.71#m Maximum Number of Disconnects
#m230.72#m Grouping of Disconnects
#m230.74#m Simultaneous Opening of Poles
#m230.75#m Disconnection of Grounded Conductor
#m230.76#m Manually or Power Operable
#m230.77#m Indicating
#m230.78#m Externally Operable
#m230.79#m Rating of Disconnect
#m230.80#m Combined Rating of Disconnects
#m230.81#m Connection to Terminals
#m230.82#m Equipment Connected to the Supply Side of Service Disconnect
#m230.83#m Transfer Equipment
#m230.84#m More Than One Building or Other Structure

G. Service Equipment--Overcurrent Protection
#m230.90#m Where Required
#m230.91#m Location of Overcurrent Protection
#m230.92#m Locked Service Overcurrent Devices
#m230.93#m Protection of Specific Circuits
#m230.94#m Relative Location of Overcurrent Device and Other Service Equipment
#m230.95#m Ground-Fault Protection of Equipment

H. Services Exceeding 600 Volts, Nominal
#m230.200#m General
#m230.201#m Service Conductors
#m230.202#m Service-Entrance Conductors

```
      #m230.203#m  Warning Signs
      #m230.204#m  Isolating Switches
      #m230.205#m  Disconnecting Means
      #m230.206#m  Overcurrent Devices as Disconnecting
      Means
      #m230.207#m  Equipment in Secondaries
      #m230.208#m  Overcurrent Protection
      #m230.209#m  Surge Arresters (Lightning Arresters)
      #m230.210#m Service Equipment--General Provisions
      #m230.211#m Metal-Enclosed Switchgear').
end.   (*230*)

topic '240'.
say ('What Section of Article 240 would you like?

      A.  General
      #m240.1#m    Scope
      #m240.2#m    Protection of Equipment
      #m240.3#m    Protection of Conductors--Other Than
      Flexible Cords and Fixture Wires
      #m240.4#m    Protection of Fixture Wires and Cords
      #m240.6#m    Standard Ampere Ratings
      #m240.8#m    Fuses or Circuit Breakers in Parallel
      #m240.9#m    Thermal Devices
      #m240.10#m   Supplementary Overcurrent Protection
      #m240.11#m   Definition of Current-Limiting
      Overcurrent Protective Device
      #m240.12#m   Electrical System Coordination

      B.  Location
      #m240.20#m   Ungrounded Conductors
      #m240.21#m   Location in Circuit
      #m240.22#m   Grounded Conductors
      #m240.23#m   Change in Size of Grounded Conductor
      #m240.24#m   Location in or on Premises

      C.  Enclosures
      #m240.30#m   General
      #m240.32#m   Damp or Wet Locations
      #m240.33#m   Vertical Position

      D.  Disconnecting and Guarding
      #m240.40#m   Disconnecting Means for Fuses and Thermal
      Cutouts
      #m240.41#m   Arcing or Suddenly Moving Parts

      E.  Plug Fuses, Fuseholders, and Adapters
      #m240.50#m   General
      #m240.51#m   Edison-Base Fuses
      #m240.52#m   Edison-Base Fuseholders
      #m240.53#m   Type S Fuses
```

```
    #m240.54#m  Type S Fuses, Adapters, and Fuseholders

    F.  Cartridge Fuses and Fuseholders
    #m240.60#m  General
    #m240.61#m  Classification

    G.  Circuit Breakers
    #m240.80#m  Method of Operation
    #m240.81#m  Indicating
    #m240.82#m  Nontamperable
    #m240.83#m  Marking

    H.  Overcurrent Protection Over 600 Volts, Nominal
    #m240.100#m Feeders
    #m240.101#m Branch Circuits').
end.   (*240*)

topic '250'.
say ('What Section of Article 250 would you like?

    A.  General
    #m250.1#m   Scope
    #m250.2#m   Application of Other Articles

    B.  Circuits and System Grounding
    #m250.3#m   Direct-Current Systems
    #m250.5#m   Alternating-Current Circuits
    #m250.6#m   Portable and Vehicle-Mounted Generators
    #m250.7#m   Circuits Not to Be Grounded

    C.  Locations of System Grounding Connections
    #m250.21#m  Objectionable Current over Grounding
    Conductors
    #m250.22#m  Point of Connection for Direct-Current
    Systems
    #m250.23#m  Grounding Service-Supplied
    Alternating-Current Systems
    #m250.24#m  Two or More Buildings or Structures
    Supplied from a Common Service
    #m250.25#m  Conductor to Be Grounded--
    Alternating-Current Systems
    #m250.26#m  Grounding Separately Derived
    Alternating-Current Systems
    #m250.27#m  High-Impedance Grounded Neutral System
    Connections
```

D. Enclosure Grounding
#m250.32#m Service Raceways and Enclosures
#m250.33#m Other Conductor Enclosures

E. Equipment Grounding
#m250.42#m Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed)
#m250.43#m Fastened in Place or Connected by Permanent Wiring Methods (Fixed)--Specific
#m250.44#m Nonelectric Equipment
#m250.45#m Equipment Connected by Cord and Plug
#m250.46#m Spacing from Lightning Rods

F. Methods of Grounding
#m250.50#m Equipment Grounding Conductor Connections
#m250.51#m Effective Grounding Path
#m250.53#m Grounding Path to Grounding Electrode at Services
#m250.54#m Common Grounding Electrode
#m250.55#m Underground Service Cable
#m250.56#m Short Sections of Raceway
#m250.57#m Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed)--Grounding
#m250.58#m Equipment Considered Effectively Grounded
#m250.59#m Cord- and Plug-Connected Equipment
#m250.60#m Frames of Ranges and Clothes Dryers
#m250.61#m Use of Grounded Circuit Conductor for Grounding Equipment
#m250.62#m Multiple Circuit Connections

G. Bonding
#m250.70#m General
#m250.71#m Service Equipment
#m250.72#m Method of Bonding Service Equipment
#m250.73#m Metal Armor or Tape of Service Cable
#m250.74#m Connecting Receptacle Grounding Terminal to Box
#m250.75#m Bonding Other Enclosures
#m250.76#m Bonding for Over 250 Volts
#m250.77#m Bonding Loosely Joined Metal Raceways
#m250.78#m Bonding in Hazardous (Classified) Locations
#m250.79#m Main and Equipment Bonding Jumpers
#m250.80#m Bonding of Piping Systems

H. Grounding Electrode System
#m250.81#m Grounding Electrode System
#m250.83#m Made and Other Electrodes
#m250.84#m Resistance of Made Electrodes
#m250.86#m Use of Lightning Rods

```
      J.  Grounding Conductors
      #m250.91#m  Material
      #m250.92#m  Installation
      #m250.93#m  Size of Direct-Current System Grounding
      Conductor
      #m250.94#m  Size of Alternating-Current Grounding
      Electrode Conductor
      #m250.95#m  Size of Equipment Grounding Conductors
      #m250.97#m  Outline Lighting
      #m250.99#m  Equipment Grounding Conductor Continuity

      K.  Grounding Conductor Connections
      #m250.112#m To Grounding Electrode
      #m250.113#m To Conductors and Equipment
      #m250.114#m Continuity and Attachment of Branch-
      Circuit Equipment Grounding Conductors to Boxes
      #m250.115#m Connection to Electrodes
      #m250.117#m Protection of Attachment
      #m250.118#m Clean Surfaces

      L.  Instrument of Transformers, Relays, etc.
      #m250.121#m Instrument Transformer Circuits
      #m250.122#m Instrument Transformer Cases
      #m250.123#m Cases of Instruments, Meters, and Relays
      Operating at Less than 1000 Volts
      #m250.124#m Cases of Instruments, Meters, and Relays
      Operating Voltage 1kV and Over
      #m250.125#m Instrument Grounding Conductor

      M.  Grounding of Systems and Circuits of 1kV and Over
      (High Voltage)
      #m250.150#m General
      #m250.151#m Derived Neutral Systems
      #m250.152#m Solidly Grounded Neutral Systems
      #m250.153#m Impedance Grounded Neutral Systems
      #m250.154#m Grounding of Systems Supplying Portable
      or Mobile Equipment
      #m250.155#m Grounding of Equipment').
end.   (*250*)

topic '280'.
say ('What Section of Article 280 would you like?

      A.  General
      #m280.1#m   Scope
      #m280.2#m   Definition
      #m280.3#m   Number Required
      #m280.4#m   Surge Arrester Selection

      B.  Installation
      #m280.11#m  Location
```

```
      #m280.12#m  Routing of Surge Arrester Connections

      C.  Connecting Surge Arresters
      #m280.21#m  Installed at Services of Less than 1000
      Volts
      #m280.22#m  Installed on Load Side of Services of
      Less than 1000 Volts
      #m280.23#m  Circuits of 1kV and Over--Surge Arrester
      Conductors
      #m280.24#m  Circuits of 1kV and Over--
      Interconnections
      #m280.25#m  Grounding').
end.   (*280*)

topic 'grounded conductors'.
say ('Grounded conductor means a system or circuit
conductor that is intentionally grounded.').
end.   (*grounded conductor*)

topic 'grounding conductor'.
say ('Grounding conductor means a conductor used to
connect equipment or the grounded circuit of a wiring
system to a grounding electrode or electrodes.').
end.   (*grounding conductor*)

topic 'device'.
say ('Device means a unit of an electrical system which is
intended to carry but not utilize electric energy.').
end.   (*device*)

topic 'Outlet'.
say ('Outlet means a point on the wiring system at which
current is taken to supply utilization equipment.').
end.   (*Outlet*)

topic 'Receptacle'.
say ('Receptacle means a contact device installed at the
outlet for the connection of a single attachment plug.').
end.   (*Receptacle*)

topic 'service lateral'.
say ('Service lateral means the underground service
conductors between the street main, including any risers
at a pole or other structure or from transformers, and the
first point of connection to the service-entrance
conductors in a terminal box or meter or other enclosure
with adequate space, inside or outside the building wall.
Where there is no terminal box, meter, or other enclosure
with adequate space, the point of connection shall be
considered to be the point of entrance of the service
conductors into the building.').
```

```
end.   (*service lateral*)

topic 'tables'.
say ('Which Table would you like to view?

    Article 210          Branch Circuits
    -----------          ---------------
#mTable 210-21(b)(2)#m   Maximum Cord- and Plug-Connected
                         Load to Receptacle
#mTable 210-21(b)(3)#m   Receptacle Ratings for Various
                         Size Circuits
#mTable 210-24#m         Summary of Branch Circuit
                         Requirements

                         Branch-Circuit and Feeder
    Article 220          Calculations
    -----------          -------------------------
#mTable 220-13#m         Demand Factors for Nondwelling
                         Receptacle Loads
#mTable 220-20#m         Feeder Demand Factors for
                         Kitchen Equipment--Other than
                         Dwelling Unit(s)

    Article 230          Services
    -----------          --------
#mTable 230-51(c)#m      Supports and Clearances for
                         Industrial Open Service
                         Conductors

    Article 250          Grounding
    -----------          ---------
#mTable 250-94#m         Grounding Electrode Conductor
                         for AC Systems
#mTable 250-95#m         Minimum Size Equipment Grounding
                         Conductors for Grounding Raceway
                         and Equipment').
end.   (*tables*)

topic 'training'.
say ('The following exercises provide training and
assistance to the user on using the National Electric
Code.  Hypertext code references are provided with each
exercise.
          Press the F3 function key to select and the F4
          function key to view the desired exercises.

     #mExercise 1#m      Branch Circuits
     #mExercise 2#m      Branch Circuits
     #mExercise 3#m      Branch and Feeder Circuits
     #mExercise 4#m      Branch and Feeder Circuits
     #mExercise 5#m      Outside Circuits
```

```
     #mExercise 6#m      Services
     #mExercise 7#m      Non-Motor Branch Circuit Design
                         Single Load').
     do (!main).
end.   (*training*)

topic 'Exercise 1'.
    ask ('What is the maximum allowed load (in amperes) of
    a receptacle rated 20 amperes?
         REF #m210.21#m(b)(2)  REF #mTable 210-21(b)(2)#m
                  Numeric Answers Only',load).

    if ?load is 16
    then say ('16 amperes is correct') and do (training)
    else say ('16 amperes is the correct answer.  You
    should review section #m210.21#m(b)(2) and/or
    #mTable 210-21(b)(2)#m.') and do (training).
    reset (load).
end.   (*Exercise 1*)

topic 'Exercise 2'.
ask ('What is the minimum allowed branch-circuit conductor
size in AWG?
        REF #m210.19#m(c)    REF #mTable 210-24#m
            Numeric Answers Only',size).
if ?size is 14
then say ('No. 14 AWG is correct but AFM 88-15 requires
the minimum in all cases to be No. 12 AWG(7:16-2).') and
do (training)
else say ('No. 14 AWG is the correct answer with a further
minimum required by AFM 88-15 to No. 12 AWG
(7:16-2).  You should review section #m210.19#m(c) and/or
#mTable 210-24#m and AFM 88-15, section 16.') and do
(training).
end.   (*Exercise 2*)

topic 'Exercise 3'.
ask ('When computing a branch circuit load, what is the
minimum load rating, in volt-amperes(VA), of a general-use
receptacle outlet?
     REF #m220.3#m(c)(5)
         Numeric Answers Only',load).
if ?load is 180
then say ('180 volt-amperes is correct') and do (training)
else say ('180 volt-amperes is the correct answer.  You
should review section #m220.3#m(c)(5).') and do
(training).
end.   (*Exercise 3*)

topic 'Exercise 4'.
```

```
ask ('What is the allowed feeder demand factor (in percent
notation) for non-dwelling receptacle loads of more than
10 KVA?
     REF #m220.13#m   REF #mTable 220-13#m
          Numeric Answers Only',factor).
if ?factor is 50
then say ('50% is correct') and do (training)
else say ('50% is the correct answer.  You should review
section #m220.13#m and #mTable 220-13#m.') and do
(training).
end.   (*Exercise 4*)

topic 'Exercise 5'.
ask ('What is the minimum clearance from ground (in feet)
of an open conductor not over 600 volts, nominal, over a
public street subject to truck traffic?
     REF #m225.18#m   REF #m230.24#m(b)
          Numeric Answers Only',clearance).
if ?clearance is 18
then say ('18 feet is correct') and do (training)
else say ('18 feet is the correct answer.  You should
review sections #m225.18#m and/or #m230.24#m(b).'). and do
(training).
end.   (*Exercise 5*)

topic 'Exercise 6'.
ask ('What is the minimum, non-family dwelling, service
disconnect rating, (in amperes), serving more than 2
circuits?
     REF #m230.79#m(d)
           Numeric Answers Only',rating).
if ?rating is 60
then say ('60 amperes is correct') and do (training)
else say ('60 amperes is the correct answer.  You should
review section #m230.79#m(d).') and do (training).
end.   (*Exercise 6*)

topic 'Exercise 7'.
say ('This exercise will take you through a series of
decision steps to arrive at a non-motor branch circuit
design.  The design steps are set up in a similar format
that an expert would go through in solving this type of
problem.
               Provide Numeric Answers Only

               Press Return to Continue').

ask ('Is the current three phase or single phase?

     Press the UP or DOWN ARROW key to select
     Press RETURN to continue',phase,[3,1]).
```

```
ask ('What is the one-way circuit length (in feet) from
the overcurrent device location to the outlet?
     Press RETURN after your answer',length).

ask ('What is the kilowatt rating of the load being
served?
     Press RETURN after your answer',kw).

ask (What is the voltage rating of the circuit?
     Press RETURN after your answer',VLL).

ask ('What is the power factor (in decimal notation) of
the load to be served?
     Press RETURN after your answer',pf).

ask ('Is the load to be served considered continuous (3
hours or more in duration)?
     Press the UP or DOWN ARROW key to select
     Press RETURN to continue', cont,[yes,no]).

do (?phase).

topic '3'.
kv = ?VLL / 1000.
IFL3 = ?kw / [1.73 * ?kv * ?pf].
do (?cont).

topic 'yes'.
ampacity 3y = ?IFL3 * 1.25.

ask (['Your conductor ampacity is',#s,?ampacity3y,
'amperes.'#n,#n,#n,#t,'#mTable 310-16#m will give you your
conductor size.',#l,#n,#t,'Based on the conductor size,
#mTable VLF#m will give your voltage',#n,#t,'loss factor.
What is the voltage loss factor?'],vlf).

VDROP = [?IFL3 * ?vlf * ?length] / ?VLL.

say ('The design requirements for the information supplied
are:',#n,#n,#t,'Conductors - number of -',#s,
?phase,#n,#t,#t,#t,'size - based on an ampacity of',#s,
?ampacity3y,#n,#t,#t,#t,#t,'and #mTable 310-16#m',#n,#n,
#t,'Voltage Drop - ',#s,?VDROP,#t,'if < 3% acceptable',
#n,#t,#t,#t,#t,#t,'REF NEC #m210.19#m(a) FPN',#l,#n,#n,
#t,'Overcurrent',#l,#t,'Device Size - ',#s,?ampacity3y,
#t,'if nonstandard size is shown',#n,#t,#t,#t,#t,#t,'use
next higher standard size',#l,#n,#t,#t,#t,#t,#t,'NEC
#m240.3#m',#l,#t,#t,#t,#t,#t,'NEC #m240.6#m

                    Press RETURN to continue').
end.   (*yes*)
```

```
topic 'no'.
ask (['Your conductor ampacity is'#s,?IFL3,'amperes.'#n,
#n,#n,#t,'#mTable 310-16#m will give you your conductor
size.',#l,#n,#t,'Based on the conductor size, #mTable
VLF#m will give your voltage',#n,#t,'loss factor.  What is
the voltage loss factor?'],vlf).

VDROP = [?IFL3 * ?vlf * ?length] / ?VLL.

say ('The design requirements for the information supplied
are:',#n,#n,#t,'Conductors - number of -',#s,
?phase,#n,#t,#t,#t,'size - based on an ampacity of',#s,
?IFL3,#n,#t,#t,#t,#t,'and #mTable 310-16#m',#n,#n,#t,
'Voltage Drop - ',#s,?VDROP,#t,'if < 3% acceptable',#n,
#t,#t,#t,#t,#t,'REF NEC #m210.19#m(a) FPN',#l,#n,#n,#t,
'Overcurrent',#l,#t,'Device Size - ',#s,?IFL3,
#t,'if nonstandard size is shown',#n,#t,#t,#t,#t,#t,'use
next higher standard size',#l,#n,#t,#t,#t,#t,#t,'NEC
#m240.3#m',#l,#t,#t,#t,#t,#t,'NEC #m240.6#m

                    Press RETURN to continue').
end.   (*no*)
end.   (*3*)

topic '1'.
kv = ?VLL / 1000.
IFL1 = ?kw / [?kv * ?pf].

if ?VLL is 208.0
  or ?VLL is 240.0
  or ?VLL is 480.0
then phase = 2.
do (?cont).

topic 'yes'.
ampacity1y = ?IFL1 * 1.25.

ask (['Your conductor ampacity is',#s,?ampacity1y,
'amperes.'#n,#n,#n,#t,'#mTable 310-16#m will give you your
conductor size.',#l,#n,#t,'Based on the conductor size,
what is the voltage loss factor?'],vlf).

VDROP = [?IFL1 * ?vlf * ?length] / ?VLL

say ('The design requirements for the information supplied
are:',#n,#n,#t,'Conductors - number of -',#s,
?phase,#n,#t,#t,#t,'size - based on an ampacity of',#s,
?ampacity1y,#n,#t,#t,#t,#t,'and #mTable 310-16#m',#n,#n,
#t,'Voltage Drop - ',#s,?VDROP,#t,'if < 3% acceptable',
#n,#t,#t,#t,#t,#t,'REF NEC #m210.19#m(a) FPN',#l,#n,#n,
#t,'Overcurrent',#l,#t,'Device Size - ' #s,?ampacity1y,
```

```
#t,'if nonstandard size is shown',#n,#t,#t,#t,#t,#t,'use
next higher standard size',#l,#n,#t,#t,#t,#t,#t,'NEC
#m240.3#m',#l,#t,#t,#t,#t,#t,'NEC #m240.6#m

          Press RETURN to continue').
end.   (*yes*)

topic 'no'.

ask (['Your conductor ampacity is'#s,?IFL1,'amperes.'#n,
#n,#n,#t,'#mTable 310-16#m will give you your conductor
size.',#l,#n,#t,'Based on your conductor size, what is the
voltage loss factor?'],vlf).

VDROP = [?IFL1 * ?vlf * ?length] / ?VLL.

say ('The design requirements for the information supplied
are:',#n,#n,#t,'Conductors - number of -',#s,
?phase,#n,#t,#t,#t,'size - based on an ampacity of',#s,
?IFL1,#n,#t,#t,#t,#t,'and #mTable 310-16#m',#n,#n,#t,
'Voltage Drop - ',#s,?VDROP,#t,'if < 3% acceptable',#n,
#t,#t,#t,#t,#t,'REF NEC #m210.19#m(a) FPN',#l,#n,#n,#t,
'Overcurrent',#l,#t,'Device Size - ',#s,?IFL1,
#t,'if nonstandard size is shown',#n,#t,#t,#t,#t,#t,'use
next higher standard size',#l,#n,#t,#t,#t,#t,#t,'NEC
#m240.3#m',#l,#t,#t,#t,#t,#t,'NEC #m240.6#m

               Press RETURN to continue').
end.   (*no*)
end.   (*1*)
end.   (*Exercise 7*)

topic 'instructions'.
say ('The following text contains user instructions
beginning with loading the three disk set.  If this is the
first time KnowledgePro is loaded into this computer,
start with step 1, otherwise skip to step 6.  The hardware
requirements to run the software are; an IBM or compatible
PC and a fixed hard drive.  A color monitor is highly
recommended but not required.

Step 1.  To install KnowledgePro, boot your system,
         insert the Run-Time system disk into drive a and
         at the C Prompt type:

                    a:install

         Follow the on screen instructions until you see
         the opening KnowledgePro window.

Step 2.  At the opening KnowledgePro window, press the
```

F8 function key. This will send you to the C:\Garden prompt for loading the other disks.

Step 3. Insert the disk marked 'NECMENU' into drive a and at the C:\Garden prompt type:

copy a:necmenu.ckb

Step 4. Insert the disk marked 'NEC TEXT FILES' into drive a and at the C:\Garden prompt type:

copy a:2*.

Step 5. After all files have been copied, and at the C:\Garden prompt type:

exit

This will return you to the opening KnowledgePro window. The window should show a menu of available knowledge bases. Arrow down to 'NECMENU' and hit return. The Automated National Electric Code expert system should now be active. Skip step 6.

Step 6. To get to the opening KnowledgePro window with the three disks already installed, at the C prompt type:

cd garden

At the C:\Garden prompt type:

kp

You should now see the opening KnowledgePro window.

Step 7. The automated NEC menu allows the user to view the chapters and tables of the National Electric Code, work through a sample training program on the use of the code, and gives an instruction set for using the software. Since this is a #mprototype#m expert system, only chapter 2 is available for viewing.

The 'chapter' and 'table' portion is designed for quick and easy access of the code rules and can be used just as if you had the codebook in front of you.

```
        The 'training' portion is designed to assist in
        training on and teaching the use of the rules in
        the National Electric Code.

        The 'instructions' portion is self-explanatory.

Step 8. The following Keys are active to assist your
        consultation with the expert system:

        Function Key-F1  help, follow the on screen
        directions
        Function Key-F3  Select a hypertext(inverse
        video) word or phrase
        Function Key-F4  View(execute) on the selected
        hypertext word or phrase
        Function Key-F8  sends you to the DOS prompt,
        type exit to return to
        KnowledgePro
        Function Key-F10 Exits KnowledgePro
        Space Bar        returns the user to the
        previous menu
        Pagination Keys   scrolls pages up or down').
end.   (*instructions*)

topic 'prototype'.
say ('Prototype means that this is an experimental expert
system.  If successful, the full text of the code could be
incorporated into the expert system.').
end.   (*prototype*)

topic mark (n)
text is read (?n div 10,concat('///',?n),'///').
window(,white,blue,white,3,3,80,17).
say (?text).
close_window().
end.   (*n*)
```

Appendix F: List of Individuals Tested

The following list outlines the four groups of individuals tested during the validation phase of the research.

Group A. Electrical Engineering Instructors, School of Civil Engineering, Air Force Institute of Technology (AU).

1. Captain Michael H. Ufnal
2. Captain Jorge L. Monserrate
3. Captain Bradlee J. Beer

Group B. Electrical Design Engineers, 2750th Civil Engineering Squadron, Wright-Patterson AFB Ohio.

1. Lieutenant Vincent Ardizzone
2. Lieutenant Doug Freund
3. Anil Jain (GS-11)
4. Gavin Jones (GS-11)
5. Ron Lee (GS-11)

Group C. Electrical Engineer, HQ AFLC/DEE, Wright-Patterson AFB Ohio.

1. Richard Winters (GM-13)

Group D. Graduate of Engineering Management Students, School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB Ohio.

1. Captain Bill Buckingham
2. Captain Paul Scott

Bibliography

1. Allen, Mary Kathryn. The Development of an Artificial Intelligence System for Inventory Management Using Multiple Experts. PhD dissertation. Ohio State University, Columbus OH, 1986 (ON 15695228).

2. Arnold, William R. and John S. Bowie. Artificial Intelligence, A Personal, Commonsense Journey. Englewood Cliffs NJ: Prentice-Hall, Inc., 1986.

3. Berkovitch, Israel. and John Baker. "Proving the Use of Expert Systems," Computer Aided Engineering, XX: 25-28 (December 1985).

4. Bielawski, Larry. and Robert Lewand. Expert Systems Development, Building PC-Based Applications. Wellesely MS: QED Information Sciences, Inc., 1988.

5. Bierals, Gregory P., President, Electrical Design Institute. Personal interviews. Davie FL, 27 and 28 April 1989.

6. Bryant, Nigel. Managing Expert Systems. New York: John Wiley & Sons Ltd., 1988.

7. Department of the Air Force. Criteria and Standards for Air Force Construction. AFR 88-15. Interim Draft Report. Washington: HQ USAF/LEEE, January 1986.

8. Dreyfus, Hubert L. and Stuart E. Dreyfus. Mind Over Machine, The Power of Human Intuition and Expertise in the Era of the Computer. New York: The Free Press, 1986.

9. Harmon, Paul. and David King. Expert Systems. New York: Wiley Press, 1985.

10. Holt, Lt Col James R., Assistant Professor of Engineering Management. Personal interview. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, July 1989.

11. Johnson, Tim. The Commercial Application of Expert Systems Technology. London: Ovum Ltd., 1984.

12. Karwatzki, J. M. "Expert Systems in Engineering," Computer-Aided Engineering Journal, 4: 99-102 (April 1987).

13. McCain, Steven A. An Expert System for Asset Reconciliation. MS thesis, AFIT/GLM/LSY/87S-46. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AF OH, September 1987.

14. Mcgraw, Karen L. "Guidelines for Producing Documentation for Expert Systems," IEEE Transactions on Professional Communications, PC-29 NO 4: 42-47 (December 1986).

15. Schram, Peter J. National Electrical Code Handbook. Quincy MA: National Fire Protection Association, 1986.

16. Thompson, Bev. and Bill Thompson. KnowledgePro User Manual. Nassau NY: Knowledge Garden, Inc., 1987.

17. Turban, Efraim. "Expert Systems-A Management Perspective," Journal of Policy and Information, 9: 33-49 (December 1985).

18. Ufnal, Captain Michael H., Electrical Engineering Instructor. Personal Interviews. School of Civil Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH, 1 April through 15 August 1989.

19. Waterman, Donald A. A Guide to Expert Systems. New York: Addison-Wesley Publishing Company, 1986.

20. Winters, Richard. Electrical Engineer. Personal interview. HQ AFLC, Wright-Patterson AFB OH, 3 August 1989.

Vita

Captain Jeffrey M. Liddle [redacted] He graduated from high school in Platteville, Wisconsin, in 1973 and attended Madison Area Technical College, from which he received an Associates degree in Business in May 1975. In October 1975 he entered the United States Air Force and upon completion of basic training and technical school was assigned to the Air Force Accounting and Finance Center, Lowry AFB, Colorado as a separations pay auditor. In March 1980 he was assigned to Zaragoza AB, Spain, as Chief of Military Pay. He was accepted into the Airmen Education and Commissioning Program in April 1982 and attended Arizona State University, from which he received the degree of Bachelor of Science in Electrical Engineering in May 1985. Upon graduation, he received a commission in the USAF through Officer Training School. He then served as an electrical design engineer in the 2849th Civil Engineering Squadron, Hill AFB, Utah, until entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1988.

[redacted]

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GEM/LSM/89S-12	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics 6b. OFFICE SYMBOL (If applicable) AFIT/LSM	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB OH 45433-6583	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

AN EXPERT SYSTEM FOR LEARNING THE NATIONAL ELECTRIC CODE

12. PERSONAL AUTHOR(S)
Jeffrey M. Liddle, B.S., Captain, USAF

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1989 September	93

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
10	02		ELECTRICAL ENGINEERING, EXPERT SYSTEM, ELECTRICITY, ELECTRICAL POWER DISTRIBUTION, ELECTRICAL POWER, ARTIFICIAL INTELLIGENCE

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Thesis Advisor: Lt Col James R. Holt
Assistant Professor
Department of Logistics Management

Approved for public release: IAW AFR 190-1.

Larry W. Emmelhainz

LARRY W. EMMELHAINZ, Lt Col, USAF 11 Oct 89
Director of Research and Consultation
Air Force Institute of Technology (AU)
Wright-Patterson AFB OH 45433-6583

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Lt Col James R. Holt, Assis. Professor	22b. TELEPHONE (Include Area Code) 785-5023 / 22c. OFFICE SYMBOL AFIT/LSM

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

The purpose of this research was to apply hypertext and expert system technology to the National Electric Code to assist with learning and using the code. Presently, there is no formalized training available on learning the code. Also, using the code is awkward and cumbersome at best because of the code's large quantity of text.

Hypertext brings to the expert system a very quick and efficient way of viewing and moving through the code. The user controls the direction taken based on their selection of a hypertext path. The expert system, through a series of exercises, provides the training needed to learn the code rules and electrical design procedures. Hypertext provides the link between the exercises and the code rules to assist in answering the exercises. This process strengthens the users knowledge of code rules and standard electrical design procedures.

The expert system was developed using the expert system shell KnowledgePro by Knowledge Garden. The prototype expert system provides complete access to chapter 2 of the National Electric Code and a series of learning exercises. The system was tested to determine; how useful the system is, how can it be integrated into the traditional engineering and computer environment, and how user-friendly the system is.

Four different groups of individuals were tested to achieve a cross-section of information. Test results clearly indicate that the system is useful, user-friendly, and that the prototype should be expanded to include the entire code.