SIGNAL DESIGN AT ISOLATED INTERSECTIONS USING EXPERT SYSTEMS TECHNOLOGY

A. Faghri

Department of Civil Engineering
University of Delaware
Newark, Delaware 19716, USA

Abstract The procedural steps for developing an expert system for designing signals at isolated intersections are described and the most important development issues for each step are discussed. The steps include problem analysis and definition, preliminary prototype specification, knowledge acquisition strategy development, prototype development plan, knowledge extraction, knowledge representation, tool/paradigm selection, prototype development, testing and refinement, and verification and validation. The result is a user friendly expert system that can be used by practicing engineers to design signalization for isolated intersections; for intersections that already exist but no control configuration such as detector placement, phasing, or timing has not been determined yet; and, for intersections that already have all the required features but need to be updated and enhanced.

Key Words Expert Systems, Isolated Intersections, Design, Software

چکیده دراین مقاله کاربرد تکنولوژی سیستمهای هوشیار در رابطه با طراحی و برنامه ریزی تقاطع های ترافیکی مجزا، شرح داده شده است. مسائل مهمّی که در طراحی این برنامه کامپیوتری توضیح داده شده مشتمل بر آنالیز کلی، طرح اولیه، کسب کردن علم طراحی تقاطع ها، انتخاب نرم افزار و آزمایش سیستم ساخته شده می باشد. این نرم افزار می تواند برای طراحی تقاطع های مجزا توسط مهندسین ترافیک مورد استفاده واقع شود.

INTRODUCTION

Current methods for design of signalization at individual intersections can be classified under three categories: manual, algorithmic, and computerized.

- Manual methods consist of publications, charts, and tables used by experienced engineers who use these techniques along with their own judgement, heuristics and rules of thumb to design control for different intersections.
- Algorithmic methods are mathematical and logical procedures that have been developed by researchers to achieve optimum settings for traffic signal timing at isolated intersections. A prominent example is chapter 9 of the 1985 Highway Capacity Manual (HCM) [1].
- Computerized methods are automated versions of these algorithmic methods to which simulation and optimization models are added. These models provide a more quantifiable means of assessing and evaluating proposed improvements than their predecessors.

There is currently no truly comprehensive tool for isolated intersection signal design. While the HCM does provide a detailed procedure for the timing of signals at isolated intersections, it does not, have even, provide an optimum solution. Furthermore, the HCM software [1] developed by the Federal Highway Administration (FHWA) does not offer signal timing output directly.

While recent advances represent significant improvements which enhance the appeal to and usage of these models, they do not provide the decision makers with a direct response to their questions. Furthermore, there remains the need for highly skilled professional engineers to interpret the results and translate them into design or policy decisions. Finally there is no organized and readily accessible inventory of current knowledge and experience which can be used to guide the decision maker.

Potential Expert Systems Applications

Advances in Expert Systems (ES) offer a potential for solving and ameliorating the above-mentioned shortcomings and producing a new "user friendly" intersection design tool.

Some potential applications that employ ES techniques might improve the current design methodologies and evaluation models. These techniques can provide knowledge bases, intelligent interfaces, and knowledge based intersections design decision systems. The core of all Expert Systems is a knowledge base which contains information describing a specified "domain".

The lack of determinancy (i. e. closed form solutions) in many signal control design problems is beyond the capability of present algorithmic, signalization design tools. Knowledge based expert systems offer a new approach for solving and analyzing non-deterministic problems for the transportation engineers and managers. Such an expert system would include an explanation module, knowledge acquisition module, context (also called workspace), knowledge base, and inference machine (Figure 1).

Overview of the System

The approach employed for the expert system reported here is based upon the following principles.

- It is generally acknowledged that fully traffic actuated signal controllers offer the most effective control of traffic at isolated intersections over a wide range of traffic demand conditions.
- They are particularly effective over low traffic volume conditions where there are fluctuations in

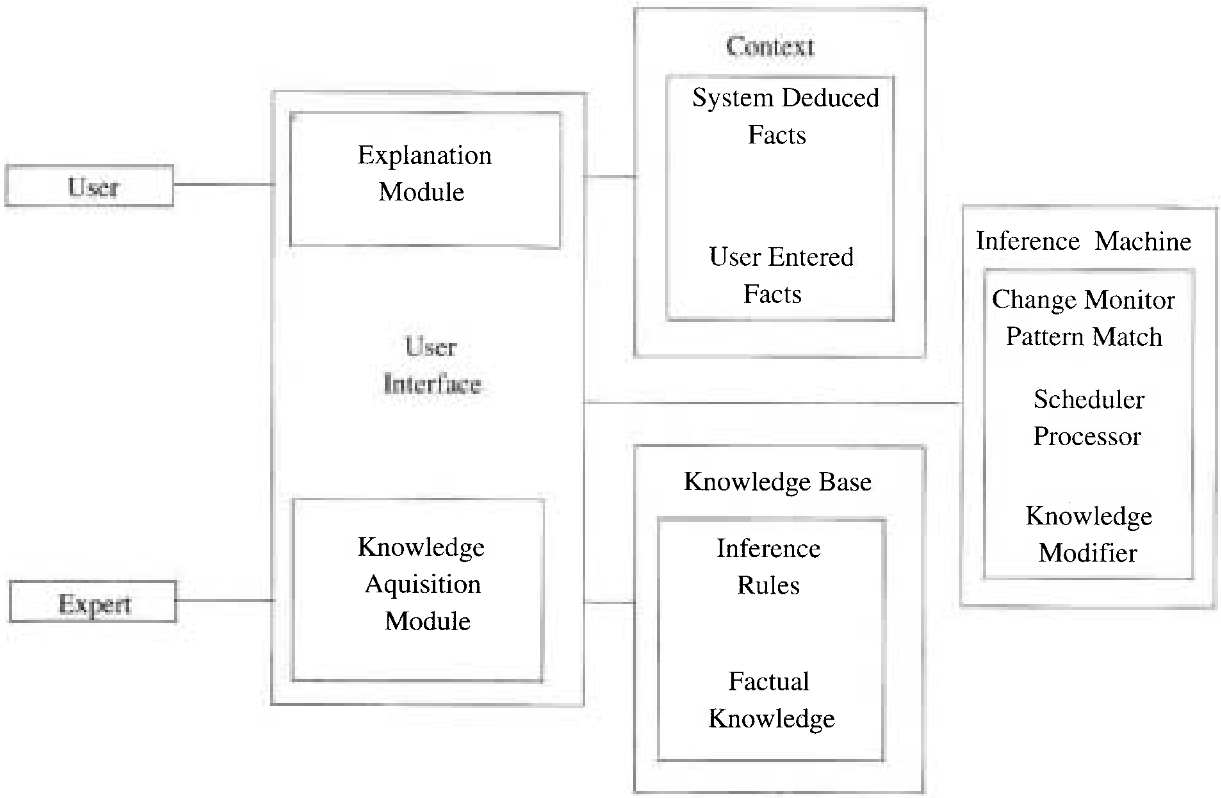

Figure 1. Schematic Framework of an Expert System.

demand and turn movements over time.

• They are more costly to install and maintain than pretimed or semiactuated controllers.

Figure 2 presents an overview of the specific functions performed by the expert system.

EXPERT SYSTEM DEVELOPMENT PROCESS

For developing the expert system for signal design at isolated intersections, 12 steps, illustrated in Figure 3, were considered, starting with problem selection and ending with system delivery. The steps are defined and significant development issues are discussed below.

Problem Selection

Issues included characteristics, benefits and critical success factors for implementable expert system problems. Example of system issues include the similarity of problem type to ongoing research, documented success and failures, and experienced judgements from past projects.

Problem Analysis and Definition

Problem statement and initial analysis include issues such as who is affected by the problem and how extensive it is. Key issues include formulating an

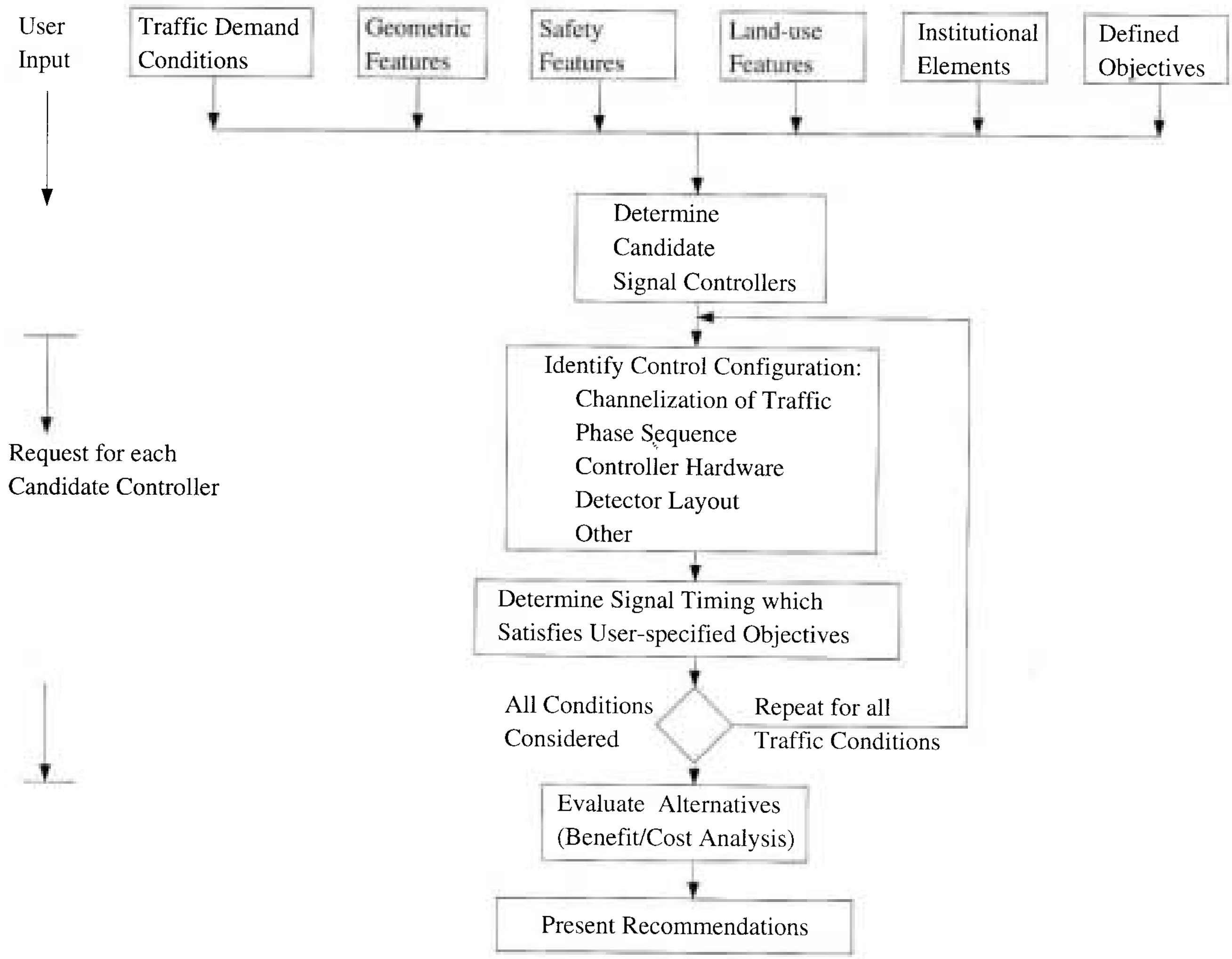

Figure 2. An Overview of the Specific Functions Performed by the ES.

expert system applicability assessment, identifying sources of expertise, defining the problem scope, and considering alternative solutions. For this system, two major sources of knowledge were employed:

• The existing documented and published literature including the Manual on Uniform Traffic Control Devices (MUTCD) [2], Traffic Control Devices Handbook [3], and NCHRP Report 233 [4].

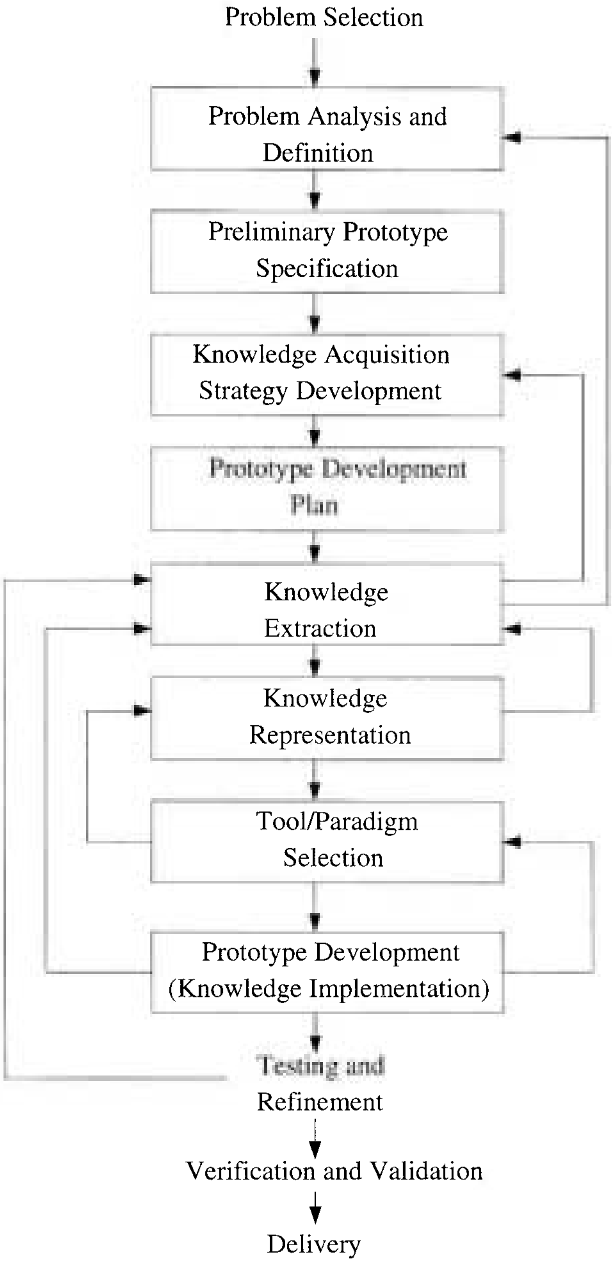

Figure 3. The Development Process of the ES.

• The experience and guidence of three selected experts. Each expert possesses many years of experience in designing traffic control for isolated intersections.

Throughout this step important issues were considered. These issues include:

• Warrants for installation of traffics signals. Prior to the selection of type of signal control to be installed at an isolated intersection, the need for such a signal must be identified.

• Signal Controller Types: Signal controllers may be classified as either pre-timed, or traffic actuated. The choice of signal controller type is not a well defined procedure. Figure 4, presents the regions of main and cross street critical lane volumes

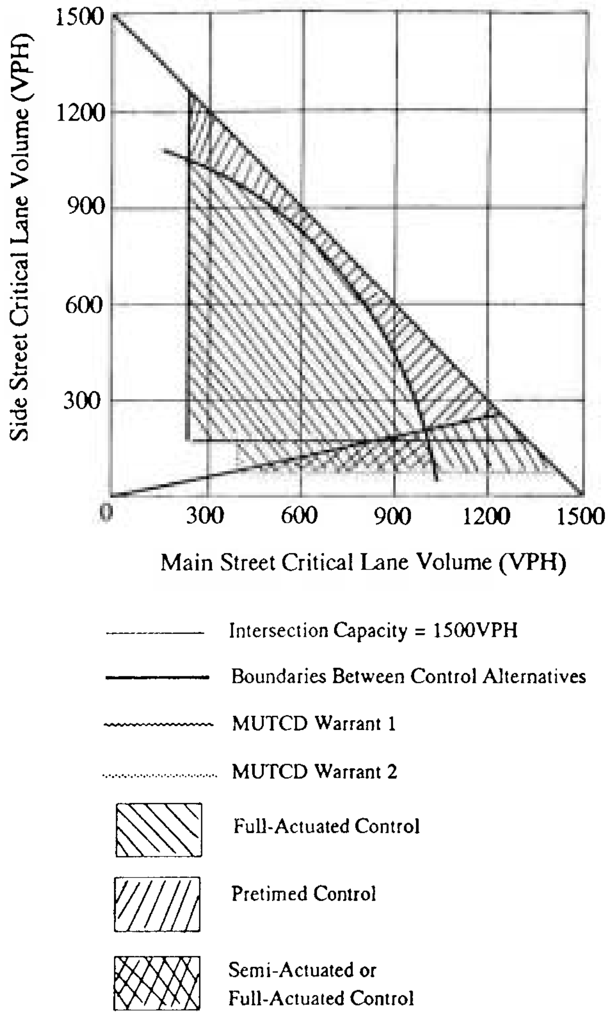

Figure 4. Traffic Signal Controller Identification.

where various traffic control alternatives are applicable.

• Vehicle detector issues: The consideration of actuated controllers for isolated intersections also requires the consideration of the type of vehicle detectors to be used and their installation configuration [3, 4, 5, 6, 7].

• Signal timing issues: The evaluation of various signal controller options by the expert system is conducted on the basis that each candidate option exhibits parameters which have been optimized for the given traffic conditions. For example, if a semi-actuated controller is evaluated relative to a fully actuated controller, the signal timing plan for each is optimized in order to provide an objective comparison.

Preliminary Prototype Specification

Issues include key feature identification, end-user considerations, delivery environment, and preliminary knowledge base analysis. For the intersection design expert system developed in the project, constant interaction with two local traffic engineers was maintained to ensure that the initial prototype specification takes the needs of the end-user into account.

Knowledge Acquisition Strategy Development

Issues included analysis of background documents, expert interaction (how available the experts are, interviewing techniques, etc.), identification of other knowledgeable people about the problem, examples/cases/sample results, and a strategy for extending the analysis to the prototype.

Prototype Development Plan

Issues included identification of development environment (discussed earlier), staffing including assigning extraction risk, project scope risk, user acceptance risk, delivery risk, maintenance risk, and management risk.

Knowledge Extraction

This step involved identifying the correct mix of knowledge extraction techniques to include interviews (structured/unstructured), expert led tutorials, independant research, examples or cases, and on-site observation of an expert and a traffic engineer. Key issues included the means for expert interaction in the evolutionary system development and the strategy for the extension of prototype into an operational expert system for the design of signals at isolated intersections.

Knowledge Representation and Control Strategy

The knowledge extracted must be represented in the expert system by any of the acceptable knowledge representation paradigms. The control mechanism of the expert system searches through the knowledge base to efficiently and logically control the sequence of questions that the system asks the user, as well as to infer new knowledge from the existing knowledge base. As a result, the selection of representation and control strategies for developement of an expert system is an important issue which directly affects the selection of the tool (discussed in the next section) as well as the quality of the end product. The subject of selecting suitable representation and control strategy for building expert systems in transportation engineering has been thoroughly covered elsewhere [8,9]. Here, a brief analysis of the subject as it pertains to the aforementioned problem is presented.

For the intersection design expert system, the ability to provide maximum flexibility to accurately represent the acquired knowledge was a key factor to a successful acceptance system. As a result, a hybrid (mixed representation of rules and frames) approach to knowledge representation proved beneficial for the maximum possible options for user interface/maintenance and programming ease.

The control strategies for a rule based system include backward and forward chaining. Another commonly used method is object oriented programming. Again, a hybrid approach (combination of forward and backward chaining) to control strategy proved beneficial because of the inherent nature of the problem being formulated and the greater flexibility and options available.

Tool/Paradigm Selection

Issues included the ability of the expert system shell to support the knowledge representation and control strategies (discussed above) that best complement the problem as currently understood. Delivery issues such as cost, hardware platform, software environment, communication requirements, other system interfaces (databases, models, graphics, programs), integration requirements, maintenance capability, and documentation requirements were addressed. An alternative evaluation resulted in 11 preliminary candidates. A detailed investigation subsequently narrowed the list to three final candidates. Each of these three final alternatives was subjected to further analysis by obtaining the detailed documentation, and by asking the vendors to demonstrate their product. The final selected product was "EXSYS Professional" [10] which met all the requirements, and proved to be a valuable tool for this project.

Prototype Development (Knowledge Implementation)

This was the actual programming step of the development. issues included expert system shell usage and early prototype availability for meaningful discussion by the experts and local practicing engineers. The use of accepted programming techniques such as code documentation and modularity, were also addressed during this step. Three major items under this activity for programming purposes were developed:

1. A comprehensive list describing the overall functions and capabilities of the system for a complete design of signalization at isolated intersections. The list of knowledge based on all the input items that are required from the user during a consultation session were provided. Table 1 provides a list of sample input items and Table 2 is the list of sample outputs presented by the system. The core of the knowledge base of the expert system consists of all the causal relations between the input data, the type of controller, and the design configuration for the intersection.

2. After listing the knowledge items, the following issues were addressed:

- How will the expert system determine possible signal control strategies?
- How will the strategies be compared among themselves?
- What criteria will be used for selection?

As noted earlier, the two main sources of knowledge that are used in developing the system's knowledge base are the literature and the panel of experts. All the factors leading to the determination of control strategies (i. e. the type of controller, and design configurations) were determined and were explicitly listed under this item.

Next, the expert system determines the initial design configurations and parameters for each type of controller selected from among those mentioned above. The knowledge of determining these initial design configurations (including channelization, timing, phasing, detector configuration and placement, and all issues regarding turns) are available in the existing literature. For example Pignataro [11] provides procedures for determining design elements of pretimed (including computation of critical lane volumes, vehicle clearance intervals), fully actuated (including assumed detector placements, unit extension, initial portion, extension limit, vehicle clearance interval, and pedestrian requirements), and semi-actuated signals (including minimum green, clearance interval and pedestrian requirements for the

TABLE 1. A List of Sample Input Items.

Geometric Features	Traffic Conditions	Safety Features
- Intersection Geometry *Number of Legs *Angles *Approach Lanes (Directions)	*Vehicular Volumes Seasonal, Day of Week Time of Day *Speeds *Composition of Traffic *Pedestrian Traffic *Turning Volumes	- Nature of Accidents (accident type) - For Each Type Provide the Number of Accidents - Type: 1. Vehicular Accidents a) Rear End b) Right Angle c) Head to Head 2. Pedestrian Accidents a Pedestrian and Vehicle - Number of Accidents. - Location of Accident (Within the Intersection) - Severity of Accidents *Property Damage *Injuries *Death
Land-use Features	**Institutional Elements**	**User Objectives**
- Adjacent Land-use: Type of Adjacent Land- use: *School *Mall *Theatre * * - Location of Land - use - Amount of Traffic Generated by Land-use - Amount of Pedestrians Generated by Land-use - Urban - Rural	- Available Budget - Availability of Personnel for Monitoring the Controller	- Just Provide the Optimum Design Parameters (If the User is Simply Designing the Intersection Now) - Minimize Delay - Minimize Number of Stops - Minimize Number of Accidents - Minimize Fuel Consumption - Minimize Other Operating Costs - Minimize Queue Length

main street, initial portion, unit extension, and clearance interval for the main street). Other sources, Traffic Control Devices Handbook [3] for example, also provide design related information.

When the initial design elements for each type of controller are determined, the system will need to compute the optimized design elements. The optimized design elements will later determine the different MOE's for each type of controller (this is discussed later), and these MOE's will, in turn, establish the necessary parameters for computing the cost/benefit for each control strategy, and as a result compare the different control strategies.

The optimization process of the initial quantities is performed by the powerful mathematical and linear facilities provided in the EXSYS Professional expert system shell. The knowledge for the optimization of each controller type was obtained from the literature. For instance, the application of the Webster Model in determining the optimum cycle length for pretimed controllers which appears in [11], was used for the system.

TABLE 2. Items Provided as Output by the System.

1. Type of Controller:	
*Pretimed	*Semi-actuated
*Full-Actuated	*Volume-density
2. For Pre-timed Controller Determine:	
*Channelization of Traffic	*Time Cycle
*Intervals	*Interval Sequence
*Traffic Phase	*Turn Controls
*Clearance Interval	*All-red Interval
*Pedestrian Requirements	*Signal Timing Plan(s)
For Semi-Actuated Controller Determine:	
*Channelization of Traffic	*Turn Controls
*Detector Configuration Placement	*Phasing
*As a Result for Main Street	
-Minimum Green	
-Clearance Interval	
-Pedestrian Clearance (If Pedestrian Actuator Provided)	
*For the Side or Minor Street	
-Initial Portion	
-Unit Extension	
-Maximum Green	
-Clearance Interval	
For Full-actuated Controller Determine:	
*Channelization of Traffic	*Turn Controls
*Detector Configuration and Placement	*Pedestrian Requirements
*Phasing	
*As a Result we get:	
-Initial Portion	-Extendable portion
-Unit Extension	-Extension Limit
-Minimum Period	-Carryover
For Volume-Density Controller Determine:	
*Channelization of Traffic	*Turn Controls
*Detector Configuration and Placement	*Pedestrian Requirements
*Phasing	
*As a Result we get:	
-Minimum Initial Portion	
-Expanded Initial Portion	
-Passage Time	

After the optimized design elements are determined, different Measures of Effectiveness (MOE's) are computed. In this system the optimized designed data for the different types of controllers are fed to NETSIM [12]. NETSIM, which is capable of determining various MOE's for each approach to the intersection and for different types of controllers, is interfaced with the expert system.

Furthermore, NETSIM's powerful graphics and aniamtion capabilities were employed to enhance the quality of the user-interface. This feature provides a data entry window on the left side of the screen and provides visual feedback of the entered information in additional windows on the right side of the screen.

The MOE's are subsequently used for determination of cost/benefit quantities for each type of selected controller(s). The cost/benefit analysis procedure consists of the available procedures in the literature (NCHRP 233, [4] for example) along with other relevant knowledge that the panel of experts provided. This takes into account such considerations as delays, fuel consumption, etc.

The MOE's and the subsequent cost/benefit results for each type of controller establish the basic type of criteria used for selection among the different control strategies.

3. Determination of the final selection of alternatives is made by the expert system based on: 1) The selected control strategies, i.e., the controller and the associated design elements, 2) The MOE's and 3) The resultant cost/benefit analysis for each type of controller. The knowledge contained in this part of the knowledge base, i.e. final selection of alternatives, is mostly heuristic and provided by the expert panel.

Testing and Refinement

Issues included the early planning for testing, determining acceptance criteria, designing test data, and defining testing priorities. The testing of the prototype was performed by the knowledge engineer (not the programmer) and included a few hypothetical as well as real-life signal timing problems for isolated intersections. Minor modifications and revisions were then made by the programmer.

Verification and Validation

Issues included identification of objectives, standards, procedures and techniques, and the environment for verification and validation. Verification techniques included system testing, ad hoc testing, customized automatic test tools, comaprison of the system to requirements, code reviews and analysis. Validation techniques included critical subsystem validation, ad hoc testing, system "boundary" (when the expert moves from outside the prespecified domain) testing, and "expert" validation. The verification and validation steps included all the participants in the project including the experts, the knowledge engineer, the programmer, and the engineers.

Delivery

Issues that will automatically promote the use of the developed expert system include: expert and user "buy in" to the system; maintenance capability by the expert or practicing traffic engineers; system simplicity; sytem responsiveness within users; and good on-line help to include example screens, a help function, explanation capabilities, and other on-line documentation.

SUMMARY AND CONCLUSION

An expert system for designing signals at isolated intersections has been developed. The develop -mental phases of the system which consisted of twelve inter-related steps were fully described and the most significant issues related to the system's implementation were analyzed and discussed. The system is operational in a microcomputer environ - ment, has the capability of documenting the decision process, is driven by user-friendly menus, includes on-line help features, provides computer graphics displays input and output, and enables the users to modify the knowledge base in a user friendly manner to meet local standards and practices.

The applications and potential benefits of expert systems technology for a variety of transportation engineering problems were demonstrated in this paper. Although "stand alone" expert systems are able to tackle many of the "heuristic type" transportation engineering problems, it is best to consider the integration of expert systems with the existing powerful simulation, evaluation, and optimization tools to develop intelligent systems.