EXPERT SYSTEMS APPLICATIONS FOR ODOT

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16. ABSTRACT

Expert systems are "intelligent" computer programs which have the capabilities of reasoning, learning, and simulating human sensory capabilities. Solutions to many problems in transportation engineering which are not well structured as well as those which do not have an explicit numerical algorithmic solution, can benefit from using expert systems. Many state transportation agencies and research institutes have shown varying degrees of interest in the application of expert systems for various problem domains.

The study presented in this report was aimed at critically reviewing the expert systems in transportation engineering with an idea of examining their suitability in the ODOT environment. The study included computerized search of the databases and a telephone survey of various research institutes and state transportation agencies. The literature was reviewed based on the following factors: problem domain, data required for the system, verification and validation, stage of development, future directions, use of shell/AI language, hardware requirements, and developer/ contact person.

Despite their high potential for application, it was noted that, the utilization of expert systems in many transportation engineering problems has been rather limited. The reasons for such limited use could be attributed to the lack of technology transfer from the research arena to practice, difficulties involved in knowledge acquisition for certain problems, variation in practice from one agency to the other, lack of sufficient documentation and absence of effective economic treatise to the problem. It is, however, recommended that ODOT should plan on introducing expert sysytems to maintain its competitive edge. Such expert systems could help ODOT in restoring its institutional expertise in a cost effective manner and can also serve as a training tool.

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SUMMARY

Increasing urbanization and a rapid growth in traffic volume and intensity have posed many challenging problems to the transportation agencies in the area of planning, design, construction, operations, maintenance and management. Many experts agree that some of the problems in transportation engineering are not well structured and a numerical algorithmic solution is not available or is impractical. A sample list of the problem domain includes devising effective pavement maintenance, management and rehabilitationn strategy, rehabilitation of bridges and traffic safety. Effective solution to such problems are often guided by cognitive skills, judgement, and expertise of professionals involved. In many cases, human expertise is not availble at all locations. Also, transportation agencies are sometimes faced with a situation in which human expertise is lost due to retirement.

Expert systems are "intelligent" computer programs which have the capabilities of reasoning, learning, and simulating human sensory capabilities. Thus, solutions of many problems in transportation engineering can benefit from using expert systems. Many state transportation agencies and research institutes have shown varying degrees of interest in the application of expert systems for different problem domains.

The study presented in this report, funded by Oklahoma Department of Transportation (ODOT), was aimed at critically reviewing the expert systems in transportation engineering with an

idea of examining their suitability in the ODOT environment. The study included a computerized search of the databases and a telephone survey of various research institutes and state transportation agencies. Published work on expert systems was reviewed critically based on following factors: problem domain, data required for the system, verification and validation, stage of development, future directions, use of shell/AI language, hardware requiremnts, and the developer/contact person.

From this study it is noted that many transportation agencies are getting involved in the applications, implementations and development of expert systems. Loss of human expertise due to retirement, coupled with the availability of improved expert system software, is causing an increased interest of various transportation agencies in expert system research. An expert system developed by an agency may not be directly suitable for use by other agencies because of the differences in the design, construction, maintenance and rehabilitation strategies and policies of different agencies. Finally, based on the review of some selected systems studied, recommendations are made.

CHAPTER 1

INTRODUCTION

1.1 Background

A Transportation Research Board study (Transportation research Board, 1985) characterized the decade of 1990s as a dynamic one for the transportation agencies. Greater than average turn-over is expected among the most senior professionals and approximately one-third of the professional engineers are expected to retire. As a result, a significant amount of expertise will be lost. The need to preserve and transfer the expertise to the younger generation for use and further enhancement is of prime importance to the transportation agencies nationwide.

Recent advancements in the field of Computers and Artificial Intelligence have led to the development of a new breed of "intelligent" computer programs commonly known as "Expert Systems" (Waterman, 1986). Expert Systems are a result of many years of research efforts to simulate or reproduce intelligent problem solving behavior in a computer program. Expert Systems can be described as a set of interactive programs incorporating judgment, experience, rules-of-thumb, intuition, and other expertise to solve an ill-structured problem in a specialized field.

Expert Systems are specifically helpful in cases where (a) there exists a shortage of experts, and it is physically impossible for the experts to be available at all sites, and (b) when there is a need to formalize, capture, preserve, and transfer the expertise and knowledge of experts in certain domains where there is a likelihood of the loss of expertise due to retirement, death or disability of human experts. Also, the expert systems can be effectively used as a valuable tool for training purposes. Many problems in transportation engineering lack explicit numerical algorithms and require intuition, rules-of-thumb, experience and human judgment for their solution.

Transportation engineering by virtue of the nature of problems it encompasses and the attrition problem of personnel seems to be a prime candidate for the application of Expert Systems. Keeping in perspective, the problems foreseen by the transportation agencies and the current technology of Expert Systems, a study relating to the use of Expert Systems for transportation agencies was undertaken by a team of researchers at the University of Oklahoma. The study, sponsored by the Oklahoma Department of Transportation (ODOT), was initiated in January and concluded in June 1991. This report presents the findings of the study.

1.2 Objectives

The objectives of the study were:

(a) to investigate the current practices of transportation agencies in other states in the development, use, and implementation of Expert Systems technology, and

(b) to identify potential problems and/or areas within the domain of Oklahoma Department of Transportation (ODOT) activities that would benefit from Expert Systems applications.

Furthermore, it was expected that the study would provide a general direction for research pertaining to the introduction and/or adoption of Expert Systems within the ODOT operations environment.

1.3 Methodology

The study chiefly encompassed the following four tasks:

<u>Task 1: Literature Review</u>

An extensive literature search was conducted to collect information relating to the development activities and use of expert systems in transportation. An on-line retrieval service, called DIALOG, was used with its subfile TRIS for this search. The detailed findings of literature review are presented in Chapter 3.

<u>Task 2: Survey of Transportation and Research Agencies</u>

A telephone survey was conducted by contacting several State Department of Transportation (DOTs) that were identified in Task 1 as actively involved with the development and application of Expert Systems. In addition to the DOTs, Federal, State, and Regional Research Centers were also contacted to determine the current status of Expert Systems technology related to Transportation agencies. A detailed account of information collected from these agencies during this survey is presented in Chapters 3 and 4.

<u>Task 3: Analysis and Evaluation</u>

The information collected in Tasks 1 and 2 was compiled into a database. A complete summary of different Expert Systems, highlighting their attributes such as problem domain, system requirements, developer, agency involved, number of rules, etc., is presented in Chapters 3 and 4. A few selected Expert Systems were reviewed and examined in more detail and are described in Chapter 4.

Task 4: Preparation of the Final Report

The findings of the study are documented in this report which is the final outcome of this task.

1.4 Format of the Report

A general introduction describing the purpose and scope of this study is described in Chapter 1. A detailed account of General Overview of Expert Systems is presented in Chapter 2. An overview of the literature review and the telephone survey conducted in this study is presented in Chapter 3. A review of selected expert systems in transportation engineering and their application issues are discussed in Chapter 4. Also, a critique of these selected expert systems, including problem domains addressed, stage of development and various attributes, is presented in Chapter 4. The conclusions and recommendations are presented in Chapter 5.

CHAPTER 2

GENERAL OVERVIEW OF EXPERT SYSTEMS

2.1 History of Expert Systems

Expert systems are a result of many years of research into a branch of computer science that is referred to as Artificial Intelligence (AI). AI is concerned with a broad range of topics that are related to simulating human intelligence in a computing machine. Some of the better known areas of AI are neural networks, machine vision, robotics and expert systems.

One of the goals of AI scientists had always been to develop computer programs that could in some sense "think". They created computer programs that solved problems in a way that would be considered intelligent if done by a human. In the 1960s, AI scientists tried to simulate the complicated process of thinking by finding general methods for solving broad classes of problems; they used these methods in general purpose programs. However, despite some interesting progress, this strategy produced no breakthroughs. Developing general-purpose programs was too difficult and ultimately fruitless.

It wasn't until the late 1970s that AI scientists began to realize something quite important: the problem-solving power of a program comes from the knowledge it possesses, not just from the formalism and inference schemes it employs. Thus, a conceptual breakthrough was made which could be simply stated as "to make a program intelligent, provide it with lots of high quality, specific knowledge about the problem area" (Waterman, 1986). This realization led to the development of special-purpose computer programs that were expert in some narrow problem area and were called "Expert Systems".

Expert Systems created before 1981 include MYCIN for diagnosing infectious diseases, PROSPECTOR for interpreting geological information, and MOLGEN for planning molecular genetics experiments. These systems are highly successful due to their ability to solve problems at the level of an expert in their respective fields and their ability to communicate easily with novice users. These earlier systems were developed using conventional programming techniques such as sequential execution of program statements, because those techniques were available at the time. Significant advancements have been made since then, and other programming techniques have been developed. These techniques, commonly referred as expert system techniques, include relaxing the sequential nature of the computer program, and providing facilities for separating the problem solving strategy from the knowledge about the problem domain.

2.2 Features of an Expert System

A schematic representation of general features of an expert system is shown in Figure 2.1. The following section describes the characteristics of an expert systems in more detail.

The heart of an expert system is the powerful corpus of knowledge that accumulates during system building. The knowledge is explicit and organized to simplify decision making. The

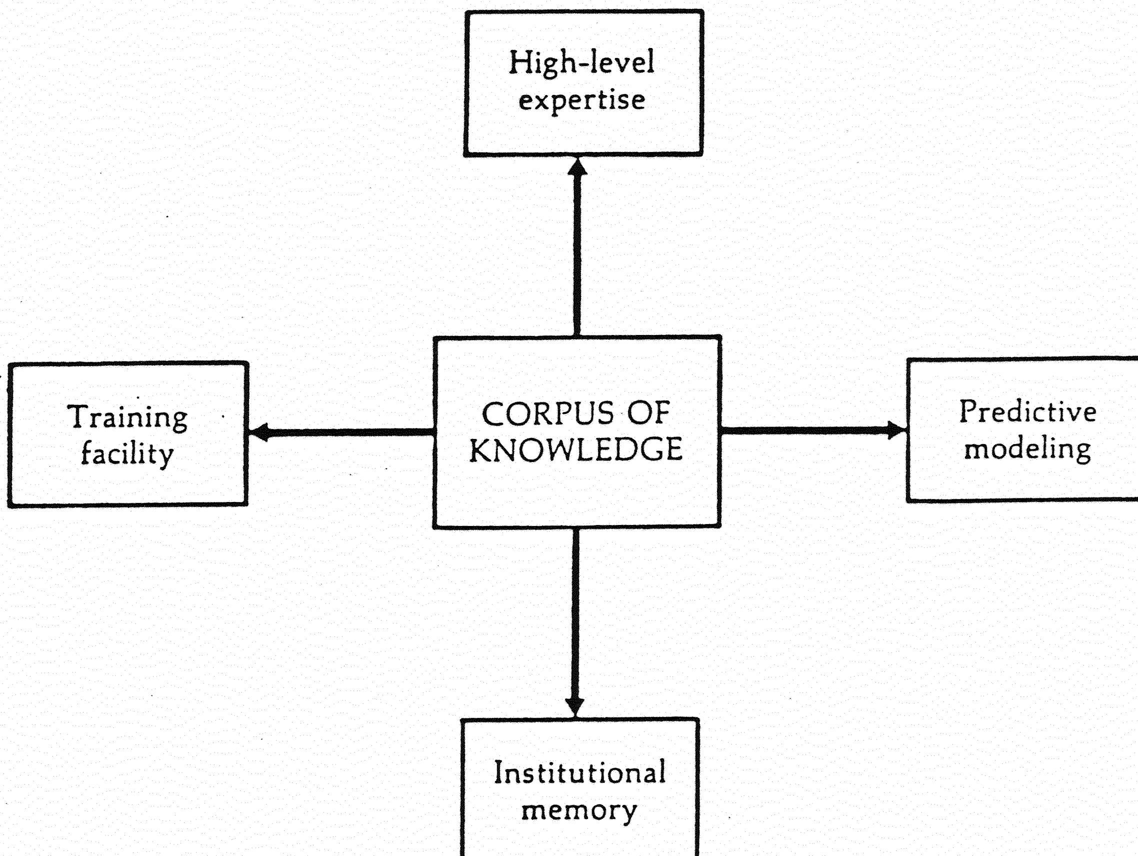

Fig. 2.1 General Features of an Expert System

accumulation and codification of knowledge is one of the most important aspects of an expert system. The explicit nature and accessibility of the knowledge, unlike most conventional programs, makes the accumulation and codification of knowledge as one of the most important aspects of an expert system.

The high-level expertise provided by an expert system to aid in problem solving is one of the most useful features of an expert system. It represents the best thinking of the top experts in the field, leading to problem solutions that are imaginative, accurate, and efficient. The high-level expertise coupled with the flexibility of the system and the ability to grow incrementally makes the system cost-effective (Waterman 1986).

Another useful feature of an expert system is its predictive modeling power. It enables the system to act as an information processing theory or model of problem solving in the given domain, providing the desired answers for a given problem situation and showing how they would change for new situations. The expert system can explain in detail how the new situation led to the change. This attribute lets the user evaluate the potential effect of new facts or data and understand their relationships to the solution. Similarly, the user can evaluate the effect of new strategies or procedures on the solution by adding new rules or modifying existing ones.

The corpus of knowledge that defines the proficiency of an expert system can also provide an additional feature, an institutional memory. If the knowledge base was developed through interactions with key personnel in an office, it represents the current policy or operating procedures of that group. This compilation of knowledge becomes a consensus of high-level opinion and is retained as a permanent record of best strategies and methods used by the staff. When key people leave, their expertise is retained.

The knowledge and the ability to explain their reasoning process makes expert systems an efficient training tool. Software must be added to provide a smooth, friendly interface between the trainee and the system, and knowledge about teaching methods. As a training device, the expert systems provide a vast reservoir of experience and strategies from which the users can learn and develop their expertise.

2.3 Expert Systems Versus Conventional Computer Programs

An expert system differs significantly from a conventional, algorithmic computer program in many ways (Table 2.1). For example, expert systems infer new ideas or conclusions from their knowledge and logical inference mechanisms, while conventional computer programs process information according to an ordered set of instructions predetermined by the programmer. Conventional, algorithmic programming is oriented toward numerical processing and utilizes a numerically addressed data base, whereas an expert system is oriented toward symbolic programming and utilizes a symbolically structured knowledge base. Also, an algorithmic program runs in a sequential batch mode, but an expert system architecture allows mid-run access and processing (Hayes-Roth et al., 1983; Maher, 1987).

Table 2.1 Differences Between Conventional Programs and Expert Systems

Conventional Programs	Expert Systems
* Representation and use of data	* Representation and use of knowledge
* Algorithmic	* Heuristic
* Requires Exact Data	* Can work with Inexact/Incomplete data
* Sequential Operation	* Random access
* Repetitive Process	* Inferential Process
* Single Solution	* Multiple Solutions with different confidence levels or scenarios

Conventional computer programs are usually written in languages such as FORTRAN, PASCAL, BASIC, or COBOL. While these languages are powerful tools for algorithmic programming, they have proven to be somewhat clumsy in developing expert systems. Therefore, most expert systems are developed using symbolic programming languages. Finally, it is important to recognize that both conventional programs and expert system programs achieve certain goals by manipulating knowledge within a structured programming environment. However, the two systems achieve their goals in a fundamentally different way. Expert systems' knowledge base increases with problem solution/application or the system has potential to learn from solutions to problems, whereas a conventional program cannot.

2.4 Expert System Development

In describing the characteristics that make a problem appropriate for expert system development, the experts offer broad guidelines which can best be summarized as follows:

> **consider expert systems only if expert system development is possible, justified, and appropriate** (Waterman, 1986).

In the subsequent sections, the possibility, justification, and appropriateness of expert system development is discussed.

2.4.1 <u>When Is Expert System Development Possible?</u>

There are certain characteristics of the problem domain that render it suitable for the development of expert systems. One of the most important requirements is that genuine human experts exist in the problem domain. These are people generally acknowledged to have an extremely high level of expertise in the problem area; they are significantly better than novices at solving problems in the domain. Without a source of extensive, powerful knowledge to draw on, the development effort will fail to produce a skillful program.

The existence of experts must be supplemented by another very important condition that they must also generally agree about the choice and accuracy of solutions in the problem domain. Otherwise, the experts must also be able to articulate and explain the methods that they use to solve domain problems. If they cannot do this, the knowledge engineers will have little success "extracting" knowledge from them and encoding it in the knowledge base.

The other requirement for expert system development deals with the characteristics of the problem that the expert system will solve -- the task it will perform. If the task requires physical skills, it could very well be solved using conventional programming methods. If the task requires cognitive skills, then it is said to be more suited for an expert system solution. Another requirement is that the task be not extremely difficult. If an expert cannot teach the process to a novice because expertise can only be developed through on-the-job experience, the process may be too difficult to capture in an expert system. Also, there is a certain degree of limit on task difficulty. Task difficulty relates to how well the experts understand the problem domain -- that is, the degree to which problem-solving knowledge is precise and well-structured. If the task is so new or so poorly understood that it requires basic research to find solutions, expert systems will not work.

2.4.2. When Is Expert System Development Justified?

The justification of an expert system development effort depends on many factors such as:

-- when the task solution has a very high payoff;

-- when human experts are unavailable or unable to do the job;

-- when significant expertise is being lost due to retirement, job transfer and other personnel changes; and

-- when expert decision making must take place in an unfriendly or hostile environment, such as nuclear power plant, space station, or alien planet. It would be either too expensive or dangerous to try to maintain a human expert in such an environment. Of course, the expertise could be administered remotely by a human expert via electronic communication channels.

2.4.3. When Is Expert System Development Appropriate?

The key factors which determine the appropriateness for the development of an expert system are nature, complexity, and scope of the problem to be solved.

Nature - the problem must lend itself to be solved by manipulating symbols and symbol structures, and should be heuristic in nature.

Complexity - the problem should not be too easy, so that it is not difficult to justify the cost and effort of expert system development.

Scope - the problem should be of manageable size and should have practical value.

2.5. Tasks Involved in Building Expert Systems

A simplified flow-chart for expert system development is shown in Fig. 2.2. Overall, an expert system development project can be viewed as five highly interdependent and overlapping phases: identification, conceptualization, formalization, implementation, and testing. Although these phases are distinct, there is no simple way to describe the order in which they should take place. Identification does happen first and testing last, but at any time during system development, the knowledge engineer may engage in any of the processes.

During the identification phase, the knowledge engineer and expert determine the important features of the problem. This includes identifying the problem itself, the identification of experts, the required resources, and the goals and objectives of building the expert system. During the conceptualization phase, the knowledge engineer and expert decide what concepts, relations, and control mechanisms are needed to describe problem solving in the domain. Formalization, involves expressing the key concepts and relations in some formal way, usually within a framework suggested by an expert system building language.

During implementation, the knowledge engineer turns the formalized knowledge into a working computer program. Developing a program requires content, form, and integration. The content comes from the structures, inference rules, and control strategies necessary for problem solving. Implementation should proceed

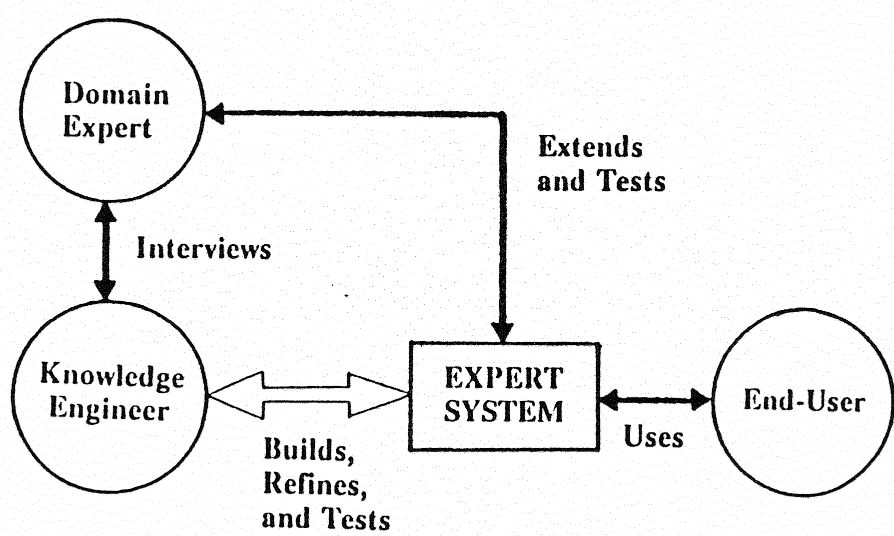

Figure 2.2 Expert System Components

rapidly because one of the reasons for implementing the initial prototype is to check the effectiveness of the design decisions made during the earlier phases of development.

Finally, testing involves evaluating the performance and utility of the prototype program and revising it as necessary. The domain expert typically evaluates the prototype and helps the knowledge engineer to revise it. As soon as the prototype runs on a few examples, it should be tested on many problems to evaluate its performance and utility.

2.6 Stages of Expert System Development

An expert system evolves over a period of time. Most expert systems begin as a demonstration prototype, which is a small demonstration program that handles a portion of the problem that will eventually be addressed. This type of program is often used in two ways: first, to convince potential sources of funding that expert systems technology can effectively be applied to the problem in question, and second, to test ideas about problem definition, scoping, and representation for the domain. A typical demonstration prototype might contain 50 to 100 rules, perform adequately on one or two test cases, and take one to three months to develop.

The next stage in the life cycle of expert systems is the stage of research prototype. This is a medium-sized program capable of displaying credible performance on a number of test cases. A typical research prototype might contain 200 to 500 rules and normally takes one to two years to develop.

Some expert systems have evolved past the research prototype to the stage of field prototype. These are medium- to large-sized programs that have been revised through testing on real problems in the real world. They are moderately reliable, contain smooth and friendly interfaces and address the needs of the end-user. A typical field prototype might contain 500 to 1,000 rules, perform very well on many test cases, and take two to three years to develop.

A few expert systems have reached the stage of production prototype. These systems are large programs that have been extensively tested in the field. A typical production prototype might contain 500 to 1,500 rules and take two to four years to develop.

Only a very few expert systems have reached the stage of commercial system. These systems are production prototypes used on a regular commercial basis. A typical commercial system might contain over 3,000 rules and may take five to seven years to develop.

2.7 Human Experts Versus Expert Systems

Some people tend to believe that expert systems would eventually replace human experts, which is a misconception. Tables 2.2 and 2.3 provide a comparison between various elements of an expert system and human expertise. Expert systems aid human experts just like computers and other problem solving tools. They provide various options in obtaining economic solutions to a given problem where algorithmic solutions alone are not a viable option.

Table 2.2 Human Expertise Vs. Expert Systems

Human Expertise	**Expert System**
* Perishable	* Permanent
* Difficult to Transfer	* Easy to Transfer
* Difficult to Document	* Easy to Document
* Unpredictable	* Consistent
* Expensive	* Affordable

Table 2.3 Human Expertise Vs. Expert Systems
(Other view point)

Human Expertise	Expert System
* Creative	* Uninspired
* Adaptive	* Needs to be told
* Sensory Experience	* Symbolic Input
* Broad Focus	* Narrow Focus
* Common Sense Knowledge	* Technical Knowledge

Expert systems provide an opportunity for integration of opinions/knowledge of a group of human experts and can be used as a consultant.

Human experts are creative, adaptive, have broad focus and can use common sense knowledge. On the other hand, expert systems are uninspired, have narrow focus and their success depends upon the completeness of the knowledge base that is derived from human experts.

Chapter 3

OVERVIEW OF LITERATURE REVIEW AND TELEPHONE SURVEY

3.1 Introduction

An extensive literature search was conducted in this study to identify the existing expert systems in transportation engineering. An on-line information retrieval service, called DIALOG, available at the University of Oklahoma (OU) was used for this purpose. The subfile TRIS was searched for literature related to expert systems applications in transportation. Also, a manual search of literature available at the OU library was pursued. An overview of the outcome of this literature review is presented in this chapter. A more comprehensive review of some selected expert systems is presented in Chapter 4.

In addition to review of literature, a telephone survey of selected state transportation departments, as well as research centers and academic institutions that are actively involved in expert system research pertaining to transportation engineering, was conducted. Findings of this telephone survey is presented in this chapter.

3.2 Existing Expert Systems in Transportation Engineering

Development of the existing expert systems in transportation engineering in the United States has been largely possible due to active research by a number of state transportation departments

(DOTs) and other agencies. Table 3.1 provides a listing of these agencies. It is noted that while only few DOTs have been actively involved in expert system research so far, many more DOTs seem to have realized the importance of expert system research in transportation engineering and have begun focusing attention in expert system development and applications.

Table 3.2 includes a list of the existing expert systems in transportation engineering. The following items are included in the table: name of the expert system, contact person and agency, shell/AI language used, problem domain, status of development and remarks. It is noted that a majority of the existing systems are demonstration prototype, which is an indication that these systems are limited in scope and are not suitable for field applications. Most of the existing systems are not available commercially. Also, except in few cases, applications of these systems have been limited within the developing agencies.

From Table 3.2 it is observed that the existing expert systems have primarily addressed the following problem domains:

-- Traffic Engineering

-- Pavement (materials, design, maintenance, management)

-- Bridge (design, maintenance)

-- Hazardous materials transportation

-- Others (retaining structures, tunnels, etc.)

Looking at them differently, the existing systems address the following areas:

-- Planning

Table 3.1 Transportation and Research Agencies Involved in Expert Systems

TRANSPORTATION & RESEARCH AGENCIES INVOLVED IN ES

Agencies Actively Involved (DOTs)

California

Washington

Illinois

Pennsylvania

Texas

Preliminary Stages (DOTs)
(Alabama, Georgia, Florida, Kansas, Kentucky, Arizona, Colorado, New York, Maryland, Virginia

Other Agencies (Univ.)
Texas Transp. Institute (Texas A&M)
Inst. Transp. Studies (UC-Irvine)
CE Dept., Univ. of Illinois, Urbana

Table 3.2 Expert Systems in Transportation Engineering

No.	Name & Ref. No.	Contact Person & Agency	Shell/AI Language	Problem Domain	Status	Remarks
1	OVERDRIVE	S. Ritchie, ITS, Univ. of California at Irvine, CA	EXSYS	To design structural thickness of asphalt pavement overlays	Field Prototype	Part of an integrated system PARADIGM
2	HIBIC	G. Manolis et al., St. Univ of NY at Buffalo, NY	M.1	To determine dynamic response of highway bridges to random traffic loads	Research Prototype Field	
3	TRANZ	A. Faghri, Univ. of Delaware, Newark, DE	EXSYS	To have efficient traffic control in work zones	Prototype	
4	EXPEAR	K. Hall et al., Univ. of Ill, Urbana- Champaign, Ill	Turbo Pascal	To evaluate concrete pavement performance & rehabilitation strategies.	Field Prototype	
5	SCAD	K. Sharp et al., Tudor Engg., GA	Insight 2+	To increase the efficiency of responding to traffic - signal malfunctions	Demonstration Prototype	
6	The Intersection Advisor	D. Bryson (Jr.), North Raleigh, Carolina St. Univ., NC	M.1	To recommend geometric modifications to improve intersection operation	Demonstration Prototype	
7	ROSE	J. Hajek et al., Ontario Ministry of Transp. & Communications , Ontario, Canada	1. EXSYS 2. FORTRAN	To recommend routing & sealing of asphalt concrete pavements in cold areas	Field Prototype	EXSYS is used for the PC version & FORTRAN is used for the IBM mainframe version
8	Not Stated	E. Chang, TTI, Texas A&M Univ., College Stn., TX	1. Insight 1 2. PD PROLOG 3. Turbo PROLOG	To recommend alternative left-turn phase selection	Demonstration Prototype	The study compares use of various programming types (shell/ language) for the same domain

Table 3.2 (Continued)

Expert Systems in Transportation Engineering

No.	Name & Ref. No.	Contact Person & Agency	Shell/AI Language	Problem Domain	Status	Remarks
9	EXPERT-UFOs	R. Tung, Dept. of Public Works, Seattle, WA	M.1	To design an optimal Transportation network by adding or deleting capacity increment to and from any link in the network		
10	TNOP-Advisor	J. Schneider et al., Univ. of Wash., Seattle, WA	Runnner	To assist in the development of high performance by providing the capability for modifying & predicting the performance of designs	Demonstration Prototype	
11	Not Stated	E. Chang, TTI, Texas A & M Univ.,College Station, TX	AutoLisp	To assist users in completing the decision making for potential highway design applications	Demonstration Prototype	
12	RETAIN	T. Adams et al., Carnegie Mellon Univ., Pitts., PA	DIGR	To help users in evaluating a retaining wall failure	Demonstration Prototype	
13	PMES	H. Lee, Wash. St. Univ., Pullman, WA	Insight 2+	To integrate expert systems in existing pavement management systems	Demonstration Prototype	
14	Bridge PIARS	S. Mcneil et al., Carnegie Mellon Univ., Pitts., PA	GEPSE	To establish the facility condition and to evaluate the need of bridge painting, identify appropriate painting strategies & their cost	Demonstration Prototype	
15	SEG	D. Elton, Auburn Univ., Ala.	Insight 2+	To diagnose hot-mix asphalt segregation	Demonstration Prototype	

Table 3.2 (Continued)

Expert Systems in Transportation Engineering

No.	Name & Ref. No.	Contact Person & Agency	Shell/AI Language	Problem Domain	Status	Remarks
16	TRALI	C. Zozaya-Gorostiza et al. Carnegie Mellon Univ., Pitts., PA	OPS5	To assist in traffic signal setting for isolated intersections	Research Prototype	
17	ERASME	F. Allez, et al., Pubils Works Research Center, Les Mines, France	1. CRIQUET 2. SMECI	To facilitate decision making in the area of road maintenance	Research Prototype	
18	ISMIS	P. Seneviratne et al., Concordia Univ. Quebec, Canada	Turbo-PROLOG	To resolve safety issue at the intersection	Demonstration Prototype	This is a management Information system
19	CHINA	R. Harris, Univ. of Louisville, KY	FRANZ-LISP	To design highway noise barriers	Production Model	
20	SCEPTRE	S. Ritchie, ITS, Univ. of Calif. at Irvine, CA	EXSYS	To assist in planning cost effective flexible pavement rehabilitation strategies at the project level	Field Protype	
21	Not Stated	J. Robinson, Univ. of New Brunswick, NB, Canada	Micro-Expert	To assess the legality of various truck configurations	Demonstration Prototype	
22	Not Stated	A. Touran, Northeastern Univ., Boston, MA	EXSYS	To choose the most appropriate compactor under a set of job conditions	Research Prototype	
23	Not Stated [28]	T. Williams, Rutgers Univ., NJ	Rulemaster 2	To assist inspection of asphalt paving construction	Research Prototype	

Table 3.2 (Continued)

Expert Systems in Transportation Engineering

No.	Name & Ref. No.	Contact Person & Agency	Shell/AI Language	Problem Domain	Status	Remarks
24	Not Stated [13]	A. Hobeika et al., Virginia Polytech Inst. & St. Univ., Blacksburg, VA	Insight 2+	To aid in decision making about hazardous material safety in tunnel and bridge transportation	Demonstration Prototype	
25	Not Stated [29]	F. Wison et al., Univ. of New Brunswick, NB, Canada	EXSYS	To assist an emergency response system for dangerous goods movement	Demonstration Prototype	
26	TTI-FHWA Expert System	E. Chang, TTI, Texas A&M Univ. College Stn., TX	Insight 2+	To assist users in selecting computerized software packages currently being supported by FHWA	Demonstration Prototype	
27	BDES	J. Welch et al., Duke Univ. , Durham, NC	Not Stated	To design bridge superstructures	Demonstration Prototype	
28	AFNA DSS	M. Rahman et al., Arizona St. Univ., Tempe, AZ	Not Applicable	To evaluate a highway network under different scenario condition related to regional & multi-regional growth	Research Prototoype	This is a decision support system

-- Design

-- Operation Control

-- Management

-- Maintenance and Rehabilitation

Various attributes of some selected expert systems are discussed in details in Chapter 4.

3.3 Telephone Survey

A telephone survey of fifteen State transportation agencies was conducted to determine the current status of these agencies related to the application and/or adoption of expert system technology. The State agencies contacted include Alabama, Arizona, California, Colorado, Florida, Georgia, Illinois, Kansas, Kentucky, Maryland, New York, Pennsylvania, Texas, Virginia and Washington. In addition to these agencies, various research centers such as Federal Highway Administration (FHWA) Regional Research Centers, Institute of Transportation Studies at University of California -- Irvine, Civil Engineering Department at the University of Illinois -- Urbana, Texas Transportation Institute at Texas A&M University, National Center of Asphalt Technology (NCAT) at Auburn University, and Alabama Highway Research Center at Auburn University were also contacted.

The telephone survey focused on obtaining the following information:

-- the current status of expert system use in the agency

-- any ongoing expert system related research

-- expert systems being currently used

- -- hardware and software requirements
- -- the systems' development procedure (in-house/outside consultant)
- -- system introduction and implementation
- -- any problems identified during implementation
- -- any "success factors" identified in design and implementation
- -- any "pitfalls" to avoid
- -- the cost of the system

It is interesting to note that many of the agencies reported that they are in the preliminary stages of introducing the expert systems technology. As such, they are in the learning process and/or identification process of an area for which they would like to develop an expert system. The State agencies reported to be in this preliminary stage are Alabama, Arizona, Colorado, Florida, Georgia, Kansas, Kentucky, Maryland, New York and Virginia.

A number of state DOTs, namely California, Illinois, Pennsylvania, Texas, and Washington are reported to be actively involved in the implementation and development of expert systems.

The Alabama Highway Department reported to be actively undertaking a needs analysis and plans to get something going in this direction through the Alabama Highway Research Center at Auburn University. The Florida DOT has undertaken a development effort for building an expert system for rating Florida bridges and suggesting rehabilitation strategies. The Georgia DOT reported a total of three expert systems to be in use at present. However, only one relates to transportation. The system called CHINA, (see Table 3.2; further details are given in Chapter 4) is used to help engineers design highway noise barriers. Of the other two systems, one relates to hazardous waste management and the other relates to their computer operations system.

The Colorado DOT reported as using an expert system for designing retaining walls (Adams, 1988). The other State agencies Arizona, Kansas, Kentucky, Maryland, New York and Virginia reported to be in the very initial stage of introducing expert systems in their departments.

Among the agencies actively involved, the California Department of Transportation (CALTRANS) has recently completed a comprehensive study analyzing their needs and identifying the areas for which they need to develop an expert system. The study was conducted by researchers at the Institute of Transportation Studies at the University of California, Irvine. The study also investigated the resource requirements for developing the systems within the CALTRANS environment.

The Washington DOT is one of the leaders in the use of expert systems. They are currently using two systems, SCOPE and OVERDRIVE (see Table 3.2; details are given in Chapter 4), which are tied to their Pavement Management System.

The Illinois DOT uses EXPEAR (discussed in Chapter 4) and has also interacted closely during the development of the system with the team of researchers from the University of Illinois, Urbana.

The Pennsylvania DOT is developing an expert system for surface treatment and is planning to integrate it with the pavement management system.

The Texas State Highway Department is actively involved with

Texas Transportation Institute at Texas A&M University. Most of the systems were in the research or demonstration prototype stage.

3.3.1. Implementation Issues

The telephone survey also included information relating to the implementation issues. It was noted that most of the implementation issues revolved around human factors. Most agencies reported the users' involvement during the development phase as the key factor to a successful implementation. Another very important set of factors was the training of personnel and the identification of need. It was also identified that the need assessment should be carefully carried out and the involved people should be made aware of the capabilities and limitations of the expert system. It was also noted that in-house developed or customized systems were more successful than a system borrowed from another agency and adopted without making any modifications. This is particularly true because of great variations in practices of various agencies and also due to the varying climatic conditions.

Chapter 4

CRITIQUES OF SELECTED EXPERT SYSTEMS

4.1 Introduction

The literature review conducted in this study identified quite a few application areas in which the feasibility of expert systems technology has been investigated. An attempt was made to procure some selected systems and investigate their attributes in detail, including strengths and weaknesses, development stage, input data requirements and documentation available. Findings of this study are presented in the following sections.

4.2 Critiques of Selected Systems in Transportation Engineering

4.2.1. Pavement Performance Evaluation and Rehabilitation

An initial field prototype expert system was developed by Ritchie et al. (1987, 1988) to assist local engineers for evaluating pavement surface distress and recommend feasible rehabilitation and maintenance strategies for subsequent detailed analysis and design. The system is called SCEPTRE (Surface Condition Expert for Pavement Rehabilitation), which is primarily a scoping tool that evaluates pavement surface distress. It is an interactive microcomputer-based expert system that has been developed using the EXSYS knowledge engineering environment.

SCEPTRE queries the user for inputs which are used by the system to make inferences and reach conclusions, based on a collection of facts and heuristics that have been incorporated into the system's knowledge-base. This knowledge-base has been constructed from the combined expertise of two pavement specialists, with extensive experience in pavement rehabilitation in the States of Washington and Texas. The most current version SCEPTRE 1.4, addresses state-maintained flexible pavements, and reflects practices and conditions found primarily in Washington State. SCEPTRE can, however, be modified to reflect regional or agency differences (Ritchie et al., 1987).

Another prototype knowledge-based system was designed to provide interactive expert advice and guidance on the detailed design of asphalt concrete pavement overlays (Ritchie, 1987). The system, called OVERDRIVE was developed in conjunction with SCEPTRE. The two systems are interrelated such that many of the inputs to SCEPTRE can also be used by OVERDRIVE. Both systems were developed using the knowledge engineering shell EXSYS and they run on an IBM compatible personal computer. The tasks addressed by OVERDRIVE include determining the overall thickness of the existing pavement structure, determining a new full-depth asphalt concrete construction thickness, and assessing the consequent need for an overlay. Both systems are linked to the Washington State Department of Transportation (WSDOT) pavement management system (PMS). A new microcomputer version of this PMS which interfaces with both these systems has been recently developed and is called SCOPE.

Another research prototype expert system EXPEAR which focuses on cement concrete pavement and is also aimed at evaluation and rehabilitation planning and design was developed by a team of researchers at the University of Illinois, Urbana (Hall et al., 1987, 1988). A set of interactive computer programs that operate on IBM compatible personal computers have been developed to address three concrete pavement types, viz., jointed reinforced (JRCP), jointed plain (JPCP), and continuously reinforced (CRCP). It uses information provided by the engineer to identify types of deterioration present and determine their causes, to select rehabilitation techniques that will effectively correct the existing deterioration and prevent its recurrence, to combine individual rehabilitation techniques into feasible rehabilitation strategies, and to predict the performance of alternative rehabilitation strategies. Predictive models are incorporated into the system to show future pavement performance with and without rehabilitation. These models were developed from national databases of concrete pavement projects and may be of limited applicability to a specific state's climatic conditions and materials.

4.2.2. Highway Intersection Design

A demonstration prototype expert system called the Intersection Advisor has been developed (Bryson and Stone, 1987) that recommends geometric modifications to improve intersection operation. It complements existing microcomputer programs that consider the other two aspects of intersection design, volumes and signalization. Intersection Advisor is intended for eventual incorporation in a comprehensive, interactive intersection design package. M.1, a knowledge-based expert system development tool, was used to develop the Intersection Advisor to run on IBM or IBM compatible microcomputers. During an interactive consultation the program requests information on the intersection volumes, critical movements, geometry, and constraints on approach improvement. It then recommends the most efficient improvements for each approach by generating one of nearly 600 possible reports. Recommendations are arrived at by determining an "ideal" lane configuration for the given traffic flows. The ideal design is checked against the improvement constraints, and a next best design is selected, if necessary. The best feasible design is then compared with the existing design, and the user is informed of any modifications required. It is reported that the intersection designs produced with the Intersection Advisor compare well with those produced using the guidelines of the 1985 Highway Capacity Manual.

4.2.3. Bridge Design

A research prototype expert system was developed for the design of bridges (Welch and Biswas, 1986). The system is called Bridge Design Expert System (BDES), and is aimed at designing superstructures of short to medium-span bridges. The potential designs comprise practically all designs normally used today. Possibilities may include structural steel or prestressed concrete with either simple or continuous spans.

BDES is a microcomputer-based program which operates on an IBM or IBM compatible personal computer. The system is highly user interactive with graphic capabilities to aid in input and output. The system requires bridge geometry as minimal input. However, the user may intervene at each step of the design process to alter assumed facts. Graphic displays guide the user in inputing geometry. Graphic output displays various cross sections to illustrate clearly the designs generated by BDES. The system is also capable of selecting the least weight design and verifying its adequacy by structural analysis. The analysis checks for all AASHTO code requirements. The current knowledge-base of BDES contains rules conforming to the requirements of North Carolina State Department of Transportation.

Another expert system (research prototype) relating to the domain of bridge design has been developed that integrates design independent knowledge about the dynamic effects of traffic loads into the algorithmic design process (Baker et al., 1989). The integration has been done by developing HIBIC (Highway Bridge Impact Consultation), an expert system for determining the most suitable impact stress amplification factor in use in the design of highway bridges. This approach uses heuristics concerning pavement and traffic conditions, as well as a detailed numeric methodology based on concepts of random vibrations and finite elements. The system was built using the PC-based expert system shell M.1, and can operate on an IBM or IBM compatible microcomputer. The knowledge-base consists of 118 rules that were encoded using the knowledge collected from literature, experts and practicing engineers.

4.2.4. Asphalt Concrete Segregation

A demonstration prototype (SEG) was designed to operate on IBM compatible microcomputers using expert system shell INSIGHT2+ (Elton, 1988). The knowledge-base was mainly composed of knowledge extracted from literature, combined with expert input. SEG is an interactive computer program that gathers information from the program user. The user provided information is then compared to the "knowledge" in the program and results in suggestions on possible sources of segregation.

4.2.5. Noise Barriers Design

An expert system named CHINA (Computerized Highway Noise Analyst) has been developed that is capable of interacting with an existing FORTRAN model that aids an engineer in acoustically designing a highway noise barrier (Harris et al., 1987). This is so far, the only expert system which is a production model and is currently being used by the State Departments in Pennsylvania, Georgia, and Kentucky.

The system which runs on IBM compatible microcomputer has demonstrated great performance and the results provided by the system have been compared and verified. The system is claimed to generate cost-efficient design and contains the expert knowledge of leading experts in the control of highway noise and thus can act as an expert advisor to the novice engineer or as a colleague to the more experienced engineers on complex abatement problems.

4.2.6. Traffic Signal Maintenance

SCAD (Signal Complaint Aid for Dispatchers) is an expert system designed to improve the efficiency of responding to traffic-signal malfunctions (Sharp and Parsonson, 1988). This expert system is programmed in order to provide an in-depth knowledge and experience of an engineer in the operation and maintenance of traffic signals to a dispatcher who does not have the engineer's expertise in handling complaints. SCAD considers the following factors in the process of arriving at a decision: phasing and timing, type of equipment, traffic patterns, maintenance history, signalized locations with duplicate names, appropriate jurisdiction and agencies involved, and operational characteristics. SCAD is a demonstration prototype and is developed using the INSIGHT2+ shell. The system requires a dedicated phone line, an IBM compatible computer with a hard disk and internal clock and existing computerized files of signal equipment inventories with signal incident histories.

Some of the important features of SCAD are that it can be operated by a dispatcher with a high-school level education and some basic knowledge of the roadway system. The system is capable of learning from its own mistakes by comparing its predictions with trouble call/response reports from the maintenance agency. SCAD has significant application potential since the signal engineers are leaving the public sector to avoid the increasing liability associated with their duties. Future work in the development of SCAD, as thought by its developers, includes use of a different shell that would have better file manipulation facility and the one that could be distributed without infringing copyright laws.

4.2.7. Bridge Paint Maintenance and Ranking

Bridge PIARS (Bridge Paint Identification and Ranking System) is an expert system which is aimed at establishing facility condition, evaluate the need for bridge painting, identify appropriate painting strategies and the cost of the strategies (McNeil and Finn, 1987). The decisions for bridge painting involve a qualitative assessment of the site in terms of the need of painting, incompatibilities among different types of steel, paint, and surface preparation, decisions which are essentially heuristic in nature. The application of the paint, surface treatment, and bridge condition are not uniform, thus uncertainty plays an important role.

Bridge PIARS considers the following factors in arriving at conclusions: bridge paint, paint thickness, paint history, construction material of bridge, steel type used in the bridge, bridge environment, bridge geometry and grade, availability of skilled operators, and environmental regulations regarding spray painting. The system is a demonstration prototype which is developed using a microcomputer based knowledge-engineering shell GEPSE.

4.2.8. Work Zone Traffic Control

A field prototype expert system called TRANZ is developed which is aimed at recommending appropriate traffic control strategies and management techniques around highway work zones (Faghri and Demetsky, 1990). Cognitive skills, judgment and expertise along with organizational guidelines are very crucial in making such recommendations. Also, most techniques are not well documented. Thus, incorporation of these factors in an expert system makes it a useful aid. The nature of construction project, the volume of traffic on the roadway during both off-peak and peak hours, the characteristics of the road, the anticipated amount of time the project will take, roadway (limited/unlimited access, primary, secondary), position of the closed lane (inner/center/outer) are some of the factors considered by TRANZ in arriving at suitable recommendations. The system is developed using EXSYS, a microcomputer based expert system shell and operates on an IBM compatible microcomputer.

4.2.9 Highway Bridge Impact Consultant

The highway bridge impact consultant (HIBIC) is an expert system for determining the most suitable impact stress amplification factor for use in the design of highway bridges (Baker et al., 1989). This approach uses heuristics concerning pavement and traffic conditions, as well as a detailed numerical methodology based on concepts of random vibrations and finite elements. HIBIC is a prototype expert system. The shell used for HIBIC is M.1.

Future directions for this expert system include incorporating the finite element within the expert system rather than exiting from the system as is done presently by the system, improving the statistical description of traffic which is used as input by the finite element method, and varying the methodology through field studies.

4.2.10. Other Miscellaneous Areas

In addition to the expert systems described above, there are quite a few other systems pertaining to various transportation related subdisciplines. Most of these systems are either research prototype or demonstration prototype. A comprehensive list of all systems surveyed along with their attributes is presented in Table 3.2. Also for readers seeking more information about these systems, a complete bibliography is presented at the end of this report.

4.3 Summary of Remarks

Based on the discussion presented in the preceding section, the following comments can be made:

1. The techniques used to collect the desired data have not been explained in most cases. Most probably this is attributed to these systems having been developed on an in-house basis.
2. Very rarely, a system developed by one agency has been used extensively by other agencies. This brings forth the question about the full fledged application of expert system and its suitability for the same problem domain at different geographic locations.
3. From the literature review and the telephone survey, it seems that a critical study of a system before its implementation is essential. Problem domains addressed in the expert systems should encompass more issues that concern the problem. This means that the depth of problem and wide variety of constraints related to that should be incorporated to simulate

real time situation, while most of the expert systems reported in the literature are in the research/demonstration prototype stage of development.

4. The constraints addressed are mostly of a technical nature, while in real time application, economics of the solution is very critical. Some expert systems (e.g., OVERDRIVE) have attempted the life-cycle cost analysis which is essential but it has been found that transportation agencies have to deal with budget restrictions before adopting to any particular strategy. Thus, a better approach is to deal with situations seems to be to implement the initial cost of a project as a constraint for strategies before any life-cycle cost analysis is done.

5. Available documentation for a majority of expert systems in transportation engineering (e.g., OVERDRIVE) is very brief. More detailed documentations are required for an effective application and use of an expert system.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The nation's transportation agencies share a common problem in the foreseeable future, which is the anticipated shortage of senior engineers and experts due to the great rate of retirement. The agencies as such, stand to loose an invaluable amount of expertise. The response to this foreseeable situation has resulted in the awareness of agencies to devise methods to cope with this situation. Also, the field of transportation engineering deals to a great extent with problems that are ill-structured. Expert systems offer a feasible solution in addressing these issues and most agencies have begun investigating the application and adoption of expert systems technology. It is widely believed that expert systems hold great promise for the future and would help provide the answers to some of the problems facing the transportation industry.

This study noted that many transportation agencies are getting involved with the development, application and implementation of expert systems. The most commonly shared belief is to get involved before it is too late. Ideally, the involvement of an agency should begin before they loose the senior engineers and experts. This would enable them to preserve and encode the institutional memory for future use and further enhancement.

It is also noted that an agency could not directly adopt the systems developed by other agencies due to the inherent differences in decision making styles, agencies' practices, differing material properties, and climatic differences. However, the systems developed by other agencies could serve the purpose of providing a framework and a general sense of direction. A viable approach seems to be to plan a study involving analysis of needs and then identifying the problem domain for which an expert system could be developed.

5.2. Recommendations

Based on the findings of this study, the following recommendations are made for the application and implementation of expert systems' technology in the Oklahoma Department of Transportation:

-- In order to maintain its competitive edge, ODOT should consider planning for the introduction of expert systems. This would not only keep the agency at the cutting edge of technology, but would also make them join the ranks of front-runners.

-- ODOT should consider planning to capture and restore the institutional expertise through using expert system technology. This is essential to enhance growth and to minimize the impacts due to loss of expertise resulting from retirement and other reasons.

-- A study of all departments and divisions of ODOT should be undertaken to identify the levels of needs and highlight the areas which would benefit from the development of expert systems.

-- The areas identified could then be prioritized and the resources required to develop the desired expert systems could be investigated.

-- The experts whose knowledge needs to be encoded in the form of a knowledge-base would also be identified

-- ODOT could also use the expert system technology as an effective training tool.

-- An immediate area of application, where expert systems could be used to the advantage of ODOT seems to be pavement management. In light of the experience of Washington State DOT, the integration of expert systems with the pavement management system would prove very cost effective.

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