in this paper has been the recording of reconstructed collision events with the use of three-dimensional models (*11*).

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Analysis of High-Hazard Locations: Is an Expert Systems Approach Feasible?

GARY S. SPRING, JOHN COLLURA, AND PAUL W. SHULDINER

The focus of this paper is the detailed analysis of specific highway locations that have been identified as hazardous in the framework of a state Highway Safety Improvement Program (HSIP). A methodology is proposed for implementing a microcomputer-based prototype expert system that would perform the location analyses described here. A prototype system would be used to assess the feasibility of building usable microcomputer-based expert systems for this application and to make recommendations for the design and implementation of such systems. By automating these activities with low-cost, easy-to-use-computer technology, it is hoped that the effectiveness of state highway transportation agency operations will be enhanced and that the provision of consistent and comprehensive analysis procedures will improve the overall safety and efficiency of the highway network. For automation to be feasible, certain minimum requirements must be met. With those in mind, a review of current state HSIPs was conducted. It was concluded that computerization of these analyses by using expert systems concepts on a microcomputer is technically feasible. A methodology to develop such a system for a state highway agency is proposed.

Last year 43,607 people died in traffic accidents on the nation's highways (*1*). Traffic accidents are one of the major causes of death in the United States today and have been since the beginning of this century. However, it was not until the late 1950s and beyond that the numbers began to grow to alarming proportions. The combined effects of the growing highway

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system and the nation's growing affluence caused a tremendous increase in the number of people and cars on the road, increasing chances for accidents to happen.

The provision of safe highways presents a challenge to today's highway professional. Essential to meeting that challenge is an organized approach to identifying and correcting highway safety problems. A chronology of the nation's safety efforts is given in Table 1 (*2*). Although there has always been a universal concern for highway safety, before the mid-1960s there was no central coordination of efforts. Safety considerations rested largely with the individual states (*3*). States developed programs such as motor vehicle inspection, highway design standards, and high-frequency accident location identification and correction. However, not all states were active in all areas. Federal efforts were equally fragmented. Although the Bureau of Public Roads had the main responsibility for highway safety, several other governmental agencies had programs that were concerned directly or indirectly with the subject.

Finally, in the mid-1960s coordination efforts began in earnest. The 1966 Highway Safety Act authorized the federal government to provide financial assistance to states that

TABLE 1 NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION HISTORICAL AND LEGISLATIVE BACKGROUND

Year	No. of Traffic Fatalities	Significant Event
1924	18,400	National Conference on Street and Highway Safety (convened by Secretary of Commerce Herbert Hoover)
1937	37,819	Second National Conference on Street and Highway Safety; report: *Guides to Traffic Safety*
1946	31,874	Third National Conference produced Action Program for Highway Safety
1954	33,890	President's Committee for Traffic Safety established and adopted Action Program
1956	37,965	First Congressional interest: Subcommittee on Health and Safety, House Committee on Interstate Commerce
1958	35,331	Secretary of Commerce authorized to assist in carrying out the President's Action Program and to cooperate with the states in furthering highway safety
		Interstate Compacts for Traffic Safety (Beamer Resolution)
1959	36,223	Report by the Secretary of Commerce to Congress on magnitude of traffic safety problems and the role the federal government should play in attacking them
		Requirements for passenger-carrying motor vehicles purchased for use by the federal government to meet certain safety standards
		Prohibition of use in commerce of any motor vehicle that discharges substances in amounts found by the Surgeon General to be injurious to human health
1960	36,399	Registration of automobile license revocations (National Driver Register)
1961	36,285	Requirements for passenger-carrying motor vehicles for use by the federal government to meet certain safety standards
		Hydraulic brake fluid specifications
1962	38,980	Standards for seat belts in automobiles sold or shipped in interstate commerce
1965	47,089	Amendment to the Federal-Aid Highway Act providing for voluntary state highway safety standards (Baldwin Amendment)
1966	50,894	National Traffic and Motor Vehicle Safety Act of 1966; established the National Traffic Safety Agency in the Department of Commerce
		Highway Safety Act of 1966; established the National Highway Safety Agency in the Department of Commerce
		Department of Transportation Act of 1966
1967	50,724	Executive Order 11357 combined the two foregoing agencies in the Department of Transportation as the National Highway Safety Bureau
1968	52,725	Report of the Secretary's Advisory Committee on Traffic Safety
		National Traffic and Motor Vehicle Safety Act of 1966, amendments
1970	52,627	National Traffic and Motor Vehicle Safety Act of 1966, amendments
		Federal-Aid Highway Act of 1970
*		Report of the President's Task Force on Highway Safety: *Mobility Without Mayhem*
1972	54,589	Motor Vehicle Information and Cost Savings Act
		National Traffic and Motor Vehicle Safety Act, amendments
1973	54,052	Federal-Aid Highway Act of 1973
1974	45,196	Motor Vehicle and Schoolbus Safety Amendments of 1974
1975	44,525	Federal-Aid Highway Act of 1973, amendments
		Energy Policy and Conservation Act established the Automotive Fuel Economy Program by adding a new Title V to the Motor Vehicle Information and Cost Savings Act
1976	45,523	Federal-Aid Highway Act of 1976
		National Traffic and Motor Vehicle Safety Act, amendment and authorization
		Motor Vehicle Information and Cost Savings Act, amendments
1977	47,878	Automobile Fuel Economy Program amendment, contained in the Department of Energy Organization Act
1978	50,331	Highway Safety Act of 1978 (included as Title II of the Surface Transportation Assistance Act of 1978); includes an amendment to section 158(b) of the National Traffic and Motor Vehicle Safety Act of 1966
		Automobile Fuel Economy Program amendments, contained in the National Energy Conservation Policy Act

SOURCE: For 1924–1974, National Center for Health Statistics, Department of Health, Education, and Welfare, and state annual summaries (adjusted to 30-day deaths). For 1975–1976, Fatal Accident Reporting System (FARS), NHTSA.

NOTE: Federal government entities concerned with highway safety include the Department of Health and Human Services, Department of Commerce, Department of Defense, U.S. Postal Service, General Services Administration, Interstate Commerce Commission, Interdepartmental Highway Safety Board, and President's Committee for Highway Safety.

develop and maintain a safety program. The basic features of the act cast the mold for national highway safety policy (*3*). Imposing uniformity on state and local programs provided much-needed coordination of the nation's highway safety efforts. Subsequent highway safety acts have expanded the guidelines set forth in 1966. The U.S. Department of Transportation (DOT) developed the Highway Safety Program Manual (HSPM) in 1974 to guide state and local agencies in conforming with the acts. The HSPM contains 18 safety standards. Standard 9 (*4*)

> requires the development of a program for identifying and maintaining surveillance of locations having high accident experience. After identifying hazardous locations, the state must take appropriate measures to reduce accidents and to evaluate the effectiveness of safety improvements at these locations. Also, a program must be developed to maintain surveillance of the roadway network for potentially high accident locations and for correcting problems at these locations. Each state is required to periodically evaluate their program and provide the Federal Highway Administration (FHWA) with an evaluation summary.

Efforts have paid off. The fatality rate in persons per million vehicle miles peaked in 1966 at around 5.5 and has since decreased to its present value of about 2.6 (*1*,*2*).

To aid state and local agencies in the design and implementation of highway safety programs within the framework of HSPM Standard 9, FHWA formally defined a Highway Safety Improvement Program (HSIP) [Federal-Aid Highway Program Manual, Volume 8, Chapter 2, Section 3 (FHPM 8-2-3), March 1979]. The HSIP consists of components for the planning, implementation, and evaluation of safety programs and projects. The three components consist of processes related to

- Collecting and maintaining data,
- Identifying hazardous locations,
- Analyzing those locations (diagnosing their problems and developing countermeasures to the problems),
- Developing improvement projects,
- Establishing project priorities,
- Scheduling and implementing projects, and
- Determining the effects of safety improvements.

The arrows in Figure 1 indicate the flow of information in the HSIP at the process level (*4*).

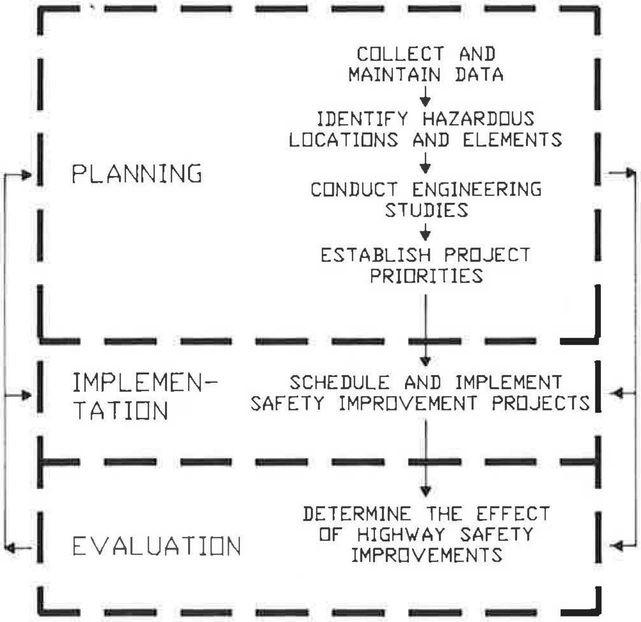


FIGURE 1 **Highway safety improvement program at the process level.**

RATIONALE AND SIGNIFICANCE OF AUTOMATION

In these days of fiscal austerity, it is essential that public agencies increase the efficiency and effectiveness of their operations. The location analyses (see Figure 2) (*5*) that are part of the HSIP are tedious and time consuming, making their computerization very desirable to the analyst. However, these analyses are based primarily on experience and good engineering judgment, and so conventional computer programs do not quite fill the bill. A microcomputer-based expert system would combine the best of both worlds. It would provide all the advantages intrinsic to microcomputers in the workplace as well as allow much of the work to be done by technicians.

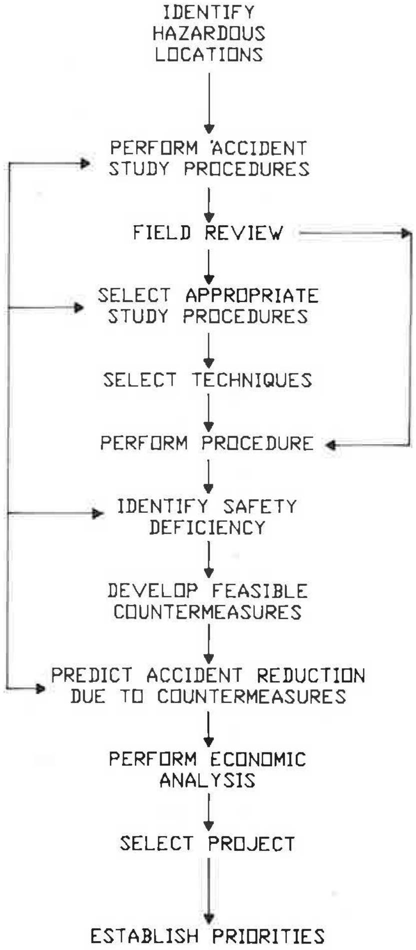


FIGURE 2 **Engineering investigation model.**

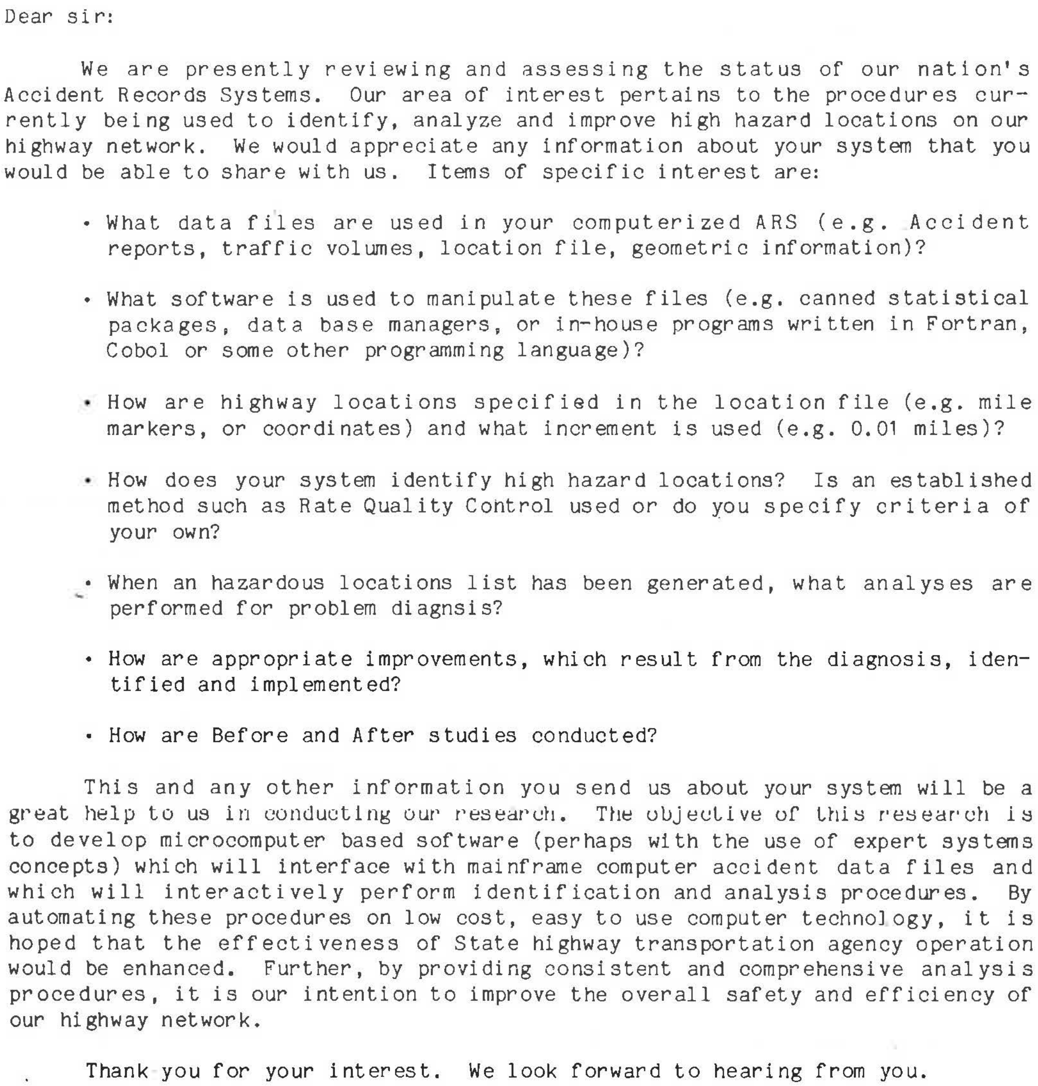
Expert systems are computer programs that solve problems too complex for conventional software, in other words, problems that cannot be represented by a model and that are based on judgment. Perhaps the most useful characteristic of expert systems is that they allow much of the expert's work to be done by technicians, thus freeing professional staff for other duties. They expose the nonexpert to the reasoning processes of the expert and offer advice to improve the nonexpert's understanding of the problem situation by proposing strategies for dealing with it. They never forget a rule or commit a simple oversight. They never go on vacation or get sick. They are easily reproduced, just by copying a few floppy disks, so that their expertise is readily available to anyone who needs it.

The primary objective of this paper is to propose a methodology for implementing a microcomputer-based prototype expert system that would perform the location analyses described here. Such a system would be used to assess the feasibility of building usable microcomputer-based expert systems for this application and to make recommendations for the design and implementation of such systems. By automating the location analyses on low-cost, easy-to-use computer technology, it is hoped that the effectiveness of state highway transportation agency operations will be enhanced. Further, by providing consistent and comprehensive analysis procedures, it is hoped that the overall safety and efficiency of the highways will improve.

The type of system considered here is for state-level highway safety programs. States are required to maintain the large accident data bases necessary to monitor their highway systems. Their safety programs are very large and therefore much more difficult to maintain than smaller-scale systems. However, they are plagued with the same money and staff shortages as are other public agencies. Consequently, it appears to these researchers that their need for an automated analysis procedure is even greater than it is at other levels of government.

IS AUTOMATION FEASIBLE?

Before the feasibility of a system such as the one proposed here can be examined, it is necessary to define what is meant by



Dear sir:

We are presently reviewing and assessing the status of our nation's Accident Records Systems. Our area of interest pertains to the procedures currently being used to identify, analyze and improve high hazard locations on our highway network. We would appreciate any information about your system that you would be able to share with us. Items of specific interest are:

- What data files are used in your computerized ARS (e.g. Accident reports, traffic volumes, location file, geometric information)?
- What software is used to manipulate these files (e.g. canned statistical packages, data base managers, or in-house programs written in Fortran, Cobol or some other programming language)?
- How are highway locations specified in the location file (e.g. mile markers, or coordinates) and what increment is used (e.g. 0.01 miles)?
- How does your system identify high hazard locations? Is an established method such as Rate Quality Control used or do you specify criteria of your own?
- When an hazardous locations list has been generated, what analyses are performed for problem diagnsis?
- How are appropriate improvements, which result from the diagnosis, identified and implemented?
- How are Before and After studies conducted?

This and any other information you send us about your system will be a great help to us in conducting our research. The objective of this research is to develop microcomputer based software (perhaps with the use of expert systems concepts) which will interface with mainframe computer accident data files and which will interactively perform identification and analysis procedures. By automating these procedures on low cost, easy to use computer technology, it is hoped that the effectiveness of State highway transportation agency operation would be enhanced. Further, by providing consistent and comprehensive analysis procedures, it is our intention to improve the overall safety and efficiency of our highway network.

Thank you for your interest. We look forward to hearing from you.

FIGURE 3 Letter of inquiry.

"feasible." A system that could and would be used by a majority of state highway agencies is a feasible one. The general process of automating location analysis on a microcomputer will be examined first. The applicability of an expert systems approach will then be examined.

For automation of these analyses on a microcomputer to be feasible, a majority of states must meet the following requirements:

- Data maintenance and identification of hazardous locations should be automated;
- It should be possible to process a location's accident data automatically;
- Manual analysis procedures currently in use should, at least in part, use downloaded accident data and should have the same general form; and
- Current automation efforts should not be duplicated.

General Approach

To determine whether these requirements are met, the safety improvement program of each state was reviewed. The letter shown in Figure 3 was sent to the 50 state departments of transportation (DOTs) across the country. The results of the survey are presented in Tables 2–5. The implementation component of the HSIP is not included in the results because it is largely administrative rather than analytical in nature. Thirty-three responses were received and supplemented with a review

TABLE 2 PROCESS ONE—PLANNING COMPONENT

STATE	REFERENCE METHOD					COMPUTER FILES					
	MILEPT	REF PT	LINKNODE	COORD	LORAN C	ACCIDENT	TRAFFIC	RD CLASS	HAZ LOC	GEOMETRY	OTHER
ALA	X*		X			X	X	X		X	
ALSK				X		X	X	X			X
ARIZ	X*	X		X		X	X	X		X	X
CAL	P					X	X	X		X	X
CONN	P*					X	X	X		P	
DEL	P*	P				X	X	X		X	X
FLA	X		X			X	X	X		X	X
GA	X					X	X	X			
IND		X				X					
KAN	X					X	X	X		X	
KEN	X					X	X	X			
LA	P					X	X	X		X	X
MASS		X		X*		X	X	X			
ME			X			X	X	X			X
MICH	P					X	X	X		X	
MINN	X					X	X	X		X	X
MISS	P	P				X	X	X	X		X
MO	P					X	X	X	F	F	F
MONT	X					X	X	X			
NC	P					X	X	X		X	X
ND	X		X			X	X	X		X	X
NEB		X				X	X	X			
NEV	X*	X				X	F	M		F	
NH			X			X	X	X			X
NJ	X*		X			X	X	X	X	X	X
NY		X*	X			X	X	X		X	X
OKLA		X*		X		X	X	X			
OREG	P					X	X	X			
PENN		X				X	X	X		X	X
TEX	X					X	X	X			X
UTAH	X*	X				X	X	X		X	X
VA	P		F			X	X	X			X
VT	X					X	X	X		X	X
WASH+	X*					X	X	X			X

* State Highway only
P indicates document method
F indicates future implementation
M indicates manual procedure
\+ Data files are not linked automatically

TABLE 3 PROCESS TWO—PLANNING COMPONENT

STATE	IDENTIFICATION METHOD							
	FREQ	RATE	FRQ/RATE	RQC	SEVERITY	HAZ IND	HAZ FEAT	OTHER
ALA				X				
ALSK								X
ARIZ		X			X			
CAL	X							
CONN				X				
DEL			X					
FLA				X			X	X
GA				X	X			
IND	X							
KAN				X	X			
KEN				X				
LA				X				
MASS			X+			X		
ME				X				
MICH	X							
MINN	X	X			X			X
MISS				X		X		
MO			X					
MONT			X		X			X
NC								X
ND			X		X			
NEB				X				
NEV						X		
NH					X			X
NJ						X		X
NY				X				
OKLA				X	X			
OREG						X		
PENN						X		X
TEX			X					
UTAH		X					X	X
VA				X				
VT				X	X			
WASH+					X			

of safety literature. The results of this effort were used to answer the following four questions:

1. What activities are currently on line and what types of data sorts are available from mainframe data bases?

Clearly, data must be available for downloading to the microcomputer in order for automation to be advantageous.

2. Do these location analyses lend themselves well to automation?

Not only must the data be available for downloading, but the analysis procedure must use those computerized data; otherwise, automating it would not be worth the effort.

3. What types of analyses are currently performed?

An automated analysis procedure would probably not be acceptable to a majority of users if manual procedures currently used are not primarily based on downloaded data and are not fairly uniform.

4. Are there any procedures that are automated now?

It is also necessary to know what efforts, if any, have been made to do what is proposed here, so the work will not be duplicated, and to ensure that all efforts complement each other whenever possible.

TABLE 4 PROCESS THREE—PLANNING COMPONENT

	COLLECT & ANALYZE DATA				DEVELOP COUNTERMEASURES				CHOOSE IMPROVEMENT ALTERNATIVE					
STATE	ACC BASE	TRAFF OP	ENVIRONS	SPECIAL	ACC PATT	FAULT TR	FIELD	OTHER	COST EFF	BEN/COST	RATE-RET	TIME-RET	NET BEN	OTHER
ALA	X				X		X							X
ALSK								X						X
ARIZ	X				X		X							X
CAL	X				X		X			X				X
CONN	X	X	X		X		X			X				X
DEL	X	X			X		X							X
FLA	X	X	X		X		X			X				
GA	X				X		X			X				
IND	X	X	X		X		X			X				
KAN	X				X					X				
KEN	X				X		X							X
LA	X				X		X							X
MASS	X				X									
ME	X	X	X		X		X		X					
MICH	X	X	X		X		X		X					
MINN	X				X		X							X
MISS	X	X	X	X	X		X			X				
MO	X	X	X		X		X							
MONT	X				X		X			X				
NC	X	X			X					X				
ND	X		X		X									
NEB	X	X	X		X		X			X				
NEV	X	X	X		X		X		X					
NH	X	X	X		X		X							X
NJ	X				X		X							X
NY	X				X		X			X				X
OKLA+														
OREG+	X													
PENN	X				X					X				
TEX	X						X	X						
UTAH	X				X		X			X				
VA	X				X		X			X				
VT	X		X		X									X
WASH	X				X									

+ Automated analysis

TABLE 5 PROCESS FOUR—PLANNING COMPONENT; PROCESS ONE—EVALUATION COMPONENT

STATE	PRIORITIZATION					EVALUATION				
	PROJ DEV	INC BC	DYN PROG	LIN PROG	OTHER	ACC BASE	NON ACC	PGM EVAL	ADM EVAL	OTHER
ALA			X							X
ALSK					X	X				
ARIZ	X					X				
CAL		X				X				
CONN	X					X		X		
DEL					X	X				
FLA					X	X		X		
GA	X					X				
IND	X					X				
KAN	X					X				
KEN						X				
LA	X									
MASS										
ME	X									
MICH	X					X				
MINN	X					X				
MISS	X					X	X	X	X	
MO	X					X		X		
MONT	X					X				
NC										
ND					X					X
NEB	X					X				
NEV	X					X		X		
NH					X	X				
NJ						X				
NY	X					X				
OKLA	X					X				
OREG										
PENN										
TEX										
UTAH	X									
VA					X	X				
VT						X				
WASH						X				

Discussion

Activities On Line and Data Sorts Available (Question 1)

In order to perform any kind of location analysis, it is necessary that, at the very least, states have accident and highway classification data on line. Further, an essential element of a traffic records system is an accurate highway location reference system. If an agency cannot pinpoint the location of accidents or other roadway data, problem locations cannot be accurately identified. Consistency of the reference system between the files was stated to be a real problem by many states. However, all but one have these data on line. Of those, only one does not provide automatic linkage of the files.

Some of the respondents have complex, state-of-the-art data base management systems (DBMS) and many others plan to implement such systems in the future. A more complete discussion of the establishment of comprehensive data systems may be found elsewhere (*6,7*). Those without a DBMS in place have programs written in a programming language (FORTRAN or COBOL) that were developed in house to manipulate their data files. In any event, all can supply a wide range of data sorts to the user for analysis. Some also perform statistical analysis of data, for example, to identify accident types that are overrepresented at a particular location. In addition, all the respondents except the two mentioned previously have automated the identification process and regularly generate listings of suspect locations. Most listings are made according to some criterion such as the ratio of accident rate to critical rate or by frequency. Those few that do not generate listings use interactive computer systems to perform cluster analysis or some other user-specified type of analysis.

Automation Possibility, Studies Now Performed, and Work Now Under Way (Questions 2–4)

All respondents use accident-based data as input to the analysis process and accident pattern analysis as a major component of the process, and all analyses have basically the same form. Most states perform location analysis manually. Few have automated analyses. Alaska has an interactive system in place on their IBM XT/370 and Tektronix 4125 that allows the user to perform cluster analysis to identify specific problems at each location. Texas has contracted with the Texas Transportation Institute to develop microcomputer software that analyzes accident experience at high-hazard locations. The software identifies factors overrepresented in accident occurrence at these locations relative to the average for similar highways in the area (*8*).

Similarly, although most states rely on collision diagrams as part of their analysis, only three or four can generate them by computer. Most also perform one of the standard economic analyses to choose the desired improvement alternatives as well as to rank projects by priority.

Current automation efforts use conventional software that either processes and selectively sorts data or performs some type of statistical analysis on the data. Although useful to the expert, the outputs are of limited use to the unskilled technician.

Summary

The feasibility of automating location analysis, as defined in the FHWA's HSIP, on a microcomputer was examined. Four questions were asked to determine that feasibility and a review of current state HSIP efforts was conducted to answer them. As a result of the review, the following observations may be drawn:

- All but two respondents have essential accident and highway data on line, can provide a wide range of data sorts for any specified location, and have a computerized high-accident location identification system.

- The location analysis performed by all respondents is, at least in part, accident based. This means that the most common procedure uses accident data that can be downloaded as input, which in turn means that data input can be automated.
- Most respondents use accident patterns as input to a field review to diagnose problems and to develop countermeasures at suspect locations. This means that only one location analysis procedure need be automated for a majority of states to use it.
- Very few states use automated location analysis procedures. Those few require an expert to run them and to interpret their output. Further, they are designed to be used with a specific system.

In short, automation is feasible. The minimum requirements for automating the location analysis portion of the HSIP are met. Because all states perform the analyses but few have automated them, automation is desirable as well.

IS AN EXPERT SYSTEMS APPROACH APPLICABLE?

To deal with the question of applicability, it is necessary first to know about expert systems, namely, what they are, what they do, how they work, where they have been applied successfully, and, perhaps most important, for what types of problems they apply. Second, it is necessary to examine the location analysis problem and, finally, to compare problems handled by expert systems with the location analysis problem to determine whether expert systems are amenable to this type of problem.

Expert Systems

Artificial intelligence (AI) is that part of computer science concerned with designing "intelligent" computer systems. That is, AI systems exhibit the characteristics usually associated with intelligence in human behavior—understanding language, learning, reasoning, solving problems, and so on. Expert systems are computer programs that apply AI problem-solving techniques to complex real-world problems normally done by experts. They attempt to use the knowledge of human experts to solve problems (*9*). Their use of domain-specific knowledge, in contrast to other AI applications that use more general reasoning methods, gives them an enormous amount of problem-solving power by greatly reducing the solution space that must be considered.

Knowledge in any specialty is usually of two sorts: public and private. Public knowledge (also referred to as "deep" knowledge) includes published definitions, facts, and theories typically found in texts and references in the domain of study. Private knowledge ("surface" knowledge) is heuristic, experiential knowledge that comes from successfully solving many problems in a specific domain, that is, doing things again and again, getting a feel for the problem, learning when to go by the book and when to break the rules. Heuristics enable the human expert to make educated guesses, to recognize promising approaches to problems, and to deal effectively with faulty or incomplete data.

Expertise consists of knowledge about a particular domain, an understanding of domain problems, and skill at solving them. An expert is distinguished not only by how much he knows about his domain, but also by how quickly he recognizes patterns and brings rules to bear (*2*). So an expert system also requires a knowledge-processing component in order to perform expertly. This component is called the system's inference engine (sometimes called the system's interpreter). It is a computer program used for deriving conclusions about problem characteristics by using knowledge in the knowledge base. Finally, the system requires a user interface to enable the user to communicate with it. Hence, expert systems have three essential components: a user interface, a knowledge base, and an inference engine (*3*).

The knowledge base consists of facts and rules representing the heuristic knowledge about the problem domain. Rules often have the form IF (premise) THEN (conclusion), whereas facts are represented as assertions of the form (variable name) = (value). An example of this structure is Rule 31 taken from PUFF, a pulmonary function disorder diagnosis expert system (*10*):

> IF:
> 1) The severity of obstructive airways disease of the patient is greater than or equal to mild, and
> 2) The degree of diffusion defect of the patient is greater than or equal to mild, and
> 3) The tlc observed/predicted of the patient is greater than or equal to 110, and
> 4) The observed-predicted difference in rv/tlc of the patient is greater than or equal to 10
>
> THEN:
> 1) There is strongly suggestive evidence (.9) that the subtype of obstructive airways disease is emphysema, and
> 2) It is definite (1.0) that "OAD, Diffusion Defect, elevated TLC, and elevated RV together indicate emphysema." is one of the findings.

The inference engine employs search procedures to manipulate and use these rules. Two common strategies are backward chaining and forward chaining. Backward-chaining (or goal-directed) strategies require selecting a goal and then scanning the rules to find those whose consequent actions will achieve that goal, trying to satisfy those rules from facts or from the conclusions of other rules, and so on until the goal is met or not met. In the forward-chaining (or data-driven) approach, the rules are searched to determine what conclusions can be drawn from information provided by the user, facts in the knowledge base, and previous conclusions. As conclusions are reached, the premises of other rules are satisfied, and the search process continues until no more conclusions can be made or until a goal is met, whichever comes first. As a simple example, if the PUFF system were provided a patient's signs and symptoms that matched the premises of the sample rule shown above, it would deduce that the patient is likely to have emphysema (i.e., it would use its knowledge about pulmonary disorders to interpret the given problem attributes).

A fundamental difference between this type of system and other types of computer systems lies in the nature of the problems that they solve. Conventional computer programs solve well-defined, well-understood problems. They use a small amount of knowledge (e.g., a mathematical model) and apply it over and over again in their solution of a problem. The expert system is applied to ill-defined, poorly understood problems. It uses an heuristic knowledge base to narrow the number of alternative solutions to a set of the most likely ones.

The Location Analysis Domain

Location analysis problems are like Sherlock Holmes mysteries: all the pieces are there, but the expert—Sherlock—is required to put them together in a meaningful way so that he can figure out what is going on (i.e., solve the problem). The safety engineer solves location analysis problems in much the same way. He uses his knowledge about why accidents happen to figure out (or to deduce) what is wrong at a particular highway location. This suggests an expert systems approach.

Another feature of the location analysis process that recommends it to an expert systems approach is the availability of expert knowledge in the domain; it should be remembered that expert systems use large amounts of it. Several efforts have been made to write down common "rules of thumb" used in the location analysis process. One such effort was made by FHWA in its *Highway Safety Engineering Studies Procedural Guide* (*5*). It includes a review of general countermeasures for accident patterns and their probable causes. The items tabulated are typical bits of knowledge long used by safety engineers to solve the mystery of what is happening. Box, in his article in *Traffic Engineering* (*11*), also presents some insights into what to look for when analyzing a problem location. Much has been written on this subject (*5,12*), all very similar to the FHWA study and the Box article. A great deal of this work is based on good common sense and years of experience.

Applications of Expert Systems

Expert systems have been successfully applied in many different areas; the general types of systems to which they can be applied are listed in Table 6. The domains in which expert systems have been applied successfully include medical diagnosis, mineral exploration, natural language understanding, and many more. All deal with problems that are poorly defined, not well understood, and data poor. The fact that a great many transportation problems are of that sort suggests some very exciting possibilities for the future of expert systems applications in that domain. Takallou (*13*) points out in his review of expert systems applications in civil engineering that there is a lack of ongoing research in the area of transportation engineering. In fact, no expert systems have been developed dealing with highway safety.

TABLE 6 EXPERT SYSTEMS APPLICATIONS

Category	Problem Addressed
Interpretation	Inferring situation descriptions from sensor data
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observables
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Comparing observations with plan vulnerabilities
Debugging	Prescribing remedies for malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosing and repairing student behavior
Control	Interpreting, predicting, repairing, and monitoring system behaviors

Summary

From the preceding discussion, an expert systems approach to performing location analyses makes sense. Not only have these location analysis problems been neglected but it appears that they are tailor made for an expert systems approach. In addition, there is a well-documented knowledge base from which to draw.

METHODOLOGY

In the previous two sections the feasibility and desirability of automating and the applicability of an expert systems approach to performing location analyses on a microcomputer have been examined. It was concluded that automation is feasible and desirable and that the expert systems approach does apply for this domain.

The basic expert systems structure that could be used for a prototype system is shown in Figure 4. A detailed description of the major components follows.

Knowledge Base

Perhaps the most critical issues that must be addressed when building an expert system are knowledge acquisition and representation. Knowledge acquisition [i.e., the process by which expert knowledge is captured for use in a knowledge-based expert system (KBES)] is not a simple linear process. One is not trying to capture fixed algorithmic approaches to problem solving. Rather, the knowledge to be acquired is heuristic, judgmental, subjective, and not necessarily organized. Further, the organization of the knowledge for application is not always consciously understood by the expert himself. To facilitate the

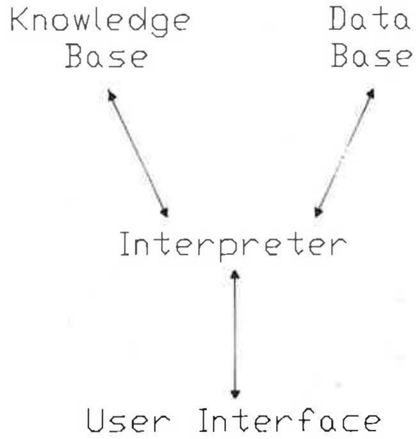


FIGURE 4 Basic structure of an expert system.

efficient and accurate acquisition of knowledge for this application, the process is best defined in the following stages (*14*):

- Identification, in which the important stages of the problem are characterized and goals for the entire project set;
- Conceptualization, during which the key attributes of location analysis are made explicit (some initial thought could be given to knowledge representation issues at this point); and
- Formulation, in which a formal model of the location analysis procedure and its key properties and relationships are mapped into a representation scheme.

The production system representation (an example of which was presented earlier) has been used with great success in many of the expert systems that have been built to date. The basic idea of this type of representation is that the data base consists of rules, called productions, in the form of condition-action pairs. The utility of the formalism comes from several facts: first, the conditions under which each rule applies are made explicit; second, the system's chain of reasoning can easily be traced, which makes it fairly simple to include explanation facilities in the system (see the discussion of transparency in the following section); and, finally, the knowledge is represented in a modular form, which facilitates system learning. For these reasons it is recommended that this system be designed, at least initially, by using the production formalism.

For a prototype system, the expert knowledge used could simply be the rules of thumb developed by FHWA in their engineering guide mentioned previously (*5*). As the system developed, it would of course be necessary to augment those rules with interviews conducted with safety experts.

The Inference Engine

The inference engine manipulates the knowledge base for presentation to a nonexpert user. The choice of inference engine is strongly coupled to the nature of the task that the system is designed to perform. The system, especially for transportation applications in which problems are generally unstructured and therefore cannot be completely captured by a model, must exhibit the quality of transparency. That is, the user should be able to see the chain of reasoning that led to a given outcome or recommendation. Transparency will be considered essential in developing this system.

The fact that the inference engine (the executive that runs the expert system) is separate from the knowledge base allows the use of "shells," which are general inference engines that can operate on different knowledge bases. A great number of shells have been developed just in 1986 alone (*15*). They range in price from around $50 for McGraw-Hill's Microexpert to $5,000 for Teknowledge's M.1 (*16*). A recent issue of *Computerworld* (*16*) includes a review of several of them and presents many of their essential characteristics. Whether to use any of these shells (and if so, which one) or to create the inference engine by using an appropriate programming language such as LISP depends largely on the goals and resources of the system's developer.

System Design and Implementation

To provide a system that can be used by any state that is interested, the system should be designed so that it can run in a wide variety of environments with its component hardware and software kept as inexpensive as possible. It should be designed and implemented for a pilot project in a specific state. The subject state in which to implement the system should have the following characteristics:

- Has requisite data available on mainframe,
- Has problems with HEP submissions because of staff shortages,
- Has microcomputer technology available to use the system,
- Is easily accessible to the builder of the system, and
- Has an interest in automating these analyses and in using its microcomputers.

The problem of interfacing with the chosen state's mainframe computer can be addressed at this point. First, a mainframe computer program would need to be written that prepares the accident information for downloading to a microcomputer. The communications format chosen depends on what type of link is available (i.e., hard-wired versus telephone line). The appropriate communications software can be chosen at this time. Once the microcomputer is linked to the mainframe, the file format must be ascertained so that data can be downloaded to the microcomputer. The uploading question, although potentially useful, does not have to be addressed at this time (information uploaded could be used to rank safety projects by priority statewide).

Testing provides feedback for problem reformulation, redesign of knowledge representation, and other refinements to the system. Therefore, the prototype system should be exercised by using a library of already-solved problem locations. The conclusions of the expert system could then be evaluated by comparing them with the human expert's solutions.

CONCLUSIONS

An expert systems approach to performing the location analysis portion of state HSIPs appears feasible. The true test, though, will come after a prototype system has been developed and implemented. Clearly, the benefits offered by expert systems are many. Nevertheless, there is more to developing them than simply buying a shell, hiring an expert, and writing some rules.

The tasks to which they are applied must be reasonably well defined and fairly narrow in scope. The chief reason for the success of expert systems lies in their specificity. If this is missing, this approach is not appropriate.

In addition, expert systems are expensive in terms of both time and money. So even if it turns out that the tasks are appropriate, they must be performed fairly often to make the system cost-effective. Also, the rules used to represent the knowledge base must be generally accepted by experts in the field. For such a large investment to be worthwhile, the results must be usable by more than just a handful of people. Most important, however, is that it must be possible to represent the knowledge by a set of rules.

To conclude, then, the system described here is theoretically feasible. Whether it can be reasonably designed and implemented is a question that must still be answered. It is hoped that the methodology presented here will be helpful in answering that question.

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Safety Implications of Truck Configuration

Oliver Carsten

The relative safety of single and double tractor-trailer combinations is examined in the light of recent findings on the performance characteristics of the two classes of vehicle. In particular, the accident data are searched for evidence of a safety deficit for the doubles resulting from the phenomenon of rearward amplification. Although there is no conclusive evidence of an overall difference in fatal and injury accident involvement rates between singles and doubles, this is tempered by the finding of a generally safer operating environment for the doubles. There are strong indications that the doubles have a rollover problem in property-damage accidents. The overall conclusion is that the handling characteristics of large trucks are reflected in their accident experience.

In the last 15 years a considerable body of literature has appeared on the dynamic performance of truck combinations. One major focus of this literature has been the phenomenon of rearward amplification for combinations with one or more trailers (*1–3*). Rearward amplification is defined as the tendency in multitrailer combinations traveling at highway speeds for motions of the tractor to be exaggerated further in each successive trailer. The phenomenon is particularly severe in emergency maneuvers, when the motion of the tractor may be both abrupt and of large amplitude. But it may also occur in negotiating tight curves, such as those encountered on exit ramps, or even in regular highway driving if travel speed is sufficient. The major effect of the rearward amplification is to cause the second (or third) trailer to have a lower rollover threshold than the first trailer or, in turn, the tractor.

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