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16. Abstract <p>This study is to develop a microcomputer knowledge-based Expert System for assisting urban freeway corridor incident management. Study activities include: literature review, conceptual design, prototype system development, and program documentation. Efforts were made to summarize the information and decision-making processes involved in implementing freeway incident management strategies. The study has investigated the Expert Systems Design for representing incident management techniques. The study summarized the state-of-the-art expert system development, conceptual design, and system user interface design. A unified development process has been identified for expert knowledge representation, implementation procedures, and translation system using conventional languages. This report summarizes the design considerations, concept design, program implementation, and system operations of microcomputer-based Expert Systems development in the Transportation Engineering Field.</p>					
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**CORRIDOR ANALYSIS FOR RECONSTRUCTION ACTIVITIES,
TRAFFIC CONTROL STRATEGIES, AND INCIDENT MANAGEMENT TECHNIQUES**

**TASK B. DEVELOPMENT OF EXPERT SYSTEMS FOR
FREEWAY INCIDENT MANAGEMENT**

- LITERATURE REVIEW -

by

**Edmond Chin-Ping Chang, P.E.
Associate Research Engineer**

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evaluation determines the critical volume cross-product as calculated from the input. The forward chaining inference mechanism, i.e., a check to determine whether goals or sub-goals fit the input, models dependencies among decision-making activities in human reasoning. This inference process optimizes the design objectives by starting from known information. The third process models the domain knowledge with IF-THEN-AND-ELSE rules. For example, the existence of sight distance restrictions and severe left turn accidents can justify providing protected left turn signal treatments.

These reasoning processes, as documented by rules in the decision table similar to Figure 3, are very useful in developing problem-solving techniques in instances which may not be covered by established design guidelines. Constructing specialized Expert Systems can provide users with reasoning knowledge similar to that which would be provided by a human expert. The Expert System, once proven useful, can generate solutions resembling those used by other engineers for determining the proper actions. Since only a few heuristics are being evaluated each time, the system operation is very efficient. Therefore, traffic engineering Expert Systems are especially useful in assisting users in solving problems that occur repeatedly, sharing common working experience for mutual learning, and providing better understanding of design alternatives. By correctly constructing the knowledge-based Expert System, engineers can further refine decision-making rules to reflect the learning process from a previous analysis.

Knowledge Engineering Tools

Most conventional programs are written in high-level computer languages, such as BASIC, COBOL, FORTRAN, PASCAL, LISP or C. AI languages are used in ES designs to process information and derive conclusions and recommendations. Problem-solving languages, such as LISP and PROLOG, are often used in developing Expert Systems. LISP, which stands for LIST Processing, is suited for symbolic and numeric processing in decision analysis. LISP is suitable for manipulating lists of symbols, i.e., strings of numbers and/or words. For years, United States AI researchers have preferred LISP. On the other hand, PROLOG, representing Programming in LOGic, is preferred in Europe and Japan. PROLOG contains data structures more suitable for writing computer programs that evaluate logical expressions, whereas LISP contains operators that facilitate programs that manipulate lists representing specific knowledge.

Knowledge Engineering (KE) Tools or Shells are the programming tools that allow quick system implementation for specialized applications. These tools provide the development environment for applying knowledge systems through the natural language interface. As a result, the KE Tools are often used to build Expert Systems, since they provide the system features needed, such as the help functions, windowing capabilities, graphics support, and other functions. The knowledge shell usually includes an explanation subsystem describing the steps necessary to reach a conclusion. Using these tools, the users can evaluate the viability of a reasoning path or a chain of production rules depending on the probability of occurrence. Today, many KE Tools are available on user-friendly microcomputers for commercial programming. The KE tools are needed to define specific operational constraints required to describe study goals and analysis objectives.

the human expert's expertise in making judgments under various conditions. They "clone" experts by capturing knowledge that is perishable, scarce, and vague and difficult to apply, distribute, or accumulate. Expert Systems afford cost-effective services in areas that require symbolic processing of knowledge and rule-of-thumb judgmental problem-solving methods. An initial application of Expert Systems was in the diagnosis and treatment of human physical disorders; the basic purpose of these systems was to determine what the symptoms indicated and what remedial treatment was appropriate.

Expert System technology is one of the most successful branches of Artificial Intelligence (AI) field. Other branches of AI technology include robotics, voice recognition and synthesis, and vision. Expert System technology started to emerge as a potent force in 1977 when Professor Feigenbaum of Stanford University stated that the problem-solving power of a computer program comes from the knowledge it processes in a given domain, not just from the programming techniques and formalism it contains. However, the programming techniques and formalism may also determine the eventual destiny of an Expert System.

Basic Design Concept

The basic structure of an Expert System resembles the conventional software program, as shown in Figure 4. Its major components are a knowledge base, inference engine, user interface mechanism including explanation facility and data. Major components of conventional programs are data, database, code, the interpreter/compiler, and sparse user-interface mechanism, but the interpreter may be embedded in the system. Expert Systems are capable of providing the symbol processing, knowledge inferencing, and explaining.

Simulation Programs and Expert Systems

Because of the different programming techniques being used, Expert Systems can be considered an advanced form of representation for programming specific decision-making knowledge for various potential applications. The terminology of Expert Systems can be referred, on a one-to-one basis, to the terminology of the conventional software programs as shown in Table 1. For example, a knowledge base of an Expert System can contain decision rules or IF-THEN rules, and facts that match the program code of a software. However, a knowledge base does not correspond to a database. A knowledge base is executable, but a database is not. A database can only be queried and updated. Like an interpreter that evaluates a program in the source code and executes the statements, the inference engine takes the statements in a knowledge base and executes them because the inference engine contains search control and substitution mechanisms.

On the other hand, AI/ES programming languages, such as LISP, Prolog, CLIPS, and Smalltalk, can also be used to build an entire computer program package with a customized knowledge base, inference engine, and user-interface. This package is commonly called an Expert System shell, or knowledge engineering tool. Expert System shells are usually used to build Expert Systems are high-level programming languages with many unconventional conveniences, such as reasoning explanation and tracing facilities.

There are several major differences between the design and development of simulation programs and Expert Systems:

- o Simulation applications often involve the iterative process wherein a model is designed, inputs are specified, an experiment is executed, the study results are analyzed, and a new run is designed, executed, and analyzed until sufficient insight is gained to render a controlled decision. In the Expert Systems design, the designer constructs a knowledge base. The user must define the goal and lets the computer work to identify the decision rules.
- o In simulation models, the data base is integrated with the program logic internally. For the expert system, the knowledge base is distinct from the inference engine which controls the logical flow.
- o The data base for simulation models is generally numeric and formally structured. In an Expert System, the data base is symbolic and represents facts, decision rules, judgment, and experiences or heuristic knowledge about a narrow problem area.
- o Simulation programs employ algorithms; Expert Systems employ fact lists, production rules, and symbolic inference.
- o Simulation languages are procedural or imperative (FORTRAN, GPSS, SIMSCRIPT). Expert Systems may use knowledge shells (OPS5, ROSIE, Expert-Ease) which, in turn, are usually written in functional or descriptive languages (LISP, PROLOG, CLIPS, NxPERT).

Knowledge acquisition is considered the slowest and most costly process in the Expert System development. This is due primarily to the need for large amounts of knowledge base. However, the expert system has high potential for expanding the traffic engineering and transportation planning knowledge base and eventually can provide important savings in costs and time.

Knowledge Base

The programmer can use three types of knowledge to build Expert Systems. These include the rules of thumb, facts and relations among design components, assertions, and questions. To represent decision-making knowledge in the knowledge base, three different methods and terminologies have been used:

- o **Rules** to represent rules of thumb,
- o **Frames** to represent structured facts and relations, and
- o **Logic** to represent assertions and queries.

Rule Rules, or production rules, are conditional sentences; they can usually be expressed in the following form:

```
IF (premise) FACT 1, FACT 2,...  
THEN (conclusion) FACT 9, FACT 10,...
```

For example, the production rule for the "signalization based on accident experience" could be written as follows:

```
IF ( severe left turn accident recorded at the particular intersection )  
THEN ( protected left turn phase needs to be provided )
```

Frames or Units A frame or unit contains the hierarchies of objects or components. The attributes of objects can be assigned, inherited from another frame, or computed through analysis procedures or other programs. The attributes or elements are filled in "Slots" of a frame. The following example shows a sample unit representing the 8-Phase Pretimed Signal Control used to describe a particular signalized intersection.

Frame name:	8-Phase Pretimed Signal Control
Installed to:	Intersection
Inherited from:	Signal Control
Created by:	03-03-89
Modified by:	04-07-89
Slot: Capacity	
Type:	Real number, value: 0 to 1800 VPHPL
Slot: Main-component	
Type:	Alphanumeric, value: STREET NAME
Slot: USAGE	
Type:	Alphabet, value: (inherited from ES)

Logic Logic expressions consist of predictions and values to assess facts of the real world. A predicate is a statement concerning an object, such as the kind-of (8-Phase Pretimed Control, Signal Control or SC).

This representation scheme can be interpreted as an 8-phase pretimed control commonly used in signal control. The object can be either a constant or a variable that may change over time. A predicate may have one or more arguments that are the objects it describes. In the example of a signal timing control advisor, the other kind of logic expression is appropriate for asking questions such as the following:

? - (Matrix, X): - (X), SC (X), operations
(X, excellent).

The above question can be interpreted as "Show me all possible ASD installations in a given system that can be implemented with only pretimed control that are considered to possess excellent operation."

Inference Engine Once the knowledge base can be somewhat obtained, it can then be executed by different users through a reasoning and search control mechanism to solve similar problems. The most common reasoning method in Expert Systems is the application of the following simple logic rule, predicate calculus, or modus ponens.

IF A is true, and IF A THEN B is true, then B is true.

The implication of this simple rule is that:

	IF B is not true, and IF A THEN B is true, then A is not true.
	or
Given:	IF A, THEN B and IF B, THEN C.
Conclusion:	IF A, THEN C.

In other words, IF A is true, THEN you can conclude C is also true.

These three reasoning principles can be used to solve different problems by examining rules, facts, and relations in Expert Systems. However, to minimize the reasoning time, search control methods are used to determine where to start the substitution process and which rule to examine next when several rules conflict at the same point. The two main search methods are forward and backward chaining. In an Expert System, these two methods may also be combined for the maximum efficiency of search control.

Forward Chaining When the rule interpreter is forward chaining and if premise clauses match the situation previously specified, then the conclusion clauses are asserted. For example, in the decision rule of yellow demand interval, if the field operating situation matches the premise, that is, the average travel speed exceeds 35 mph, the operational potential for Expert Systems to suggest the use of a longer clearance interval will increase. Once the rule is used, or "fired," it will not be used again in the same search. However, the fact concluded as the result of that rule's firing will be added to the knowledge base. This cycle of finding a matched rule, firing it, and adding the conclusion to the existing knowledge base will be repeated until no more matched rules are found.

Backward Chaining The Backward chaining mechanism attempts to prove the hypothesis from known facts. If the current goal is to determine the fact in the conclusion or hypothesis, then you must determine whether the premises match the situation. For example,

Rule One:
IF you lose the key and
the gas tank is empty,
THEN the car is not running.

Rule Two:
IF the car is not running and
you have no cash,
THEN you are going to be late.

Fact One: You lost the key.

Fact Two: The gas tank is empty.

To prove the hypothesis "You are going to be late," given the facts and knowledge rules, Facts 1 and 2, and Rules 1 and 2, the backward chaining process must be applied to determine whether the premises or subhypotheses match the facts. Rule 2, which contains the conclusion "You are going to be late," would be fired first to determine whether the premises match the actual situation. Since the knowledge base does not contain the facts in Rule 2's premises, "The car is not running" and "you have no cash," "the car is not running" becomes the first subhypothesis. Rule 1 will then be fired to assert whether the premises "you lost the key" and "the gas tank is empty" match the facts. Because the Facts 1 and 2 in the knowledge base match the premise of Rule 1, the subhypothesis "the car is not running" is proven; however, the system still has to prove "you have no cash," which is not contained in the knowledge base and cannot be asserted through rules because no rule is related to it. The system will then ask the user "IS IT TRUE THAT: you have no cash?" If the answer is "Yes," then the second subhypothesis is also proven, and the original hypothesis is proven as well, concluding "You are going to be late."

Man-Machine Interface The man-machine interface mechanism produces a dialogue between the computer and user. The current Expert System can be equipped with templates, menus, mice, or natural language to facilitate its use and an explanation module to allow the user to challenge and examine the reasoning process underlying the system's answers. Menus are groups of simplified instructional statements that appear on the computer screen and can be selected by pushing designated buttons, using a mouse, or designated keys on the keyboard. The user does not need to type instructions. A semi-natural or fully natural language interface is more sophisticated than a menu interface; it allows computer systems to accept inputs and produce outputs in a language closer to a conventional language, such as English. Several Expert Systems incorporate primitive forms of natural language into their user interface to facilitate knowledge base developments. Explanation modules generate output statements of Expert Systems in a language that can be understood by non-computer user professionals.

Uncertainty of Knowledge Rules, obtained from human experts, are sometimes uncertain; they describe some rules as "maybe," "sometimes," "often," or "not quite certain about the conclusion." The users may use the "Uncertainty" or "Fuzzy Set Logic" to handle these statements. Furthermore, like human experts, Expert Systems may have to draw inferences based on incomplete information, such as unavailable, unknown, or uncertain information. Unavailable or unknown information can be resolved by allowing rules to fail if the information needed is critical in evaluating different premises, i.e., the information needed is in the condition (IF) statements connected by AND. When IF statements are connected by OR, the absence of one or more of them will not affect the outcome of the rule. Although the reliability of knowledge inserted into the knowledge base is questionable, the ability to represent facts not guaranteed to be 100% accurate is important to Expert Systems.

The likelihood that a fact is true is called the fact's **Certainty Factor (CF)**. In most Expert Systems, this number is between 0 and 1, where 0 represents no confidence in the fact, and 1 represents complete trust in the validity of the fact. For example, you may assign a CF of 1.0 to:

"Pre-timed Control is suggested"

and perhaps a CF of 0.5, representing 50% certainty, to:

"Pre-timed control is the best strategy."

The CF is an integral part of any fact and is always displayed to the user along with any display of the fact.

"Pre-timed Control is suggested" [CF = 1.0]

"Pre-timed control is the best strategy." [CF = 0.5]

Certainty factors for representing the facts can be established in either of two ways. First, the source of the fact, generally the user, supplies a certainty factor for the fact. Second, an Expert System uses rules to compute the certainty factor. Any fact not assigned a certainty factor is assumed to have a factor of 1.0.

Probability and Expert Systems

Some Expert System shells do allow the user to include "Probability," "Confidence Factors," or "Certainty Factors" in the user's rules. This is equivalent to having all of the user's conclusions be absolutely certain, with all rules precisely implying each conclusion with no room for doubt or error. Unfortunately, the real world is usually not quite so precise in determining "Absolute Yes" or "Absolute No" in some decision-making analyses. Often, certain decisions become fuzzy in resolving conflicts among opinions, even for the experts. Therefore, most Expert System shells allow probability to be included in the definition of production rules. Being able to include the probability or uncertainty in the rules, the knowledge engineer can better determine whether a user will be asked to specify confidence in the answer. This facility is primarily provided to allow reasoning with partial or uncertain information, which is known in AI jargon as "Fuzzy Reasoning."

The following two examples illustrate how Certainty Factors can be implemented through the commercial available INSIGHT 2+ and EXSYS packages.

Probability in INSIGHT 2+ The knowledge engineer can determine whether a user will be asked to specify confidence in the answer, or whether INSIGHT 2+ will simply prompt for TRUE or FALSE answers during a query session. In order to enable confidence prompting, the CONFIDENCE ON statement is included in the control element specification portion of the user knowledge base. The user will then be asked to specify the confidence (0-100) associated with each goal to be analyzed. When used as a knowledge base control element, the CONFIDENCE statement can disable prompting for user input during execution of the knowledge base. If omitted, the default value is OFF. The statement should precede the goals of the knowledge base in the user PRL source. On the other hand, if it is not necessary or desirable for the user to enter his confidence, confidence prompting can be disabled by the statement CONFIDENCE OFF. In this case, INSIGHT 2+ will assign confidence values of 100 to a TRUE response and 0 to a FALSE response.

For example, the commonly recognized values below can also be used as a general design guideline for selecting the needed confidence values and the related level of certainty in analyzing particular problems.

Level of Certainty	Confidence Value
Confident it is true	100
Possibly true	75
Not sure	50
Possibly false	25
Confident it is false	0

Confidence can also be placed in the logical assertion or conclusion of the production rule used by the knowledge engineer. If omitted, the conclusion is automatically assigned a confidence value of 100. The THRESHOLD statement allows users to specify the lowest level of confidence needed for the INSIGHT 2+ to reach a particular conclusion or goal. When running knowledge base under INSIGHT 2+, and CONFIDENCE has been enabled (ON), the user will be prompted to input confidence levels. If no value is assigned, the default value of 50 will automatically be used by INSIGHT 2+. For example:

```

TITLE
.....
THRESHOLD = 60
.....
CONFIDENCE ON
.....
RULE   To tell if the Actuated Control is Recommended
IF     The intersection has volume variations
AND    The intersection has high-type control strategy
THEN   The main/cross street volume variations is high CONFIDENCE 85
AND    The degree of saturation (DOS) is under 0.80 CONFIDENCE 50
END

```

Probability in EXSYS EXSYS allows the user to show the degree of belief in a given fact or event through the use of "Certainty Factors." Certainty factors can be used in conjunction with rules and attached to conclusions to be recommended to a user. If there is more than one answer to a given problem, EXSYS can attach a certainty factor to each answer and rearrange the answers in order of certainty factors.

In EXSYS, certainty factors can be assigned with the following scales: 0 or 1, 0 to 10, and 0 to 100. When the 0 or 1 scale is used, the 0 corresponds to the absolute meaning that the solution should be rejected, and the 1 represents an absolute meaning that the solution be accepted as true. For the 0 to 10 scale, 0 represents absolutely false and 10 absolutely true; the numbers in-between are used to represent degrees of certainty. The 0 to 100 scale is similar to the 0 to 10 scale, except that the range is 0 to 100. This scale provides granularity in providing the certainty specification.

A rule in EXSYS states one or more statements in the IF part should be followed by one or more statements in the THEN and ELSE parts. There may also be choices in the THEN part indicated by a text statement followed by:

- Probability = <either 0,1, or a ratio>

For example, in the determination of computer hardware specification:

```
RULE NUMBER: 5
IF: (1) A LARGE AMOUNT OF DISK STORAGE SPACE IS NEEDED
and (2) THE LARGEST FILE CAN BE DIVIDED INTO SECTIONS
      EACH LESS THAN 100 PAGES
and (3) COST IS A MAJOR FACTOR
THEN:
      IBM PC - Probability=10/10
and IBM PC XT - Probability=5/10
and EXPANSION UNIT - Probability=3/10
```

In some cases, it may be easier to write rules that eliminate certain choices by giving them the value of 0/10, or include them by giving a value of 10/10. For example, we might have the four production rules that relate to choice 1:

```
RULE NUMBER: 1
IF
      ....
THEN
      CHOICE1 - Probability=0/10
RULE NUMBER: 2
IF
      .....
THEN
      CHOICE1 - Probability=2/10
.....
RULE NUMBER: 4
IF
      ....
THEN
      CHOICE1 - Probability=10/10
```

If both Rules 2 and 3 are true, then the final value for CHOICE1 will be the average of 2 and 8, or 5. If the Rule 1 is also true, then the 0 value will prevail and lock the value at 0. If Rule 4 is true, the 10 will prevail and lock the value at 10. EXSYS will present the user with a list of possible solutions to the problem arranged in order of the likelihood with their final probability factors.

These two examples, listed above, are simple illustrations of the possible applications of the "Fuzzy Theory" that may be applied in the expert system design. The uses of probability, confidence factor, or certainty factor can provide the key solution that is often needed to resolve the complexity and possible conflict in opinion when developing suitable production rules for intersection signal design.

SUMMARY OF EXPERT SYSTEM DESIGN

- o An expert system mimics experts or specialists (i.e., in medicine or computer configuration).
- o The power of an expert system relies more in the knowledge base and not in the programming technique.
- o The principal components of these current systems are knowledge base, inference engine, and man-machine interface.
- o The knowledge base contains facts and production rules that comprise an expert's expertise.
- o Three commonly used methods for encoding knowledge, facts and relationships are rules, frames, and logical expressions.
- o Inference engines are relatively simple; the two most commonly used methods are backward chaining and forward chaining.
- o User interface is often a weak but critical element in Expert Systems; many Expert Systems are equipped with menus and explanation modules to allow users to examine their output statements.

EXPERT SYSTEMS IN TRANSPORTATION ENGINEERING

Expert Systems offer an effective means of utilizing the specific knowledge and experience of recognized professionals. The major advantages of developing Expert Systems are that they permit the systematic examination, organization, and application of specific human knowledge to particular problem areas for use by other users. At present, there is much interest and activity in highway applications. The major prototype Expert System development in transportation includes: network scheduling, project management, system management, software selection, alternative evaluation, route location, site planning, landslide evaluation, material analysis, intersection design, parking facilities, crash barriers, and structural design. This development also includes signal systems, positive guidance, traffic management, intersection performance analysis, safety evaluation, pavement maintenance and rehabilitation, bridge repair, pavement management, and other AI/ES applications.

Several research studies have been conducted to survey the state-of-the-art Expert System development and implementation in the transportation engineering field. Ritchie surveyed the uses of Expert Systems in the field of transportation engineering and identified a number of systems that were either operational or under development in 1986. Since the completion of his survey, additional research work has begun; however, much of it is still in the conceptual design or early prototype stage. Stone, et al in 1988, summarized recent progress of the Expert System development for applications in highway engineering.

STATE-OF-THE-ART DEVELOPMENT

As indicated in Figure 5, each catalog presented below may be assigned a location in the matrix of Highway Engineering Categories and Expert System Tasks. For example, the following Expert System development for the network scheduling generator, called GHOST, falls into the "Administration and Management" and the task "Planning and Design" category. The following sections illustrate a number of expert systems currently developed or being developed in the transportation engineering field.

Administration and Management

Network Scheduling Two Expert Systems in this category have been identified. A project network generator called GHOST has been developed by R. D. Logcher, D. Navinchandra, and D. Sriram, Department of Civil Engineering, M.I.T. The program takes a list of construction activities and develops a schedule by setting up precedence among activities; it uses IMST. In another effort, Logcher and M. Toro wrote a knowledge-based Expert System using KEE for planning schedules of public works projects.

Project Management M. McGartland and Chris Hendrickson of Carnegie-Mellon used OPS-5 to explore an application of Expert Systems to construction project monitoring. Satish Mohan of the State University of New York at Buffalo is using Expert Systems to rank project risks according to their severity, assign probability of occurrence, and suggest contingency measures for bid advertisements and contracts. INSIGHT 2+ is being used.

System Management STREET-SMART was developed by C. Yeh of the University of California, Irvine. It employs LISP to advise users of "Streets of the City," a simulation of an urban transportation system over a 10-year period.

Highway Planning

Software Selection Under the direction of Edmond Chang of the Texas Transportation Institute, INSIGHT 2+ has been applied to assist users in selecting software packages supported by the Federal Highway Administration. In another effort, D. Fayegh and S. Russell have written an expert system to select the most appropriate computational model for flood estimation.

Evaluation of Alternatives EVALUATOR was designed by Jerry Schneider of the Civil Engineering Department of the University of Washington. The M.I.-based system provides advice about which criteria to examine in multi-criteria transportation alternatives. M.I. is also being used in EXPERT-UFOS by S. Tung of the University of Washington to help design optimal, large-scale networks.

Route Location Jon Fricker and Ron Thieme of Purdue University have worked on an Expert System to assist in forest road designs and adjustments for terrain and other constraints. A goal is to use the LISP language to interface the Expert System with digital terrain models, optimization programs, data storage, and retrieval procedures. In another effort, C. Yeh used CLIPS in HERCULES to generate a traffic control plan using the links remaining in a post-disaster urban road network.

	INTERPRETATION	DIAGNOSIS/ MONITORING	PREDICTION	PLANNING/ DESIGN
ADMINISTRATION AND MANAGEMENT	<ul style="list-style-type: none"> o REGULATIONS o CONTRACTS & SPEC'S o LEGAL LIABILITY 	NOT AVAILABLE YET	NOT AVAILABLE YET	NOT AVAILABLE YET
HIGHWAY PLANNING	<ul style="list-style-type: none"> o ZONING o SITE REVIEW o NETWORK MODELING ASSISTANCE 	<ul style="list-style-type: none"> o SYSTEM DEFICIENCIES 	<ul style="list-style-type: none"> o TRAFFIC VOLUMES o LAND USES o TRIP GENERATION 	<ul style="list-style-type: none"> o BUDGETING o PROJECT SCHEDULING o PROGRAM PLANNING
HIGHWAY DESIGN	<ul style="list-style-type: none"> o TECHNICAL STANDARD o ENVIRONMENTAL GUIDELINES 	<ul style="list-style-type: none"> o DESIGN REVIEW o CADD "HELP" 	NOT AVAILABLE YET	<ul style="list-style-type: none"> o CORRIDOR SELECTION o ROUTE SELECTION o NETWORK ASSIGNMENT o INTERACTIVE INTERSECTION DESIGN
OPERATION AND CONTROL	<ul style="list-style-type: none"> o SIGNAL CONTROL o WARRANTS o ACCIDENTS ANALYSIS o CAPACITY ANALYSIS 	<ul style="list-style-type: none"> o SIGNAL CONTROL o ACCIDENT RECONSTRUCTION o INCIDENT IDENTIFICATION 	<ul style="list-style-type: none"> o SIGNAL WARRANTS o INCIDENT PREDICTION o FREEWAY INCIDENT MANAGEMENT 	<ul style="list-style-type: none"> o SIGNAL CONTROL o WORK ZONES o EVACUATION PLANNING
MAINTENANCE AND REHABILITATION	<ul style="list-style-type: none"> o PAVEMENT INSPECTION 	<ul style="list-style-type: none"> o BRIDGE INSPECTION o MATERIALS TESTING 	<ul style="list-style-type: none"> o MAINTENANCE FORECAST 	<ul style="list-style-type: none"> o MAINTENANCE SCHEDULING o MATERIALS SELECTION

Figure 5. Survey of Expert System Development in Transportation Engineering.

Site Planning Ray Levitt of Stanford University used the prototype SITEPLAN to design and update a siting plan. BBI Blackboard was used.

Landslide Evaluation Verne McGuffey of Geotechnical Engineering will provide the expertise for a landslide evaluation system that is being developed at the Rensselaer Polytechnic Institute.

Highway Design

Materials Analysis David Ashley and M. Wharry of the University of Texas use SOILCON for conducting soil exploration. The Expert System evaluates known soil conditions and recommends methods for continued exploration. Peter Mullarkey applied OPS5 to develop CONE, a system to classify soil and infer soil shear strength based on penetrometer data.

Intersections Don Bryson and John Stone of North Carolina State University used M.1 to convert rules of Chapter 9 of the Highway Capacity Manual to an advisor for intersection design. Satish Mohan is using safety and capacity criteria for an intersection design tool based on INSIGHT 2+. Professional expertise for the system is elicited by induction and repertory grid techniques. Edmond Chang has also developed an Expert System scheme, through the AutoLisp programs, to interact with the design process of the AutoCAD system. The system was developed to associate the benefit/cost estimation with traffic demands for intersection geometric designs.

Parking Facilities Mohan is working on another system that evaluates an existing off-street parking facility, assigns it a level of service and makes suggestions for design improvements based on rules, standards, and a knowledge base of professional expertise.

Crash Barriers Jack Carney of Vanderbilt University is beginning work on an Expert System that will design a new highway impact attenuation system. The system would consider the various needs for a particular site, recommend a configuration, and design details.

Noise Barriers At Vanderbilt, Lou Cohn, Al Harrid, and Bill Bowlby developed CHINA using UCI LISP to address highway noise barrier design problems. Bill Bowlby is also building an Expert System to help engineers decide how to model a site for the noise prediction program STAMINA 2.0.

Structural Design A number of projects address structural design problems. Chris Hendrickson is using OPS5 to develop an Expert System that will evaluate retaining wall failures or conduct a survey of the condition and possible repair strategies for existing walls. Jerome Connor of M.I.T. used the C language in designing a knowledge-based system for plate girder design.

Another prototype system was developed by Connor and T. Pagnoni to conduct preliminary concrete bridge design. J. Welch of Duke University has an operational system to assist the novice bridge engineer with superstructure design of short-to-medium span bridges. C. W. Ibbs, University of California at Berkley, has a prototype system to select highway bridge foundations.

Operation and Control

Signal Systems Permissive, exclusive, and exclusive/permissive left turn phases may be used to allow vehicles to turn left. Edmond Chang of the Texas Transportation Institute is developing an Expert System which facilitates the left turn phase selection process. In another effort, Dr. Chang is applying Expert Systems to make traffic signal control analysis more efficient for arterials and arterial networks. A. E. Radwan, M. Goul, and T. O'Leary of the Arizona State University Center for Advanced Research in Transportation are building a prototype Expert System for signal system control. They are basing the system on Chapter 9 of the Highway Capacity Manual and appropriate traffic engineering expert heuristics.

Choosing alternative control logics for adaptive signal control is the goal for the Expert System of Feng-Bor Lin, Department of Civil and Environmental Engineering, Clarkson University. Nicholas Vlahos of the Transportation Center of Northwestern University has designed a front-end Expert System for TRANSYT-7F. When completed, the system will use Expert System concepts and management decision support theories to help traffic analysts incorporate qualitative factors and constraints not considered in TRANSYT-7F. Adolf May of the University of California, Berkley, is exploring the feasibility of processing real-time traffic data for an adaptive controller at isolated intersections. Chris Hendrickson and C. Zozaya-Gorostiza used OPS5 to program TRALI, a signal setting aid for isolated intersections.

Positive Guidance Peter Parsonson and Syed Hussain of Georgia Tech are gathering heuristic knowledge, caveats, and shortcuts that experts use to identify where positive guidance is required. They will use INSIGHT 2+ to incorporate a knowledge base for locating and designing guidance measures.

Traffic Management Michael Demetsky and Ardeshir Faghri of the Virginia Highway and Transportation Research Council in Charlottesville, Virginia, have applied EXSYS to traffic management in road construction work zones. Al Santiago of USDOT/FHWA is evaluating the application of various artificial intelligence approaches to urban traffic management.

Intersection Performance Analysis Chris Hendrickson of Carnegie-Mellon University is using semantic nets and frames to represent the intersection performance analysis for transportation networks and complex procedures, such as those in the Highway Capacity Manual.

Safety The University of Toronto is sponsoring Mark Montgomery in his effort to diagnose safety improvement problems at signalized intersections using Expert System concepts.

Maintenance and Rehabilitation

Pavement Maintenance and Rehabilitation Because of the expense involved in maintaining and rehabilitating roadway surfaces, much effort has been expended in this area. Carl Haas of Carnegie-Mellon used OPS5 to develop PRESERVER. This system analyzes pavement distress data and suggests routine maintenance. Stephen Ritchie used EXSYS to develop SCEPTER to assist highway engineers in

identifying feasible project level rehabilitation and maintenance strategies based on surface condition evaluations. An Expert System for pavement rehabilitation analysis was proposed by Mario Beland, Quebec Ministry of Transportation, Canada. His system will use EXSYS and be modeled after SCEPTER. Jerry Hajek of the Ontario Ministry of Transportation and Communications developed ROSE to rapidly prioritize hundreds of pavement sections for routing and sealing operations.

Another project under development is identifying the failure modes. In the Department of Civil Engineering at Purdue University, T. D. White is planning an Expert System that can consider a number of failure phenomena and achieve a more consistent prediction of pavement performance than can conventional inspections. Michel Ray of the Roads and Highway Department in Bagneux, France, has a prototype Expert System which evaluates alternative maintenance procedures. Sue McNeil of M.I.T. is working with Frannie Humplick and Francoise Brisson to create an Expert System that can select appropriate pavement maintenance and rehabilitation strategies. A prototype system acts for an "end-user" as an interface between a database and a program to identify optimal rehabilitation strategies.

Another new system concept being studied has a learning module that will help "lead-users" develop models and assess new technologies for pavement rehabilitation. A team of investigators led by Michael Darter of the University of Illinois at Urbana-Champaign is developing an EXPEAR in Pascal to evaluate concrete pavements, select appropriate rehabilitation techniques, and formulate and rank rehabilitation strategies. James Wentworth and John D'Angelo at USDOT/FHWA have, in development, an Expert System to assist construction inspectors with asphalt mixes, plant operation, weighing and transport, and lay-down and compaction. Ken Maser of M.I.T. has proposed a system for automated interpretation of large quantities of sensory data for evaluating in-site conditions.

Bridge Repair Sue McNeil and Anne Margaret Finn have implemented PIARS, a prototype Expert System to identify cost-feasible painting strategies for bridges. The GEPSE-based system uses information about the condition of existing paint, deterioration rate, and heuristics about incompatibilities between different types of paint and steel. Ken Maser and D. Smit of M.I.T. have a prototype system to automatically analyze radar to determine deterioration in concrete bridge decks. W. Seymour, while a student at M.I.T., wrote a rule-based decision support system for bridge management.

Jerome Connor and W. Roddis of M.I.T. are developing knowledge bases for steel bridge restoration. C. Kostem of Lehigh has written an Expert System to aid structural engineers while conducting AASHTO bridge ratings. An Expert System proposed at the University of West Virginia by Hota Gangarao will determine bridge replacement priorities. The system uses EXSYS to implement a decision tree search procedure based on life cycle costs.

Pavement Management STREETWISE, a pavement management "game," is being developed by Daniel Halbach and Patrick Flanagan in Austin, Texas. It will be coded in TURBO PROLOG to produce a natural language interface between the computer and the user for assessing pavement data.

RECENT PROGRESS AND FUTURE IMPLICATIONS

This survey represents the current developments and application interests in Expert System field for highway engineering, especially in traffic operation and control, and pavement maintenance and rehabilitation areas. As shown previously in Figure 5, applications are just beginning to emerge in highway planning and design, while substantive efforts have yet to begin in administration and management. The current development suggests that Expert Systems for highway engineering are being developed and used in areas where expertise is well known and codified, i.e., the lower half of the figure. This is understandable since a "knowledge" engineer's goal of encoding information is made much easier if he can use standard, perhaps written, design procedures, guidelines, and warrants. When the expertise is more subjective, the knowledge is inherently more difficult to capture.

Future Expert System development will remain very active in the "Operation and Control" and "Maintenance and Rehabilitation" functions of highway engineering. As Expert Systems for signalization and pavement maintenance reach maturity and demonstrate their value, institutional barriers will be overcome and more practical applications will emerge. As Figure 6 suggests, realistic future expectations include new Expert Systems that will analyze accident and capacity data used to identify candidate locations for improvement, reconstruct accidents and diagnose the cause, and develop traffic marking and signing strategies according to accepted standards.

A growing number of applications in highway design will also be apparent. Already there are initial efforts in intersection, noise barrier, and crash barrier designs. The future should bring additional Expert Systems for pavement design, lighting, and sign layout. Expert Systems may also begin to appear as background advisors or "help" functions in standardized reviews and computer-aided design. Highway planning appears to be a particularly fruitful area for Expert System development. The previous section identifies a range of potential applications. Future uses for Expert Systems in the administration and management functions of highway engineering are somewhat unclear. It is expected that Expert Systems developed in the broader field will be adopted and customized for practical implementation.

RECOMMENDED EXPERT SYSTEM APPROACH

Expert Systems can effectively utilize the specific knowledge and experiences of recognized professionals. The major advantages of developing Expert Systems are that they permit the systematic examination, organization, and application of specific human knowledge in particular problem areas.

Design Guidelines

There are two important design factors for the successful development of Expert Systems in transportation related applications. First, there must be a firm commitment of research support by management. This will encourage development and practical implementation of an Expert System and assure its success. In addition, there must be close interaction within the organization during the planning and design phases of the System in order to develop

practical and implementable programs. Ideally, the successful expert system development team should include both developers and users to facilitate the development-experiment-analysis-implementation process. In addition, the successful microcomputer-based Expert System requires clear definition of the system, a confined analysis scope, modularization of the system components, clear definition of background information, responsibilities of the research team, detailed functional requirements, adequate development tools, and proper methods of referring to Expert System knowledge bases. Established guidelines, user documentation, and product distribution of the completed Expert Systems are also needed to ensure that these critical issues will be given adequate consideration in the development process.

Recommended Development Process

Successful microcomputer-based Expert System development should include four basic steps as shown in Figure 6. These development steps include identification, concept development, rapid prototyping, and program validation. Both the problem to be addressed, and the expected outputs of the system must be clearly identified. Concept development should identify potential end users, skill levels, and knowledge transferability for specific problem-solving. Rapid prototyping, in the form of either pilot studies or small-scale workshops, is very useful in demonstrating the effectiveness of the Expert System at different development stages. Rapid prototyping can provide opportunities to modify the functional design and concept development. Also, product validation can be made through the workshop to evaluate the functional design before project completion. In particular, the research team must test the proposed applications to see if they are suitable for the Expert Systems approach. Specifically, the design concerns must address:

1. Whether the payoffs exist if the Expert System is developed from the existing design guidelines, and
2. Is there a better way to solve the particular problem other than trying to develop the new Expert System?

It is very important to review the potential applications and prototype system for probable form and expected difficulties in developing the deliverable systems. It is also important to estimate system complexities, desired appearance, level of knowledge required in advanced to accommodate the time constraints and funding resources allowed for actual system development.

In the initial design identification stages, the research team must provide detailed descriptions and proper identification of the system, its intended users, and its desired performance. This effort requires proper estimation of the development process, which includes the exact problem description, expected output, expected user skill level, and anticipated performance. It is also important to identify all the available and certified knowledge bases that could be utilized by the Expert System and other practitioners. If a recognized knowledge base is not available, then a knowledge acquisition plan must be prepared to acquire and formulate the expert knowledge needed for practical usage. Therefore, it is critical to identify the recognized experts in the specific fields and determine their availability for any contribution to system development and verification.

RECOMMENDED AI/ES APPROACH

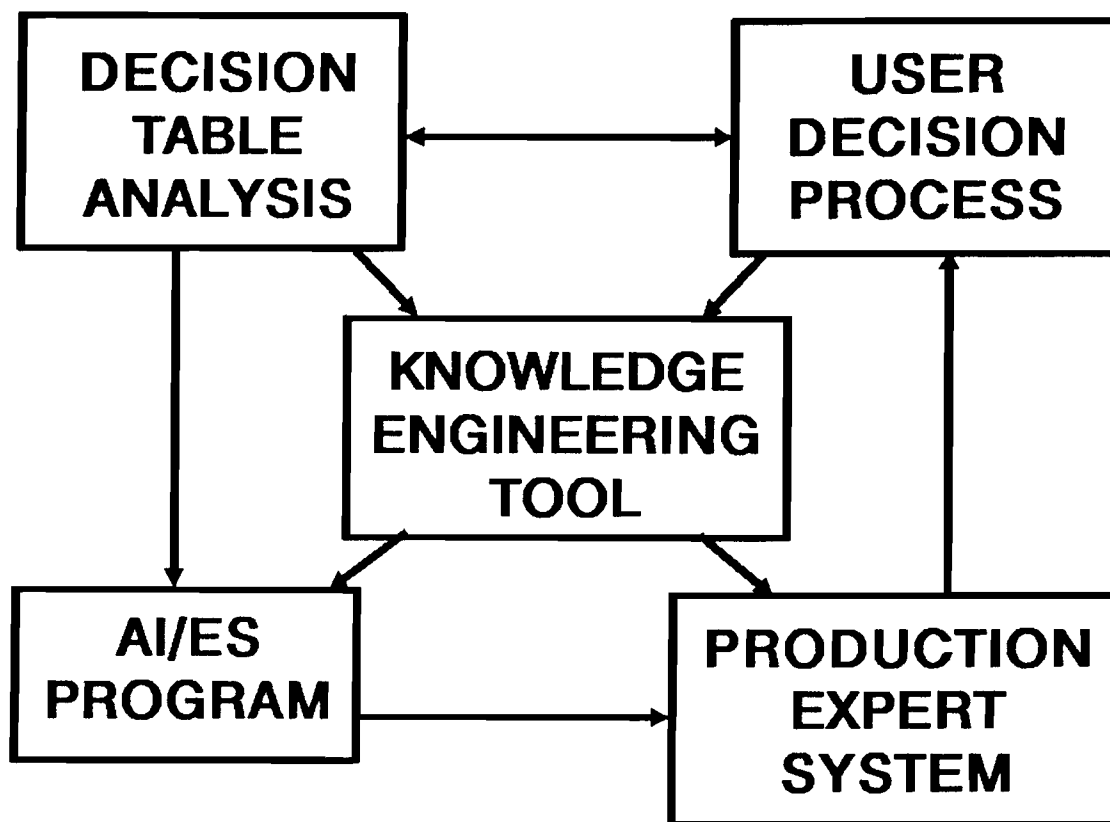


Figure 6. Recommended Approach for Expert System Development.

During concept development, the end users must be identified and their needs and skill levels seriously considered. The transferability of the software development tools, application environment, and product application must be carefully evaluated. Since there are recognized experts in the field for special problem areas, there usually exists a general agreement about the proper solutions and knowledge required to solve these particular problems. Therefore, both the problem to be addressed and expected output must be clearly defined. An important factor in the development process is the rapid prototyping and demonstration of the effectiveness of particular Expert Systems at identified milestones. Demonstrations are highly recommended in the form of smaller-scale problem applications before the completion of the full-scale development. Therefore, the use of "Expert System Shells" is highly recommended. It is also essential to provide some degree of training and to familiarize transportation personnel with the Expert System being developed.

Product Development

The recommended guidelines may also be modified to meet the requirements of different analysis systems. The typical personnel involved in the Expert System development should include the following members: Expert Systems program manager, domain expert, knowledge engineer, and representative end users. However, in many cases, certain individuals may perform more than one function in the system development process. Nevertheless, the function of the end user should always remain autonomous to provide a fair and subjective evaluation of the development. If the roles of the domain expert and knowledge engineer are combined, then a second domain expert should help the research team by providing technical inputs into the design.

The field expert should provide the expert knowledge and heuristics required for developing the Expert System. Depending on the subject area and complexity of the Expert System, the research team may consist of a team of experts. The formal work plan and time schedule should provide a knowledge acquisition plan for documentation of the necessary information about the knowledge database. If knowledge rules are to be used, the expert(s) providing these rules must be identified in a pre-selected time schedule established for interacting with other experts. If confined information, such as the databases, analysis frameworks, or examples are to be included in the knowledge base, they must also be clearly identified to provide better applicability to the problems. The system that contains the realistic facts and production rules representing the expert's knowledge may also be modified after distributing the run-time program to the end users.

The practical Expert System usually consists of the knowledge inference engine or reasoning logic and the production rules or problem-solving knowledge. The run-time version of the Expert System may, or may not, include the development software required to modify the knowledge inference engine of the Expert System. However, the run-time program must provide the capability of allowing users to modify and identify the developed rules of the Expert System to meet local conditions and liability considerations. It is extremely important to provide an easy and intelligent user interface in order to allow users to translate input information into a form that the Expert Systems can

understand and use in the analysis. On the other hand, the similar user interface should also translate the computer reasoning outputs into a form that the user can easily understand.

Implementation Requirements

The successful microcomputer-based Expert System should be implemented with run-time versions that operate on the IBM PC/XT/AT/80386 or compatible microcomputer with MS-DOS or PC-DOS 3.0 or higher operating systems. Figure 7 illustrates the typical functional requirements for microcomputer-based Expert System development. No special programs should be required for production operation. An IBM PC/XT/AT with 10 MB fixed drive and at least 640 KB RAM is usually assumed. The computer program should work with the most popular monochrome or color monitors using a CGA/EGA/VGA/HGC or compatible graphics presentation device.

The knowledge base must be readable and easy to modify in order to expedite future program system maintenance. Mathematical approaches must be clearly documented and knowledge rules must be prepared in English-like syntax. The system should allow the user to explain his problem-solving strategies and how a conclusion was reached by providing a list of the reasons or production rules used. The system must also be capable of operating with incomplete information and default data. Finally, the user should be allowed to review the default data and specific study assumptions being applied in the analysis or evaluation.

A user-friendly program user interface is essential in the Expert System sign so the end user can communicate directly and efficiently with the computer. The expert system must be easy to use so that novice computer users will not be intimidated and can operate it, without assistance, after the system is started. A problem-oriented type query or a series of well thoughtout questions are often preferred for the effective user interface design. The system can be demonstrated to end users during the validation process. Normally, three demonstrations are normally recommended during the system development process.

The "first Demo" should address the human factor considerations to insure that the intended user will use the system after the system is completed. These efforts should also be modified for the same reason. The "second Demo" should be performed after a substantial portion, generally three-fourths, of the production rules have been added, and the system is representative of the final product. The "third Demo" should verify that the system is operable, as intended by the end user. The intended end users should be able to operate the system without being prompted or assisted by the developers. Finally, user documentation describing the program and its operation should include a data dictionary, glossary of terms, and program maintenance manual. The run-time program may also be available for unlimited distribution or, with a royalty arrangement, for the specified copy distribution in order to insure future system maintenance.

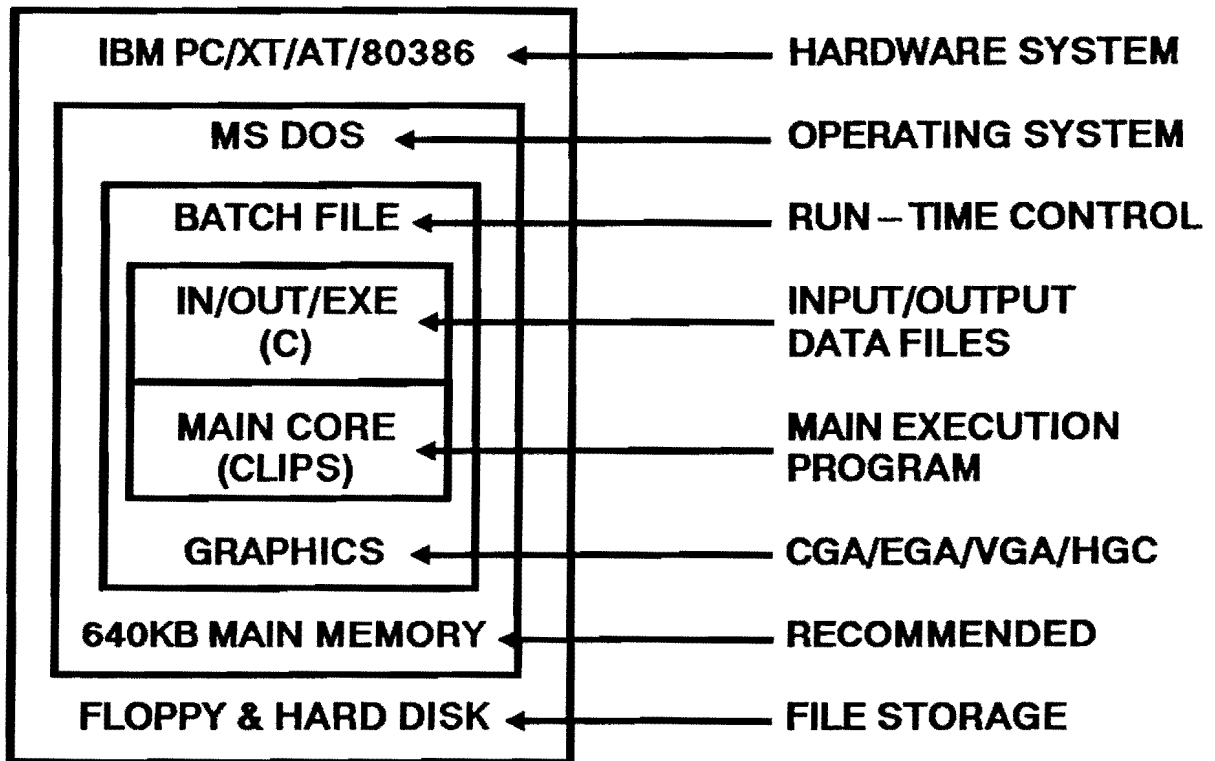


Figure 7. Typical Requirements for Microcomputer-based Expert System Design.

EXPERIENCE IN EXPERT SYSTEM DESIGN

The development of microcomputer-based Expert Systems has many advantages over the conventional computer programs. In particular, they can manipulate the decision-making process in addition to handling data being generated. They can also allow better identification of how human expertise is being applied efficiently in the problem-solving process. Once developed and proven to be useful, these decision-making knowledge can be made more permanent, easier to transfer, easier to document, and more consistent. Microcomputer-based Expert Systems, however, do have some limitations. They are far less creative and less adaptive than human experts in applying the same sets of knowledge to abnormal or complex situations. Current barriers in applying Expert Systems include: difficulty in validation, tort liability issues, and lack of knowledge formalization for problem-solving applications.

Implementing Expert System technology can save a considerable amount of time, money, and investigating efforts by many transportation agencies in the process of "selecting" and "trying" alternative traffic analysis techniques. The system will also provide a basis for future implementation by summarizing existing practices and solution methodologies used by the different transportation agencies. The benefits can result in a cost-effective reduction in urban congestion, fuel consumption, and vehicle emissions, as well as potential traffic accidents. In summary, applying artificial intelligence or machine intelligence is not likely to replace human intelligence. However, "Expert System" development can provide opportunities to apply some successful human expertise to selective repetitive problems through cautious design and well-defined engineering applications.

Determination for Developing Expert Systems

This section covers some important considerations in the overall Expert System design areas. More detailed information is needed for the subsequent research tasks. The following material illustrates those factors which must be addressed to satisfy the study objectives. However, more specific consideration will be given to basic questions: "Is an Expert System feasible for this application?" or "Is the application more appropriate for conventional programs with intelligent input/output interface?"

The feasibility study should try to answer the following questions:

- o Are there experts with the extensive knowledge and experience that can contribute to the knowledge base development in the cited domain?
- o Will these field experts agree on the development of the knowledge base and sustain their augments over time?
- o Can such expert knowledge for efficient problem-solving be reasonably acquired in a cost-effective manner?
- o Is the human expertise scarce, or is this scarcity due to the personnel retirement without replacement?
- o Will a microcomputer-based Expert System be effectively accessed and enhanced by many other users at different locations?
- o Will the implementation benefits exceed the project development and system maintenance costs of developing an expert system?

Based on the initial understanding, the answers to these system design questions indicate that an Expert System development for assisting the freeway incident management is well justified. Therefore, the necessary task is to address specific design elements of an Expert System that may be used in the freeway management center.

In addition, the following considerations must be addressed during the expert system development:

- o Define the scope of the knowledge domain and of the Expert System simulation environment, as well as the level of detail desired in the knowledge base.
- o Formalize the design concepts and recognize knowledge bases in the form of production rules and data base structure.
- o Investigate the available knowledge base programming tools. Relate their attributes to the Expert System to determine what implementation features are desired and compare those associated features with the various available shells. Assess the reliability of the tool and its long-term support facilities.
- o Determine the target microcomputer environment, the hardware/software specifications, and the desired user interface needed for the prototype system design.
- o Estimate the total time and cost expenditures of the efforts needed in the knowledge base acquisition, knowledge enhancements, computer system design, system integration, knowledge verification, prototype testing, and system documentation.

CONCLUSIONS AND RECOMMENDATIONS

Developing and implementing efficient traffic control strategies to combat the urban congestion usually involves very complex and costly study efforts. The decision-making process involves significant investments in the planning, design, hardware acquisition, installation, maintenance, and operations. In most instances, the limitations of time, personnel, and cost, together with the obvious problem of disturbing traffic, preclude extensive field experimentation with alternative traffic control strategies. That is, efficiency of control strategies is always compromised simply because of economical reasons. However, computerized traffic models can be used to evaluate and/or optimize different traffic control strategies prior to committing the full financial resources for actual design and implementation. The development of these computerized models will allow the user to address the problems by maximizing the usage of existing facilities to enable effective and efficient management of urban traffic demands.

However, non-recurring incidents may cause unexpected traffic congestion on freeways, even where surveillance, communication, and control (SC&C) systems are in operation. For example, any accident, truck spill, or stalled vehicle on or near mainlanes can significantly impact system performance and create hazardous situations for involved motorists, approaching commuters, and passing traffic. Therefore, freeway control and operating strategies are essential for successful system operations. As an integral component of the freeway control system, incident management is especially important while freeways are operating near, at, or beyond their physical capacities. Engineers often must make numerous decisions concerning the operational effectiveness and trade-offs during freeway incident management. These control decisions may be bound by either physical constraints, traffic characteristics, or traffic control practices. Off-line computer software can be developed to assist freeway control operators in identifying unique traffic conditions and control strategies which are necessary for determining when and how the computerized traffic control systems should respond.

This study summarizes the design issues, operational considerations, and recommended process needed for expert system development. The study explains the design and implementation issues of the expert system that can assist control operators in identifying and recommending alternative solutions using microcomputer systems. The expert system can be developed as a generalized decision-making assistance tool to help potential users in determining alternative actions that may be needed in order to handle specific freeway incident management problems. The system software can be implemented with the on-line urban highway traffic control systems to automatically identify non-recurring arterial and freeway incidents as well as changes in patterns of recurring congestion. The system development can also lead to the implementation of new generations of traffic control concepts to the integrated freeway corridor systems and arterial street networks in order to automate on-line, real-time traffic responses and management strategies.

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**CORRIDOR ANALYSIS FOR RECONSTRUCTION ACTIVITIES,
TRAFFIC CONTROL STRATEGIES, AND INCIDENT MANAGEMENT TECHNIQUES**

**TASK B. DEVELOPMENT OF EXPERT SYSTEMS FOR
FREEWAY INCIDENT MANAGEMENT**

- LITERATURE REVIEW -

by

**Edmond Chin-Ping Chang, P.E.
Associate Research Engineer**

Research Report Number 1188-2

Research Study Number 2-18-87-1188

**In cooperation with
Texas State Department of Highways and Public Transportation**

February 1991

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

in ²	square inches	645.2	centimetres squared	cm ²
ft ²	square feet	0.0929	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
mi ²	square miles	2.59	kilometres squared	km ²
ac	acres	0.395	hectares	ha

MASS (weight)

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft ³	cubic feet	0.0328	metres cubed	m ³
yd ³	cubic yards	0.0765	metres cubed	m ³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
km ²	kilometres squared	0.39	square miles	mi ²
ha	hectares (10 000 m ²)	2.53	acres	ac

MASS (weight)

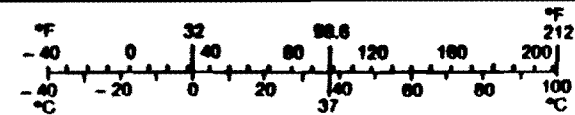
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

This study is to develop a microcomputer, knowledge-based expert system for assisting in urban freeway corridor incident management. Study activities include: literature review, conceptual design, prototype system development, and program documentation. Efforts were made to summarize the information required in the decision-making processes involved in implementing freeway incident management strategies. The study has summarized the Expert Systems Design for representing the freeway incident management techniques. The study has summarized the state-of-the-art expert system development, conceptual design, and system user interface design. A unified development process has been identified for the expert knowledge representation, implementation procedures, and translation system using conventional languages. This report summarizes design considerations, concept design, program implementation, and system operations of microcomputer-based Expert Systems development in the Transportation Engineering Field.

KEY WORDS:

Expert Systems
Freeway Incident Management
Microcomputer
Decision-making

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INTRODUCTION

The application of computerized models for traffic operation and control analysis is one exciting area in the transportation engineering field. Significant efforts have been made in developing different computer tools to analyze urban traffic improvement alternatives. Traditionally, a large time lag exists between the theoretical development of traffic models and their practical field applications. Today, this implementation barrier has been greatly reduced due to the increasing availability of microcomputers and interactive programming techniques. Applications of Artificial Intelligence (AI) have been introduced in many disciplinary areas. Knowledge-Based Expert Systems (KBES) design is a collection of AI analysis procedures and computer programming techniques that enables computers to assist people in analyzing specialized decision-making problems. Expert Systems (ES) application has very high potential for providing the spontaneous responses and decision-making support for routine traffic operations. The development process can assist engineers in selecting proper traffic control strategies to alleviate urban freeway corridor congestion problems.

Texas State Department of Highways and Public Transportation (SDHPT) has begun developing computerized real-time traffic management systems to improve the coordinated operations of freeways, frontage roads, and arterial systems in major urban districts over the next 10 years. However, the non-recurring incidents still may cause unexpected congestion on freeways, even where surveillance, communication, and control (SC&C) systems are in operation. For example, any accident, truck spill, or stalled vehicle on or near mainlanes can significantly impact system performance and create hazardous situations for involved motorists, approaching commuters, and passing traffic. Therefore, freeway control and operating strategies are essential for successful system operations.

As an integral component of the freeway control system design, incident management is especially important while freeways are operating near, at, or beyond their physical capacities. Engineers often must make numerous decisions concerning the operational effectiveness and trade-offs managing the freeway incident. These control decisions may be bound by either physical constraints, traffic characteristics, or control practices. Off-line computer software can be developed to assist freeway control operators in identifying unique traffic conditions and control strategies necessary for determining when and how computerized traffic control systems should respond.

STUDY OBJECTIVES

This study was conducted by the Texas Transportation Institute (TTI) as part of the Texas State HP&R research under HPR 2-10-87-1188, "Corridor Analysis for Reconstruction Activities, Traffic Control Strategies, and Incident Management Techniques - Task B. Development of Expert Systems for Freeway Incident Management." The study task is to develop a microcomputer-based, knowledge-based Expert System for urban freeway corridor incident management. The overall effort includes literature reviews, conceptual designs, a prototype system, and program documentation. The system was developed as an alternative decision-making tool to assist users in

EXPERT SYSTEM APPLICATIONS

Since World War II, scientists have developed the Artificial Intelligence technology (AI) to simulate human knowledge and behavior in order to improve the decision-making process. Successful applications have been made in robotics design, natural language processing, problem-solving, and Expert Systems. Among these developments, the Expert System offers the most promising applicability to traffic engineering problems.

KNOWLEDGE-BASED EXPERT SYSTEMS

As indicated in Figure 1, Artificial Intelligence (AI), Knowledge-Based Expert Systems (KBES), and Expert System design (ES) are results of recent AI developments. A Knowledge-Based Expert System (KBES) is a collection of AI techniques and decision-making analyses. AI/KBES applications require specific knowledge which permits engineers to interact with traffic characteristics, theoretical or simulation results, and specific hypotheses of traffic control measures. Since explicit algorithms for traffic analysis are usually not available and traditional programs may provide only restricted problem-solving and limited analysis, structured guidelines for most engineering problems are suitable for the KBES development.

Components in Expert System Design

There are five main elements involved in Expert System design (ES). They are the (1) Expert System, (2) Domain Expert, (3) Knowledge Engineer, (4) Expert System Building Tool, and (5) End User. Figure 2 demonstrates these AI/ES components and their corresponding relationships. The "Domain or Area Expert" is a knowledgeable person who produces solutions to problems in a particular field. The "Knowledge Engineer" is usually a person with a computer and AI background. The knowledge engineer interviews the domain expert, organizes the knowledge, decides how it should be represented, and assists in the program development. The "Expert System Building Tool" is the programming environment used by the knowledge engineer or computer programmer to build the Expert System. The "User or End User" is the person for whom the Expert System was developed. The user may be a traffic engineer debugging the Expert System building tool or AI language, a knowledge engineer refining the existing knowledge, a domain expert adding new knowledge to the system, the end-user relying on the system for advice, or a clerical person adding information to the knowledge engineering data base. A knowledge engineer can convert a domain expert's specialized knowledge into sets of IF-THEN-AND-ELSE rules and ultimately implement the Expert System into machine instructions.

Expert System Programming

The recent evolution in AI/ES has led to more application-oriented system developments. Accordingly, AI/ES has been directed into three areas: Expert Systems, natural language queries, and AI languages. Many pre-identified factors and rules are required to determine the choices among the different design alternatives. The typical traffic signal phase design includes a combination of (1) algorithmic methods, (2) knowledge inference capabilities, and (3) knowledge base of a traffic engineer. The first

EXPERT SYSTEMS ARE KNOWLEDGE – BASED SYSTEMS

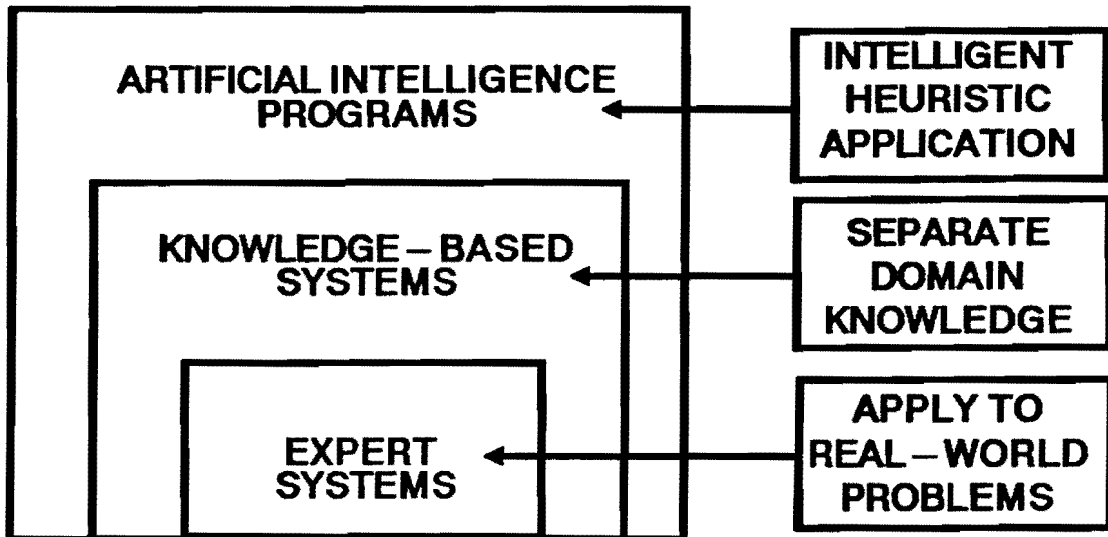


Figure 1. Relationships Among AI, KBES, and ES.

CONDITIONS	CHOICE (TRUE OR FALSE)	
	LEFT TURN DEMAND > 2 PER CYCLE	TRUE
ARE THERE TWO OPPOSING LANES?	TRUE	FALSE
IS VOLUME CROSS PRODUCT > 100,000	TRUE	FALSE
ACTIONS		
1. SUGGEST USING PROTECTED PHASE	X	
2. CHECK OTHER INPUT VARIABLE		X

Figure 3. Example of A Typical Decision Table.

the human expert's expertise in making judgments under various conditions. They "clone" experts by capturing knowledge that is perishable, scarce, and vague and difficult to apply, distribute, or accumulate. Expert Systems afford cost-effective services in areas that require symbolic processing of knowledge and rule-of-thumb judgmental problem-solving methods. An initial application of Expert Systems was in the diagnosis and treatment of human physical disorders; the basic purpose of these systems was to determine what the symptoms indicated and what remedial treatment was appropriate.

Expert System technology is one of the most successful branches of Artificial Intelligence (AI) field. Other branches of AI technology include robotics, voice recognition and synthesis, and vision. Expert System technology started to emerge as a potent force in 1977 when Professor Feigenbaum of Stanford University stated that the problem-solving power of a computer program comes from the knowledge it processes in a given domain, not just from the programming techniques and formalism it contains. However, the programming techniques and formalism may also determine the eventual destiny of an Expert System.

Basic Design Concept

The basic structure of an Expert System resembles the conventional software program, as shown in Figure 4. Its major components are a knowledge base, inference engine, user interface mechanism including explanation facility and data. Major components of conventional programs are data, database, code, the interpreter/compiler, and sparse user-interface mechanism, but the interpreter may be embedded in the system. Expert Systems are capable of providing the symbol processing, knowledge inferencing, and explaining.

Simulation Programs and Expert Systems

Because of the different programming techniques being used, Expert Systems can be considered an advanced form of representation for programming specific decision-making knowledge for various potential applications. The terminology of Expert Systems can be referred, on a one-to-one basis, to the terminology of the conventional software programs as shown in Table 1. For example, a knowledge base of an Expert System can contain decision rules or IF-THEN rules, and facts that match the program code of a software. However, a knowledge base does not correspond to a database. A knowledge base is executable, but a database is not. A database can only be queried and updated. Like an interpreter that evaluates a program in the source code and executes the statements, the inference engine takes the statements in a knowledge base and executes them because the inference engine contains search control and substitution mechanisms.

On the other hand, AI/ES programming languages, such as LISP, Prolog, CLIPS, and Smalltalk, can also be used to build an entire computer program package with a customized knowledge base, inference engine, and user-interface. This package is commonly called an Expert System shell, or knowledge engineering tool. Expert System shells are usually used to build Expert Systems are high-level programming languages with many unconventional conveniences, such as reasoning explanation and tracing facilities.

TABLE 1. ANALOGY BETWEEN SYSTEMS AND CONVENTIONAL SOFTWARE PROGRAMS.

COMPUTER APPLICATIONS	EXPERT SYSTEMS	CONVENTIONAL PROGRAMS
APPLICATIONS	Expert Systems	Program Software
MAIN BODY	Knowledge Base	Computer Program
MECHANISM	Inference Engine	Language Interpreter
DEVELOPMENT TOOL	Expert System Tool Expert System Shell	Programming Languages
INDIVIDUAL	Knowledge Engineer	Software Engineer Computer Programmer

Frames or Units A frame or unit contains the hierarchies of objects or components. The attributes of objects can be assigned, inherited from another frame, or computed through analysis procedures or other programs. The attributes or elements are filled in "Slots" of a frame. The following example shows a sample unit representing the 8-Phase Pretimed Signal Control used to describe a particular signalized intersection.

Frame name:	8-Phase Pretimed Signal Control
Installed to:	Intersection
Inherited from:	Signal Control
Created by:	03-03-89
Modified by:	04-07-89
Slot: Capacity	Type: Real number, value: 0 to 1800 VPHPL
Slot: Main-component	Type: Alphanumeric, value: STREET NAME
Slot: USAGE	Type: Alphabet, value: (inherited from ES)

Logic Logic expressions consist of predictions and values to assess facts of the real world. A predicate is a statement concerning an object, such as the kind-of (8-Phase Pretimed Control, Signal Control or SC).

This representation scheme can be interpreted as an 8-phase pretimed control commonly used in signal control. The object can be either a constant or a variable that may change over time. A predicate may have one or more arguments that are the objects it describes. In the example of a signal timing control advisor, the other kind of logic expression is appropriate for asking questions such as the following:

? - (Matrix, X): - (X), SC (X), operations
(X, excellent).

The above question can be interpreted as "Show me all possible ASD installations in a given system that can be implemented with only pretimed control that are considered to possess excellent operation."

Inference Engine Once the knowledge base can be somewhat obtained, it can then be executed by different users through a reasoning and search control mechanism to solve similar problems. The most common reasoning method in Expert Systems is the application of the following simple logic rule, predicate calculus, or modus ponens.

IF A is true, and IF A THEN B is true, then B is true.

To prove the hypothesis "You are going to be late," given the facts and knowledge rules, Facts 1 and 2, and Rules 1 and 2, the backward chaining process must be applied to determine whether the premises or subhypotheses match the facts. Rule 2, which contains the conclusion "You are going to be late," would be fired first to determine whether the premises match the actual situation. Since the knowledge base does not contain the facts in Rule 2's premises, "The car is not running" and "you have no cash," "the car is not running" becomes the first subhypothesis. Rule 1 will then be fired to assert whether the premises "you lost the key" and "the gas tank is empty" match the facts. Because the Facts 1 and 2 in the knowledge base match the premise of Rule 1, the subhypothesis "the car is not running" is proven; however, the system still has to prove "you have no cash," which is not contained in the knowledge base and cannot be asserted through rules because no rule is related to it. The system will then ask the user "IS IT TRUE THAT: you have no cash?" If the answer is "Yes," then the second subhypothesis is also proven, and the original hypothesis is proven as well, concluding "You are going to be late."

Man-Machine Interface The man-machine interface mechanism produces a dialogue between the computer and user. The current Expert System can be equipped with templates, menus, mice, or natural language to facilitate its use and an explanation module to allow the user to challenge and examine the reasoning process underlying the system's answers. Menus are groups of simplified instructional statements that appear on the computer screen and can be selected by pushing designated buttons, using a mouse, or designated keys on the keyboard. The user does not need to type instructions. A semi-natural or fully natural language interface is more sophisticated than a menu interface; it allows computer systems to accept inputs and produce outputs in a language closer to a conventional language, such as English. Several Expert Systems incorporate primitive forms of natural language into their user interface to facilitate knowledge base developments. Explanation modules generate output statements of Expert Systems in a language that can be understood by non-computer user professionals.

Uncertainty of Knowledge Rules, obtained from human experts, are sometimes uncertain; they describe some rules as "maybe," "sometimes," "often," or "not quite certain about the conclusion." The users may use the "Uncertainty" or "Fuzzy Set Logic" to handle these statements. Furthermore, like human experts, Expert Systems may have to draw inferences based on incomplete information, such as unavailable, unknown, or uncertain information. Unavailable or unknown information can be resolved by allowing rules to fail if the information needed is critical in evaluating different premises, i.e., the information needed is in the condition (IF) statements connected by AND. When IF statements are connected by OR, the absence of one or more of them will not affect the outcome of the rule. Although the reliability of knowledge inserted into the knowledge base is questionable, the ability to represent facts not guaranteed to be 100% accurate is important to Expert Systems.

The likelihood that a fact is true is called the fact's Certainty Factor (CF). In most Expert Systems, this number is between 0 and 1, where 0 represents no confidence in the fact, and 1 represents complete trust in the validity of the fact. For example, you may assign a CF of 1.0 to:

For example, the commonly recognized values below can also be used as a general design guideline for selecting the needed confidence values and the related level of certainty in analyzing particular problems.

Level of Certainty	Confidence Value
Confident it is true	100
Possibly true	75
Not sure	50
Possibly false	25
Confident it is false	0

Confidence can also be placed in the logical assertion or conclusion of the production rule used by the knowledge engineer. If omitted, the conclusion is automatically assigned a confidence value of 100. The THRESHOLD statement allows users to specify the lowest level of confidence needed for the INSIGHT 2+ to reach a particular conclusion or goal. When running knowledge base under INSIGHT 2+, and CONFIDENCE has been enabled (ON), the user will be prompted to input confidence levels. If no value is assigned, the default value of 50 will automatically be used by INSIGHT 2+. For example:

```

TITLE
.....
THRESHOLD = 60
.....
CONFIDENCE ON
.....
RULE  To tell if the Actuated Control is Recommended
IF    The intersection has volume variations
AND   The intersection has high-type control strategy
THEN  The main/cross street volume variations is high CONFIDENCE 85
AND   The degree of saturation (DOS) is under 0.80 CONFIDENCE 50
END

```

Probability in EXSYS EXSYS allows the user to show the degree of belief in a given fact or event through the use of "Certainty Factors." Certainty factors can be used in conjunction with rules and attached to conclusions to be recommended to a user. If there is more than one answer to a given problem, EXSYS can attach a certainty factor to each answer and rearrange the answers in order of certainty factors.

In EXSYS, certainty factors can be assigned with the following scales: 0 or 1, 0 to 10, and 0 to 100. When the 0 or 1 scale is used, the 0 corresponds to the absolute meaning that the solution should be rejected, and the 1 represents an absolute meaning that the solution be accepted as true. For the 0 to 10 scale, 0 represents absolutely false and 10 absolutely true; the numbers in-between are used to represent degrees of certainty. The 0 to 100 scale is similar to the 0 to 10 scale, except that the range is 0 to 100. This scale provides granularity in providing the certainty specification.

These two examples, listed above, are simple illustrations of the possible applications of the "Fuzzy Theory" that may be applied in the expert system design. The uses of probability, confidence factor, or certainty factor can provide the key solution that is often needed to resolve the complexity and possible conflict in opinion when developing suitable production rules for intersection signal design.

SUMMARY OF EXPERT SYSTEM DESIGN

- o An expert system mimics experts or specialists (i.e., in medicine or computer configuration).
- o The power of an expert system relies more in the knowledge base and not in the programming technique.
- o The principal components of these current systems are knowledge base, inference engine, and man-machine interface.
- o The knowledge base contains facts and production rules that comprise an expert's expertise.
- o Three commonly used methods for encoding knowledge, facts and relationships are rules, frames, and logical expressions.
- o Inference engines are relatively simple; the two most commonly used methods are backward chaining and forward chaining.
- o User interface is often a weak but critical element in Expert Systems; many Expert Systems are equipped with menus and explanation modules to allow users to examine their output statements.

EXPERT SYSTEMS IN TRANSPORTATION ENGINEERING

Expert Systems offer an effective means of utilizing the specific knowledge and experience of recognized professionals. The major advantages of developing Expert Systems are that they permit the systematic examination, organization, and application of specific human knowledge to particular problem areas for use by other users. At present, there is much interest and activity in highway applications. The major prototype Expert System development in transportation includes: network scheduling, project management, system management, software selection, alternative evaluation, route location, site planning, landslide evaluation, material analysis, intersection design, parking facilities, crash barriers, and structural design. This development also includes signal systems, positive guidance, traffic management, intersection performance analysis, safety evaluation, pavement maintenance and rehabilitation, bridge repair, pavement management, and other AI/ES applications.

Several research studies have been conducted to survey the state-of-the-art Expert System development and implementation in the transportation engineering field. Ritchie surveyed the uses of Expert Systems in the field of transportation engineering and identified a number of systems that were either operational or under development in 1986. Since the completion of his survey, additional research work has begun; however, much of it is still in the conceptual design or early prototype stage. Stone, et al in 1988, summarized recent progress of the Expert System development for applications in highway engineering.

	INTERPRETATION	DIAGNOSIS/ MONITORING	PREDICTION	PLANNING/ DESIGN
ADMINISTRATION AND MANAGEMENT	<ul style="list-style-type: none"> o REGULATIONS o CONTRACTS & SPEC'S o LEGAL LIABILITY 	NOT AVAILABLE YET	NOT AVAILABLE YET	NOT AVAILABLE YET
HIGHWAY PLANNING	<ul style="list-style-type: none"> o ZONING o SITE REVIEW o NETWORK MODELING ASSISTANCE 	<ul style="list-style-type: none"> o SYSTEM DEFICIENCIES 	<ul style="list-style-type: none"> o TRAFFIC VOLUMES o LAND USES o TRIP GENERATION 	<ul style="list-style-type: none"> o BUDGETING o PROJECT SCHEDULING o PROGRAM PLANNING
HIGHWAY DESIGN	<ul style="list-style-type: none"> o TECHNICAL STANDARD o ENVIRONMENTAL GUIDELINES 	<ul style="list-style-type: none"> o DESIGN REVIEW o CADD "HELP" 	NOT AVAILABLE YET	<ul style="list-style-type: none"> o CORRIDOOR SELECTION o ROUTE SELECTION o NETWORK ASSIGNMENT o INTERACTIVE INTERSECTION DESIGN
OPERATION AND CONTROL	<ul style="list-style-type: none"> o SIGNAL CONTROL o WARRANTS o ACCIDENTS ANALYSIS o CAPACITY ANALYSIS 	<ul style="list-style-type: none"> o SIGNAL CONTROL o ACCIDENT RECONSTRUCTION o INCIDENT IDENTIFICATION 	<ul style="list-style-type: none"> o SIGNAL WARRANTS o INCIDENT PREDICTION o FREEWAY INCIDENT MANAGEMENT 	<ul style="list-style-type: none"> o SIGNAL CONTROL o WORK ZONES o EVACUATION PLANNING
MAINTENANCE AND REHABILITATION	<ul style="list-style-type: none"> o PAVEMENT INSPECTION 	<ul style="list-style-type: none"> o BRIDGE INSPECTION o MATERIALS TESTING 	<ul style="list-style-type: none"> o MAINTENANCE FORECAST 	<ul style="list-style-type: none"> o MAINTENANCE SCHEDULING o MATERIALS SELECTION

Figure 5. Survey of Expert System Development in Transportation Engineering.

Operation and Control

Signal Systems Permissive, exclusive, and exclusive/permissive left turn phases may be used to allow vehicles to turn left. Edmond Chang of the Texas Transportation Institute is developing an Expert System which facilitates the left turn phase selection process. In another effort, Dr. Chang is applying Expert Systems to make traffic signal control analysis more efficient for arterials and arterial networks. A. E. Radwan, M. Goul, and T. O'Leary of the Arizona State University Center for Advanced Research in Transportation are building a prototype Expert System for signal system control. They are basing the system on Chapter 9 of the Highway Capacity Manual and appropriate traffic engineering expert heuristics.

Choosing alternative control logics for adaptive signal control is the goal for the Expert System of Feng-Bor Lin, Department of Civil and Environmental Engineering, Clarkson University. Nicholas Vlahos of the Transportation Center of Northwestern University has designed a front-end Expert System for TRANSYT-7F. When completed, the system will use Expert System concepts and management decision support theories to help traffic analysts incorporate qualitative factors and constraints not considered in TRANSYT-7F. Adolf May of the University of California, Berkley, is exploring the feasibility of processing real-time traffic data for an adaptive controller at isolated intersections. Chris Hendrickson and C. Zozaya-Gorostiza used OPS5 to program TRALI, a signal setting aid for isolated intersections.

Positive Guidance Peter Parsonson and Syed Hussain of Georgia Tech are gathering heuristic knowledge, caveats, and shortcuts that experts use to identify where positive guidance is required. They will use INSIGHT 2+ to incorporate a knowledge base for locating and designing guidance measures.

Traffic Management Michael Demetsky and Ardeshir Faghri of the Virginia Highway and Transportation Research Council in Charlottesville, Virginia, have applied EXSYS to traffic management in road construction work zones. Al Santiago of USDOT/FHWA is evaluating the application of various artificial intelligence approaches to urban traffic management.

Intersection Performance Analysis Chris Hendrickson of Carnegie-Mellon University is using semantic nets and frames to represent the intersection performance analysis for transportation networks and complex procedures, such as those in the Highway Capacity Manual.

Safety The University of Toronto is sponsoring Mark Montgomery in his effort to diagnose safety improvement problems at signalized intersections using Expert System concepts.

Maintenance and Rehabilitation

Pavement Maintenance and Rehabilitation Because of the expense involved in maintaining and rehabilitating roadway surfaces, much effort has been expended in this area. Carl Haas of Carnegie-Mellon used OPS5 to develop PRESERVER. This system analyzes pavement distress data and suggests routine maintenance. Stephen Ritchie used EXSYS to develop SCEPTER to assist highway engineers in

RECENT PROGRESS AND FUTURE IMPLICATIONS

This survey represents the current developments and application interests in Expert System field for highway engineering, especially in traffic operation and control, and pavement maintenance and rehabilitation areas. As shown previously in Figure 5, applications are just beginning to emerge in highway planning and design, while substantive efforts have yet to begin in administration and management. The current development suggests that Expert Systems for highway engineering are being developed and used in areas where expertise is well known and codified, i.e., the lower half of the figure. This is understandable since a "knowledge" engineer's goal of encoding information is made much easier if he can use standard, perhaps written, design procedures, guidelines, and warrants. When the expertise is more subjective, the knowledge is inherently more difficult to capture.

Future Expert System development will remain very active in the "Operation and Control" and "Maintenance and Rehabilitation" functions of highway engineering. As Expert Systems for signalization and pavement maintenance reach maturity and demonstrate their value, institutional barriers will be overcome and more practical applications will emerge. As Figure 6 suggests, realistic future expectations include new Expert Systems that will analyze accident and capacity data used to identify candidate locations for improvement, reconstruct accidents and diagnose the cause, and develop traffic marking and signing strategies according to accepted standards.

A growing number of applications in highway design will also be apparent. Already there are initial efforts in intersection, noise barrier, and crash barrier designs. The future should bring additional Expert Systems for pavement design, lighting, and sign layout. Expert Systems may also begin to appear as background advisors or "help" functions in standardized reviews and computer-aided design. Highway planning appears to be a particularly fruitful area for Expert System development. The previous section identifies a range of potential applications. Future uses for Expert Systems in the administration and management functions of highway engineering are somewhat unclear. It is expected that Expert Systems developed in the broader field will be adopted and customized for practical implementation.

RECOMMENDED EXPERT SYSTEM APPROACH

Expert Systems can effectively utilize the specific knowledge and experiences of recognized professionals. The major advantages of developing Expert Systems are that they permit the systematic examination, organization, and application of specific human knowledge in particular problem areas.

Design Guidelines

There are two important design factors for the successful development of Expert Systems in transportation related applications. First, there must be a firm commitment of research support by management. This will encourage development and practical implementation of an Expert System and assure its success. In addition, there must be close interaction within the organization during the planning and design phases of the System in order to develop

RECOMMENDED AI/ES APPROACH

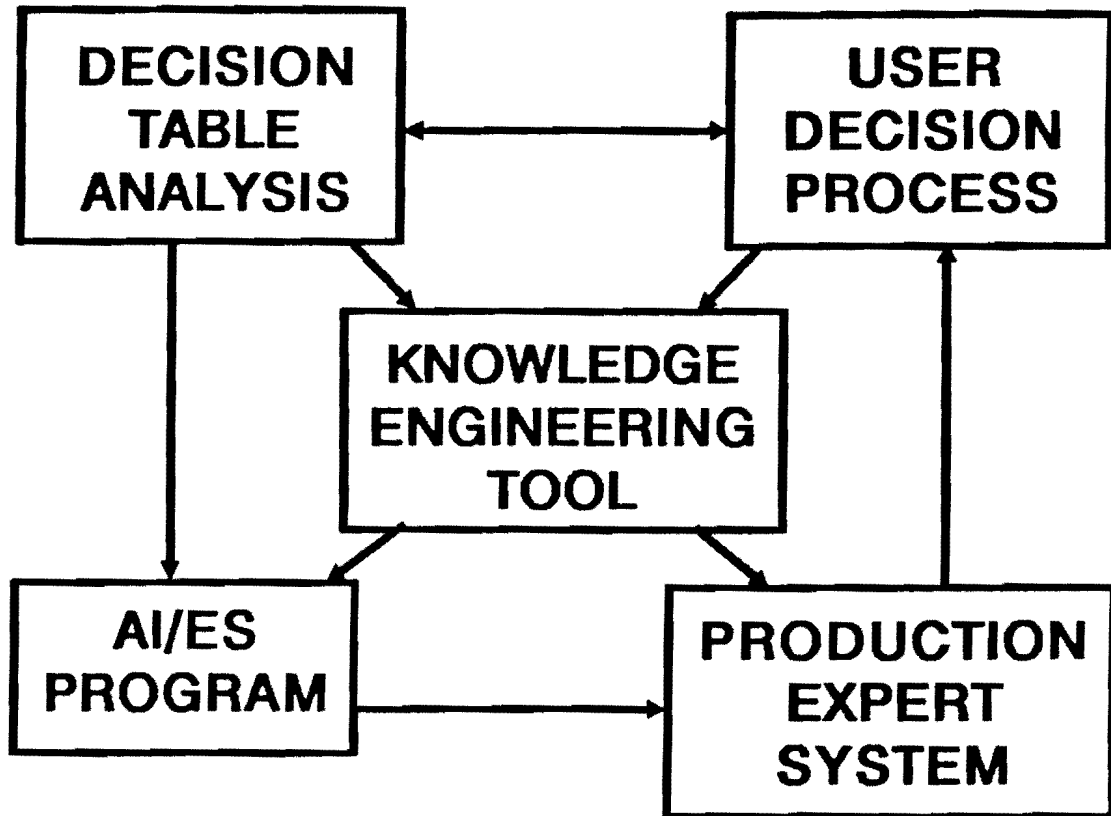


Figure 6. Recommended Approach for Expert System Development.

understand and use in the analysis. On the other hand, the similar user interface should also translate the computer reasoning outputs into a form that the user can easily understand.

Implementation Requirements

The successful microcomputer-based Expert System should be implemented with run-time versions that operate on the IBM PC/XT/AT/80386 or compatible microcomputer with MS-DOS or PC-DOS 3.0 or higher operating systems. Figure 7 illustrates the typical functional requirements for microcomputer-based Expert System development. No special programs should be required for production operation. An IBM PC/XT/AT with 10 MB fixed drive and at least 640 KB RAM is usually assumed. The computer program should work with the most popular monochrome or color monitors using a CGA/EGA/VGA/HGC or compatible graphics presentation device.

The knowledge base must be readable and easy to modify in order to expedite future program system maintenance. Mathematical approaches must be clearly documented and knowledge rules must be prepared in English-like syntax. The system should allow the user to explain his problem-solving strategies and how a conclusion was reached by providing a list of the reasons or production rules used. The system must also be capable of operating with incomplete information and default data. Finally, the user should be allowed to review the default data and specific study assumptions being applied in the analysis or evaluation.

A user-friendly program user interface is essential in the Expert System sign so the end user can communicate directly and efficiently with the computer. The expert system must be easy to use so that novice computer users will not be intimidated and can operate it, without assistance, after the system is started. A problem-oriented type query or a series of well thoughtout questions are often preferred for the effective user interface design. The system can be demonstrated to end users during the validation process. Normally, three demonstrations are normally recommended during the system development process.

The "first Demo" should address the human factor considerations to insure that the intended user will use the system after the system is completed. These efforts should also be modified for the same reason. The "second Demo" should be performed after a substantial portion, generally three-fourths, of the production rules have been added, and the system is representative of the final product. The "third Demo" should verify that the system is operable, as intended by the end user. The intended end users should be able to operate the system without being prompted or assisted by the developers. Finally, user documentation describing the program and its operation should include a data dictionary, glossary of terms, and program maintenance manual. The run-time program may also be available for unlimited distribution or, with a royalty arrangement, for the specified copy distribution in order to insure future system maintenance.

EXPERIENCE IN EXPERT SYSTEM DESIGN

The development of microcomputer-based Expert Systems has many advantages over the conventional computer programs. In particular, they can manipulate the decision-making process in addition to handling data being generated. They can also allow better identification of how human expertise is being applied efficiently in the problem-solving process. Once developed and proven to be useful, these decision-making knowledge can be made more permanent, easier to transfer, easier to document, and more consistent. Microcomputer-based Expert Systems, however, do have some limitations. They are far less creative and less adaptive than human experts in applying the same sets of knowledge to abnormal or complex situations. Current barriers in applying Expert Systems include: difficulty in validation, tort liability issues, and lack of knowledge formalization for problem-solving applications.

Implementing Expert System technology can save a considerable amount of time, money, and investigating efforts by many transportation agencies in the process of "selecting" and "trying" alternative traffic analysis techniques. The system will also provide a basis for future implementation by summarizing existing practices and solution methodologies used by the different transportation agencies. The benefits can result in a cost-effective reduction in urban congestion, fuel consumption, and vehicle emissions, as well as potential traffic accidents. In summary, applying artificial intelligence or machine intelligence is not likely to replace human intelligence. However, "Expert System" development can provide opportunities to apply some successful human expertise to selective repetitive problems through cautious design and well-defined engineering applications.

Determination for Developing Expert Systems

This section covers some important considerations in the overall Expert System design areas. More detailed information is needed for the subsequent research tasks. The following material illustrates those factors which must be addressed to satisfy the study objectives. However, more specific consideration will be given to basic questions: "Is an Expert System feasible for this application?" or "Is the application more appropriate for conventional programs with intelligent input/output interface?"

The feasibility study should try to answer the following questions:

- o Are there experts with the extensive knowledge and experience that can contribute to the knowledge base development in the cited domain?
- o Will these field experts agree on the development of the knowledge base and sustain their augments over time?
- o Can such expert knowledge for efficient problem-solving be reasonably acquired in a cost-effective manner?
- o Is the human expertise scarce, or is this scarcity due to the personnel retirement without replacement?
- o Will a microcomputer-based Expert System be effectively accessed and enhanced by many other users at different locations?
- o Will the implementation benefits exceed the project development and system maintenance costs of developing an expert system?

CONCLUSIONS AND RECOMMENDATIONS

Developing and implementing efficient traffic control strategies to combat the urban congestion usually involves very complex and costly study efforts. The decision-making process involves significant investments in the planning, design, hardware acquisition, installation, maintenance, and operations. In most instances, the limitations of time, personnel, and cost, together with the obvious problem of disturbing traffic, preclude extensive field experimentation with alternative traffic control strategies. That is, efficiency of control strategies is always compromised simply because of economical reasons. However, computerized traffic models can be used to evaluate and/or optimize different traffic control strategies prior to committing the full financial resources for actual design and implementation. The development of these computerized models will allow the user to address the problems by maximizing the usage of existing facilities to enable effective and efficient management of urban traffic demands.

However, non-recurring incidents may cause unexpected traffic congestion on freeways, even where surveillance, communication, and control (SC&C) systems are in operation. For example, any accident, truck spill, or stalled vehicle on or near mainlanes can significantly impact system performance and create hazardous situations for involved motorists, approaching commuters, and passing traffic. Therefore, freeway control and operating strategies are essential for successful system operations. As an integral component of the freeway control system, incident management is especially important while freeways are operating near, at, or beyond their physical capacities. Engineers often must make numerous decisions concerning the operational effectiveness and trade-offs during freeway incident management. These control decisions may be bound by either physical constraints, traffic characteristics, or traffic control practices. Off-line computer software can be developed to assist freeway control operators in identifying unique traffic conditions and control strategies which are necessary for determining when and how the computerized traffic control systems should respond.

This study summarizes the design issues, operational considerations, and recommended process needed for expert system development. The study explains the design and implementation issues of the expert system that can assist control operators in identifying and recommending alternative solutions using microcomputer systems. The expert system can be developed as a generalized decision-making assistance tool to help potential users in determining alternative actions that may be needed in order to handle specific freeway incident management problems. The system software can be implemented with the on-line urban highway traffic control systems to automatically identify non-recurring arterial and freeway incidents as well as changes in patterns of recurring congestion. The system development can also lead to the implementation of new generations of traffic control concepts to the integrated freeway corridor systems and arterial street networks in order to automate on-line, real-time traffic responses and management strategies.

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