

# Interactive Intersection Design Using an Expert Systems Approach

EDMOND CHIN-PING CHANG

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The development of "expert systems" for microcomputer applications has received increasing attention in the transportation engineering field. Expert systems are computer programs that include simulations of the logical reasoning and problem-solving processes of human experts for specific applications. Proper implementation of this concept offers a possible means to effectively use the specific knowledge and experience of recognized professionals, efficiently use limited highway resources and revenue, and provide safe, efficient transportation programs. The major advantage of expert systems is that they permit specific human knowledge used in the decision-making process to be systematically examined, organized, and applied to particular engineering problems. During the typical intersection design process, highway engineers make many decisions concerning the operational effectiveness and trade-offs among a number of design factors. These important decisions may be bounded by either the planning budget, the potential total project costs, the maximum lane width of each typical highway lane, or the potential traffic demand volumes. This study illustrates the prototype applications of expert system design and LISP programming in the highway design process using the AutoCAD<sup>®</sup> package. AutoLISP<sup>®</sup>, a version of LISP supported by AutoCAD, was used to create a small-scale expert system to interface with the normal drawing functions. This study demonstrates the feasibility of implementing built-in functions of the AutoCAD system through AutoLISP programs to assist end users in completing the decision making for potential highway design applications.

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This study illustrates an application of expert systems through the LISP programming using the AutoCAD package in the highway design process (1). The AutoCAD<sup>®</sup> drafting package is a powerful engineering tool, which allows engineers to prepare drawings that look virtually identical to drawings prepared by hand. AutoCAD supports AutoLISP, a version of the LISP computer programming language commonly employed in the field of artificial intelligence. AutoLISP can be used to create an expert system that can implement normal drawing functions (2). Functions are applied in AutoCAD through AutoLISP to assist end users in completing the decision-making process during the simplified highway designs application. These decisions may be bounded by either the planning budget, the potential total project costs, the maximum lane width of each typical highway lane, or the potential traffic volumes (3,4).

## STUDY APPROACH

An expert system is a computerized decision-making assistance system. It can be designed to handle complex real-world

problems through an expert's interpretation and solves these engineering problems by using a computer representation of the human reasoning process. If the system is properly designed and implemented, the computer will be able to assist users by offering suggestions, the way that human experts make recommendations in comparable situations.

This study was started to examine the feasibility of creating a highway design expert system with the built-in features of AutoCAD and AutoLISP. The programs apply some typical decision-making rules on the basis of information supplied by users and output suggestions or conclusions for users. A simplified set of production rules was defined to guide the computer program in assisting the user in reaching a viable conclusion. The simplified knowledge depends on compromises among the different highway design elements, such as the construction budget or environmental factors affecting the highway. The system applies a set of production rules to the input and gives its decisions back to the user. The data can be input interactively, retrieved from the existing input data file, or obtained from the existing design specifications.

## STUDY BACKGROUND

The development of "expert systems" for microcomputer applications has received increasing attention in the transportation engineering field. Expert systems are computer programs that include simulate logical reasoning and problem-solving processes of human experts for specific applications. Proper implementation of these programs effectively uses specific knowledge and experience of recognized professionals, efficiently uses limited highway resources and revenue, and provides safe and efficient transportation programs. Expert systems permit users to systematically examine, organize, and apply specific human decision-making knowledge to particular engineering problems.

In addition to the basic requirements, the acceptance and operational use of this estimation process depends on the simple to use but nevertheless highly sophisticated user interfaces to assist in the complicated calculations. Historically, the information required for the highway user benefit and cost evaluations has been fairly complex (3,4). Familiarity with and training in the analysis procedures are often required of users. Usefulness of the design in the operating agencies is often constrained by lack of incentive for performing operational reviewing that can further improve the data quality. To improve user implementation, computer and graphics interfaces are increasingly used. This effectively lowers resistance to the new applications and reduce a user's training

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Texas Transportation Institute, Texas A&M University System, College Station, Tex. 77843-3135.

requirements. Through these changes, an improved, overall system functional design can then be built. Different types of user interface have been used in many highway management systems, although the software necessary for implementation has not yet been fully developed. Consequently, effective use of the expert system in design relies on efficient implementation of available techniques and tools.

A useful highway design system must provide the end user with a fast, powerful, and easy information management method to interactively access, accumulate, update, and assimilate road information. Such a system can take advantage of the effective, graphics oriented environment which local authorities or divisional offices can download and operate in a familiar visual display format. The data base information may be represented through a combination of graphic displays similar to maps, general layouts of their road system, and associated installations and facilities. This paper explores the necessary interface and data requirements for such a system. Consequently, this prototype could be expanded further to enhance the interaction with different interface from the potential user's perspective. In addition, changes can easily be made to provide a good prototype which avoids potential problems encountered during user testing and product upgrade before final system implementation.

### Design Considerations

During the typical highway design process, highway engineers make certain decisions to determine the operational trade-offs among a number of design factors. Some important traffic engineering design considerations may include expected traffic demand volumes, number of traffic lanes, and necessary lane width.

One of the important underlying design objectives is to evaluate the required highway capacity that not only accommodates the current traffic demands but also provides the necessary near-term traffic demands. However, the maximum number of traffic lanes and achievable lane widths are usually bounded by the maximum available right-of-way road. Therefore, the design of highway lanes and lane widths is often constrained to certain working ranges.

In addition to these design considerations, engineers also need to consider the operating budget constraints and potential allowable total costs in certain highway improvement projects. The cost of building highway facilities can usually be broken down into fixed portions of the construction costs as well as the variable costs of constructing an additional lane. The variable cost for constructing each traffic lane may depend on the number of additional lanes, lane widths, and some other traffic related factors.

### AutoCAD System

AutoCAD<sup>™</sup>, a commercially available computer-aided design (CAD) tool, is one of the most powerful CAD packages used on IBM PC/XT/AT/386-compatible microcomputers. It is also available for many other minicomputers and engineering workstations. The system operation requires the basic computer system, which includes the processor, keyboard, text display screen, disk drives, and a graphics monitor capable

of reasonably high resolution. A plotter, or printer plotter, can be connected to the system to provide a hard copy of the drawing files. A number of graphics input or pointing devices can be used, such as the mouse, digitizing tablet, or TouchPen<sup>™</sup>.

On some computer systems AutoCAD may use two display monitors—one for command prompts and text output and the other for graphics. On other systems a single monitor may be used for both graphics and text purposes. In these situations, three lines at the bottom of the screen are reserved for command entry and prompts, and the right edge may contain a screen menu. When AutoCAD runs on a single-monitor system, it remembers a full 24 lines (or more) of text, just as it does on the regular text display. AutoCAD automatically switches to the text display when it outputs a large amount of information and automatically returns to the graphics display when drawing graphically.

When users enter AutoCAD's Drawing Editor, a screen menu will appear along the right edge of the screen, as shown in Figure 1. Users can move the mouse or digitizer cursor to select items in the menu and perform actions as needed. They can also extend AutoCAD's capabilities and customize them for particular application by designing their own menus and submenus to complement those supplied with the program.

### Program Operation

AutoCAD operates on two shell levels to reduce both the effort required to generate a drawing and the time needed to learn the system. At the outer level, AutoCAD provides a menu-driven interface, the Main Menu, that allows it to initiate various working tasks, such as creating new drawings, modifying previously stored drawings, and producing plots. The main menu is displayed on the screen at the beginning of AutoCAD execution, and users can use this screen to end an AutoCAD session. It provides quick access to various parts of AutoCAD, such as the interactive Drawing Editor and the plotter interface.

The Drawing Editor provides easy access to the drawing, as a text editor accesses a document. When users create a new drawing or edit an existing one, AutoCAD automatically loads the Drawing Editor, which displays the drawing and provides commands to create, modify, view, and plot drawings. When users have finished working with a given drawing,

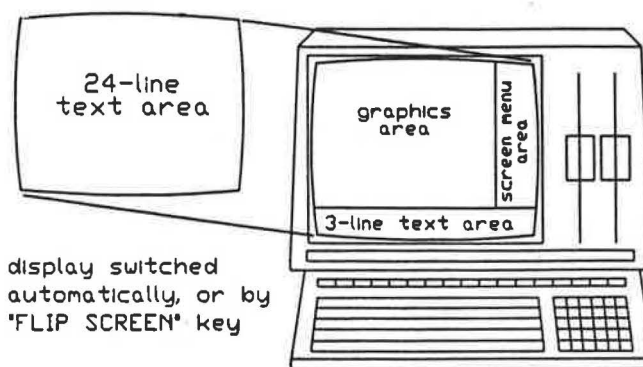


FIGURE 1 Typical single-screen configuration of the AutoCAD system.

any changes made can be saved or discarded before returning to the Main Menu. All information on the drawing—the size and position of every element, the size of the drawing itself, and its display characteristics—is automatically updated with each command. Also, users can zoom, move, pan, or rotate the drawing automatically with each command. This information will be stored when the AutoCAD system is exited.

A user can specify different points in the drawing in a variety of ways. From the keyboard, points can be designated by typing in absolute coordinates or coordinates relative to the last point specified. A user can use keyboard control keys to move the cursors around the graphics monitor and visually locate the desired point(s). A graphics input device can also be used to designate points, which can be locked or snapped to a user-defined grid.

Commands can be entered in several ways. A command can be typed in directly or selected from any of the menus. Customized menus can be constructed through the screen, tablet, and button menus. The screen menu can be displayed on the graphics monitor while the Drawing Editor is active and allows command entry by simply pointing to the command on the display screen with a pointing device or with the keyboard.

A tablet menu includes up to four menus of AutoCAD commands on the digitizing tablet, permitting a command to be entered by pointing to it with the stylus and pushing a button. If the tablet stylus or mouse has multiple buttons, the button menu can be used to enter often used commands.

An auxiliary function box can also be used. It has buttons for command selection, but it cannot be used as a pointing device. A user can also plot a hardcopy of the drawing at any stage in its development. Check-plots can also be generated while the drawing is in progress to check for positioning and dimensioning errors that might not be immediately apparent on screen. When the drawing is complete, the final plot is done to produce the finished drawing.

AutoLISP is an implementation of the LISP programming language embedded within the AutoCAD system. A popular computer programming language used in artificial intelligence programs, LISP is a very powerful language suitable for the expert system development on engineering designs because of its ability to interface with AutoCAD. AutoLISP allows users and AutoCAD developers to implement macro programming in a very powerful high-level programming language format well suited to the interactive graphics applications.

## EXPERT SYSTEM DESIGN

### Concept Design

To maximize flexibility, a dual design approach has been used to provide interactive intersection design in this prototype expert system. As shown in Figure 2, the design analysis approach can be specified through the objectives required by the users, according to their functional requirements and evaluation priorities. Users may wish to find the desired intersection configuration and total construction costs according to the traffic demands, or they may want to use the system to find the best design on the basis of budgetary concerns.

The first approach allows users to evaluate costs on the basis of traffic demand inputs and specified design require-

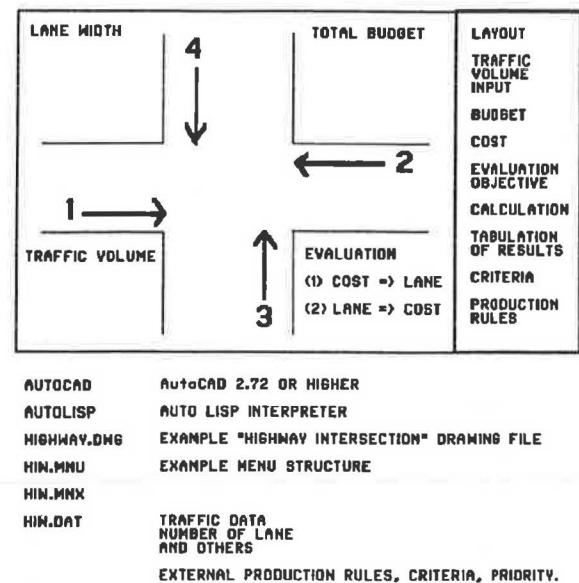


FIGURE 2 Functional design of the interactive intersection design system.

ments. Users input the number of lanes and lane widths to be used, and the program evaluates estimated costs for constructing the intersection. Another approach is for users to suggest the number and widths of traffic lanes on the basis of available financial resources and input the total budget and traffic volumes. The output suggests the total cost, number of traffic lanes, and lane widths to be used.

### Design Parameters

The estimated costs of designing the intersection can be broken down into fixed and variable portions, which can be used by the program and stored in existing data file. During program initialization, the computer can retrieve these design parameters from historical files and save the values in some memory variables. These design parameters can be modified at any time during the program evaluation. When finished, the computer will automatically update the external parameter file with the new values.

In addition, a user can also review or modify the data file directly and store design parameters outside the graphics system. In this way, interactive design systems can use the same set of parameters for consistent design evaluation each time. The program runs continuously until values are modified. The design parameters used in this prototype program development include (a) maximum capacity of a traffic lane, (b) maximum and minimum width of a traffic lane, (c) fixed cost per lane, and (d) variable cost per lane-foot.

### Production Rules

Several production rules are also implemented. The set of rules is preset and stored externally outside the AutoCAD system. The decision rules can be turned on or off during program evaluation. Similar to the design parameter file, these

production rules can also be stored or updated by editing the disk file of production rules directly. Three production rules are illustrated in this program:

1. If the total evaluated cost is greater than the total budget, either adjust the lane width to lower the total cost or ignore the budget and stick with the evaluated cost.
2. If the number of lanes input by the user does not meet the requirement of the traffic volume, increase the number of lanes.
3. If the lane width input by the user or evaluated by the program is not a whole number, either truncate or round the number off.

### System Development

Because a fairly large amount of memory is usually required in the AutoCAD operations, development of the interactive design system through interfacing with other languages is limited. This is due to the standard memory of the IBM PC/XT/AT/386-compatible microcomputers under the MicroSoft Disk Operating System (MSDOS) environment. Therefore, AutoCAD allows only a limited memory size for loading AutoLISP or other high-level languages on the IBM AT under MSDOS version 3.2 with 1024K main memory.

Compared with the commercial GCLISP system, a popular version of the common LISP program available on microcomputers, AutoLISP is not as powerful in system building, data and knowledge analysis, and logical reasoning. GCLISP provides many more built-in functions. However, AutoLISP is a programming language that is embedded within the AutoCAD system, designed to provide interfacing capability directly with the AutoCAD graphics functions. It can activate all available functions in AutoCAD directly, such as drawing a circle or setting the system variables. Therefore, AutoLISP is more appropriate for building a prototype expert system for interactive intersection design.

### Program Implementation

To run AutoCAD and load the interactive intersection design system, the user needs only to run the batch file HIW.BAT, which loads the AutoCAD main program, drawing files, and the AutoLISP environment program automatically. As shown in Figure 3, after the user points the mouse cursor to "START" on the drawing screen and activates it by clicking the button

<b>HIGHWAY</b>	- TAMU.TTI TRAFFIC OPERATIONS
<b>Layout</b>	- Draws the intersection
<b>Rules</b>	- Display the production rules
<b>Criteria</b>	- Display the criteria
<b>Vol In</b>	- Input the Traffic Volume
<b>Budget</b>	- Input the Project Budget
<b>Calc</b>	- Do the calculation
<b>Results</b>	- Summarize results in a table
<b>HELP</b>	- Display the HELP Information
<b>Exit</b>	- Exit this program

FIGURE 3 Main menu of the interactive system.

on the mouse, AutoCAD will load HIW1.LSP and HIW2.LSP. The following are brief descriptions of these program files.

### Drawing Files

As shown in Figure 4, the drawing file "HIW.DWG" interactively displays the physical layout of the study intersection, illustrates detailed design requirements, shows active design objective, tabulates evaluation results in the table, and displays descriptions of the recommended system design. At the end of the evaluation, the expert system automatically outputs the results and draws suggested lane lines onto the screen.

### AutoLISP Programs

Two AutoLISP programs were developed in this prototype intersection design to perform the necessary data input, decision making, output interpretation, and graphics illustration support. The first system component provides global system initialization and user's input. The second system component applies the linkage to the user-defined AutoLISP functions and built-in AutoCAD system drawing functions.

The first system component ("HIW1.LSP") provides the initialization and interpretation of the LISP program. It reads the prestored parameter file, production rules, number of input lanes, and traffic volume input and keeps all user-selected values as accessible memory variables. The following example illustrates the system initialization:

```

; RESET SYSTEM VARIABLES
(setvar "cmdecho" 0) ; NO COMMAND ECHO
(setvar "blipmode" 0) ; NO BLIP MODE
(setvar "expert" 1) ; NO CONFIRM QUESTIONS
(setvar "menuecho" 3) ; NO MENU ECHO

; BLANK THE MENU AREA
(menucmd
"S=BLANK")
(command "layer" "off" "help" "on" "wait" "")
; INITIALIZE BUDGET, COST AND WIDTH AS WELL
; AS VARIOUS FLAGS
(setq budget 0) ; PRE-SET BUDGET
(setq cost 0) ; COST OF HIGHWAY
(setq width 8) ; LANE WIDTH
(setq chg_made nil) ; ANY GLOBAL
; VARIABLES CHANGE

```

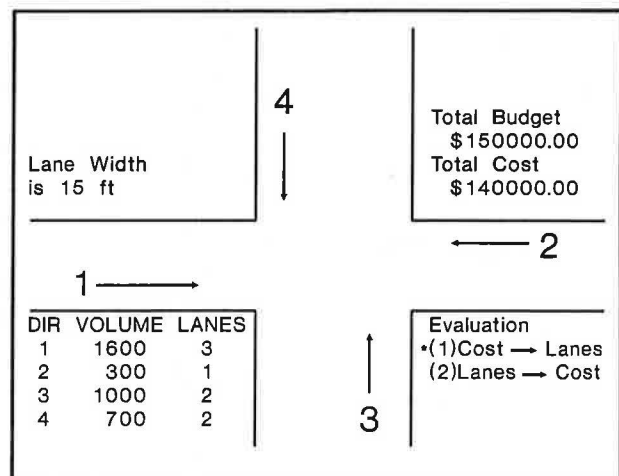


FIGURE 4 Display screen of the interactive system.

```

; FUNCTION TO TRUNCATE A REAL NUMBER
; TO INTEGER
(defun truncate (r)
  (- r (rem r 1)))

```

In addition, the following example program defines initialization of all the traffic input design considerations as default values:

```

; INITIALIZE PRM (VOLUMES, MIN LANE WIDTH, MAX
; LANE WIDTH, FIXED COST AND VARIABLE COST
; PER LINE)

(setq prm (if (or (null (setq f1 (open "hiw.prm" "r")))
                 (null (setq line (read-line f1))))
              '(vol 500) (min 8) (max 16) (fix 10000.0)
              (var 500.0))
            (read line)))

(if (null (assoc 'vol prm))
    (setq prm (cons '(vol 500) prm)))
(if (null (assoc 'min prm))
    (setq prm (cons '(min 8) prm)))
(if (null (assoc 'max prm))
    (setq prm (cons '(max 15) prm)))
(if (null (assoc 'fix prm))
    (setq prm (cons '(fix 10000.0) prm)))
(if (null (assoc 'var prm))
    (setq prm (cons '(var 500.0) prm)))

```

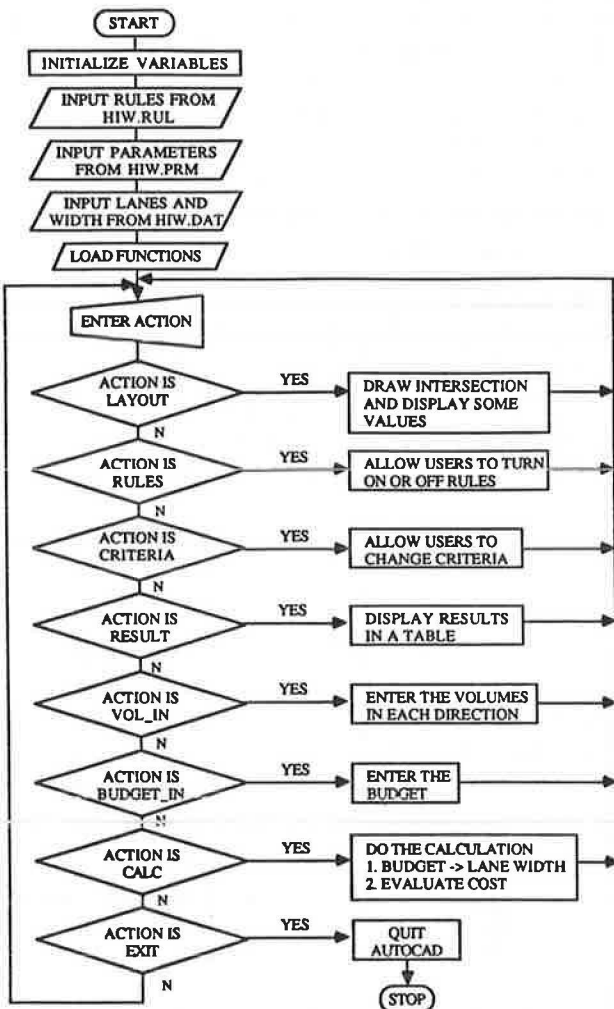


FIGURE 5 Program flowchart of the interactive system.

The second component, or "HIW2.LSP" file, applies the written AutoLISP functions for program execution. Specifically, the program will perform the following functions according to the program flowchart as shown in Figure 5. It illustrates the overall conceptual design of the prototype expert system.

First, the system draws the simplified intersection schematics to illustrate all design elements. Next, the user will be asked to update both the production rules and the evaluation criteria from the historical data files stored previously. Then, the user can select to start the evaluation objectives from the known budget constraints or the preliminary design to purely satisfy the traffic demands. The system will then acquire additional input data based on the approach selected. Basic calculations include the computation of allowable numbers of approach lanes from the available operating budget, computation of potential project costs, and the basic requirements of number of approach lanes from traffic demands. Finally, the system will summarize recommendations and provide the preliminary design configuration.

The following section presents an example of AutoLISP program application to determine the minimum design requirements of various types of inputs when a design compromise needs to be made. A user may encounter three types of decision-making processes during the analysis. According to the production rule design in this prototype system, the program will respond with three responses when determining the lane widths based on the following three conditions. The corresponding program codes being implemented are:

1. If any variable is zero, prompt the user for it;
2. If the result width is too wide, set it to the upper limit; and
3. If the result width is too narrow, no solution.

```

; IF ANY VARIABLE IS ZERO, PROMPT THE USER FOR IT
(if (<= budget 0)
    (setq budget (getreal "Enter your total budget: "))
    (if (equal vol '(0 0 0 0))
        (progn
          (setq vol ())
          (terpri) (setq i 0)
          (repeat 4
            (setq i (1+ i))
            (princ "Enter volume in direction") (princ i)
            (setq vol (append vol (list (getint ": "))))))
        (setq lanes (findlanes vol))
        (terpri)
        (setq width (truncate (/ (- (/ budget (sumup lanes))
                                   (cadr (assoc 'fix prm))) (cadr (assoc 'var prm))))))

```

```

; IF THE RESULT WIDTH IS TOO WIDE, SET IT TO THE
; UPPER LIMIT
(if (> width (cadr (assoc 'max prm)))
    (setq width (cadr (assoc 'max prm))))

```

```

; IF THE RESULT WIDTH IS TOO NARROW, NO SOLUTION
(if (< width (cadr (assoc 'min prm)))
    (progn
      (setq cost 0)
      (textscr)
      (terpri) (princ "No solutions!") (terpri)
      (terpri) (princ "Not enough budget!") (terpri)
      (setq width (cadr (assoc 'min prm)))
      (setq cost (* (sumup lanes)
                    (+ (cadr (assoc 'fix prm))
                       (* (cadr (assoc 'var prm)) width))))
      (terpri) (princ "Hit (RETN) to continue")
      (read-char) (read-char))

```

System Operations

The AutoCAD screen drawing speed is rather slow compared with interpreting and running AutoLISP functions in the overall operation. Therefore, 11 drawing layers have been implemented at the beginning of program initialization. These graphic layers appear to make the program run faster. During program execution, different calculation results and roadway elements are displayed on different drawing layers on the screen. When there is a need to display another screen, the program switches to the corresponding program layer for that particular display instead of erasing the entire screen and drawing the other screen from scratch. Using different graphics layers, the drawing file can be prepared all at one time during program initialization and take much less time to load the drawing file and speed up the screen display.

Eleven graphics layers are used in this program:

1. 0 (display values, such as budget, cost, volumes).
2. DISPLAY (number of lanes, lane width, as shown in Figure 4).
3. HIDDEN (for the purpose of drawing hidden lines).
4. CENTER (for the purpose of drawing center lines).
5. OBJECTIVE (display the evaluation objectives, as shown in Figure 6).
6. CRITERIA (display the criteria, as shown in Figure 7).
7. RULES (display the production rules, as shown in Figure 8).
8. BORDER (draw the border of the screen).
9. RESULT (tabulation of evaluation results, as shown in Figure 9).
10. LAYOUT (display the intersection and the recommended design).
11. LANES (layer for drawing the lanes, as shown in Figure 10).

In addition to the preparation of these 11 drawing layers, a "WAIT" layer has also been implemented to display the "Please Wait" message during program execution. A customized menu has been created for using this system and includes a HELP menu to provide a brief description of each item on the custom menu, as shown in Figure 3. The menu items on the right-hand side of the drawing screen can be activated individually by pointing the mouse or digitizer cursor to a particular item and pressing the button to activate the selection. In this sample run, as illustrated in Figures 6-10, only

**Evaluation Objectives**

1. Suggest number of lanes in each direction and the total cost according to the input volumes and budget.
2. Calculate the total cost according to the input number of lanes and volume in each direction.

FIGURE 6 Evaluation objectives of the interactive system.

**Criteria**

1. One lane every 600 vehicles.
2. Lane width between 8-15 ft.
3. Fixed cost each lane \$10,000.
4. Width costs \$500. per foot.

FIGURE 7 Evaluation criteria of the interactive system.

**Production Rules:**

- \*1. If Cost > Budget, Use cost and Update budget. {Otherwise, reduce cost.}
2. If original number of lanes not enough for the volume, overwrite no. of lanes.
3. Round off lane width to nearest integer. {Otherwise, Truncate lane width.}

\* - Rule is turned on

FIGURE 8 Production rules of the interactive system.

DIR	VOLUME	LANES
1	1600	3
2	300	1
3	1000	2
4	700	2

**COST = \$140000.00**  
**WIDTH = 15ft**

FIGURE 9 Evaluation results of the interactive system.

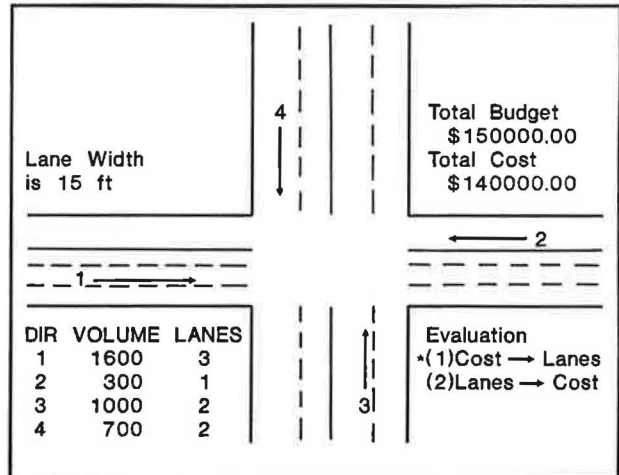


FIGURE 10 Final drawing of the interactive system.

one menu is constructed; however, this prototype system can be expanded further with a number of submenus to provide additional design features. Users can also switch to different submenu items by pointing to the submenu name on the menu, or entering the command, for switching among menu selections.

## CONCLUSIONS AND RECOMMENDATIONS

Intersection design involves the interactive evaluation of automobile, truck, public transit, taxi, pedestrian, and bicycle movements through the operating, regulatory, and service policies to achieve maximum efficiency. By properly identifying and reviewing the required traffic design improvements when developing adequate transportation facilities, many low-cost TSM strategies could be applied to improve intersection operations and achieve desired air, environmental, and community qualities, as well as fuel and economic efficiency. Many TSM type strategies may be applied through implementation of the practical, low-cost, short-range planning and programming projects. However, many current highway design and plan review procedures are difficult to implement because of the complex manual analysis process involved (5,6).

This study examines the possibilities of integrating analysis procedures and existing review processes into an interactive portable system that can interface with the existing graphics design systems. During a typical intersection design process, highway engineers have to make many decisions and determine the operational trade-offs among a number of design factors. These decisions may be bounded either by the planning budget, potential total project costs, maximum lane width of each typical highway lane, or the potential traffic demand volumes. This study illustrates the prototype applications of expert system design and LISP programming in the highway design process using the AutoCAD package. AutoLISP, the version of LISP supported by AutoCAD, was used to create a small-scale expert system to interface with the normal drawing functions.

This study demonstrated the feasibility of implementing some built-in functions of the AutoCAD system through AutoLISP programs. This implementation will assist end users in the decision making for the potential intersection design and highway planning applications. It is possible that this prototype system can be expanded into an interactive eval-

uation and plan review system to assist in designing and evaluating many TSM improvements.

The prototype can be used to identify potential problem areas, define study frameworks, develop evaluation criteria, warn of unfeasible alternatives, refine candidate actions, and recommend workable solutions for improving the design and operational analysis of the integrated intersection graphics design. The implementation of these design evaluation and plan review procedures, based on the expert systems designs and graphics design concept, can greatly assist end users in the design and plan review of various strategies, which are recommended for improving the design, planning, plan review, and implementation of the intersection design.

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