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16. Abstract

    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.

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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

- MICROCOMPUTER USER'S MANUAL -

by

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

and

Kunhuang Huarng
Research Assistant

Research Report Number 1188-3

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

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	centimetres squared	cm³
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

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

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectares (10 000 m²)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

```
°F                                              °F
        32              98.6                    212
-40     0    40     80   120    160   200
|---+---|---+---|---+---|---+---|
-40   -20    0    20    40    60    80    100
°C                      37                      °C
```

These factors conform to the requirement of FHWA Order 5190.1A.
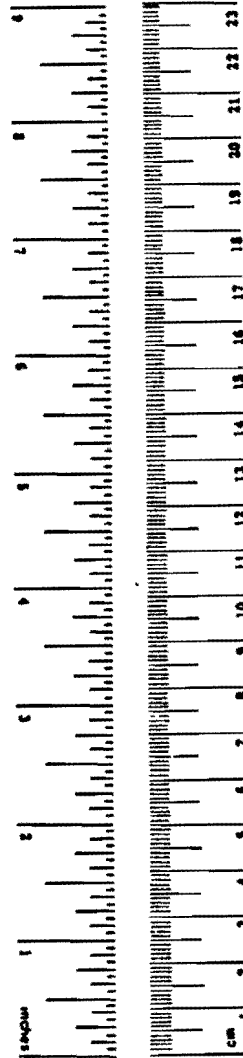
* SI is the symbol for the International System of Measurements

ABSTRACT

This study is to develop a microcomputer, knowledge-based expert system for assisting in urban freeway corridor incident management. Study activities include: the literature review, conceptual design, prototype system development, and program documentation. The information required in the decision-making processes and used in implementing freeway incident management strategies has been summarized as well as the Expert Systems Design representing incident management techniques. The study has also 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 documents the expert system being developed which includes a graphical user interface, decision-making rules, and knowledge inference mechanism to automate freeway incident management applications.

SUMMARY

The Department has begun developing a computerized real-time traffic management system to improve the traffic operations of freeways, frontage roads, and arterial systems in major urban districts over the next 10 years. Highway engineers and trade-off analyses are often needed during freeway incident management. These control decisions may be bound by either physical constraints, traffic characteristics, or traffic control practices. This report summarizes design considerations, concept design, program implementation, and system operations during the development of an expert system to assist in freeway incident management.

IMPLEMENTATION

The system was developed as a decision-making assistance to help potential users determine the proper actions needed in handling specific freeway incident management problems. This report summarizes some of the detailed operational issues involved as well as the recommended process needed for system expansion. Overall, the study illustrates the design and development of expert system analysis tools that assist in identifying and recommending alternative solutions using microcomputers.

ACKNOWLEDGMENTS

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INTRODUCTION

This study is to develop a microcomputer-based, knowledge-based expert system for assisting with the control operations during urban freeway corridor incident management. The study tasks focus on designing a knowledge-based expert advice system that recommends urban freeway corridor incident management strategies using microcomputer systems once incidents have been identified. Efforts were made to summarize, extract, and select the information needed during the decision-making process in order to implement urban freeway incident management strategies. A separate report summarizes the result of the literature review on the applications of expert systems design and possible representation schemes that allow the engineer to implement freeway incident management techniques with expert knowledge.

The research summarizes the Expert Systems applications and different representation schemes of expert knowledge and incident management techniques. Efforts were made to summarize, extract, and select the feasible decision-making processes for implementing urban freeway incident management strategies. A unified expert system development scheme has been implemented to summarize the expert knowledge representation and implementation procedures for using knowledge engineering tools. Finally, the system has translated the expert system using conventional languages for maximum system portability. An expert system, as documented, includes separate components of a graphical user interface, decision-making production rules, and an inference mechanism for automating the decision-making process. The system can be used to represent expert knowledge and assist in the decision-making process.

An expert system has been developed to offer future improvements and demonstrate potential benefits in decision-making that can optimize the traffic control applications. Efforts were made to identify those potential decision-making areas not otherwise feasible with expert systems techniques to recommend possible incident management strategies. Several expert system languages and knowledge representation methods were examined and developed. A user-friendly microcomputer program has been developed to assist in the decision-making during the freeway incident management process. The stand-alone program was written to run on MS DOS based IBM/XT/AT/386 or compatible microcomputers with or without a math co-processor. The program, as illustrated in this report, will include an input processor, error messages, and help screens. Using this program, division and district personnel can assess the alternative traffic management strategies associated with different freeway corridor control options.

This report documents the user's manual of a microcomputer-based expert system for assisting in freeway incident management. The following sections describe the incident management process, system conceptual design, user interface development, and potential system expansion. The technical materials include the incident management system process, microcomputer system design, and user-definable features available in the overall microcomputer software design that allow for future system expansion.

1

INCIDENT MANAGEMENT PROCESS

This section summarizes the basic information requirements and control responses needed to make the proper decisions during typical urban corridor freeway incident management. The following conceptual design describes the freeway incident management process. The information analysis covers the information type, quantity, and quality of data or overall information requirement needed in the highway system analysis. The decision-making process was identified by considering a step-by-step analysis when an alarm sounds, indicating the occurrence of a potential freeway incident. The analysis focused on the different types of control decisions and responses available to the control operators and field personnel. The entire process emphasized identifying data requirements and information flow to make timely decisions, such as selecting the proper incident responses.

DECISION-MAKING PROCESS

Figure 1 illustrates a step-by-step flowchart representing the necessary decision-making process control center operators normally follow when responding to a typical freeway incident. As previously indicated, the decision-making process should include five decision steps, including incident detection, incident confirmation, incident prediction, incident management, and incident response.

INCIDENT DETECTION

There may actually be different levels of information requirements or alarm status, made through the combinations of video images or audio signals, that can notify operators in the control center that an "abnormal" operating condition has already occurred in the freeway surveillance environment. This "abnormal" condition may include field equipment failure, a drastic change in traffic conditions, or a remark about scheduled special operations. Depending on the nature of the freeway incidents and needed management responses, a potential freeway incident can be properly determined. Based on the traffic control requirements of the freeway surveillance and control system, a freeway incident "alarm" may sound in response to four possible traffic operating conditions.

1. An automatic incident detection algorithm,
2. A call from the field by a service patrol, police, etc.,
3. The observation of traffic flows, or
4. A combination of visual and automatic techniques.

Incident detection by electronic surveillance serves to monitor real-time traffic data through vehicular detectors installed at critical locations along the freeway. When a delay-related incident occurs, freeway capacity is reduced at the point of incident occurrence. If capacity is reduced to a figure less than the existing demand and traffic occupancy is greater than a predetermined value, an incident has likely occurred. Similarly, incidents can be detected through logic evaluating variations in traffic flow characteristics. Some controlled experiments have been conducted using
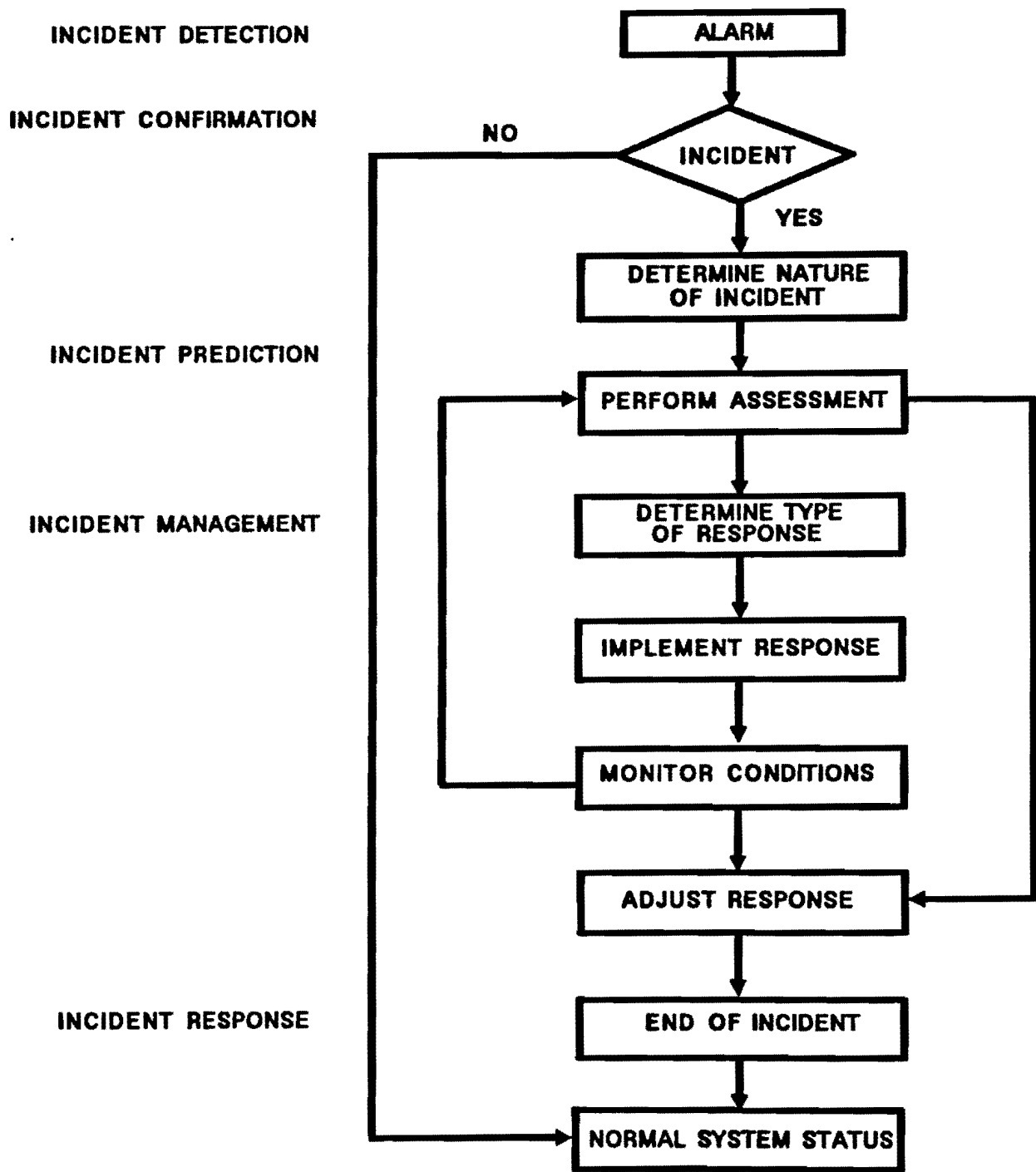
2

INCIDENT DETECTION

INCIDENT CONFIRMATION

INCIDENT PREDICTION

INCIDENT MANAGEMENT

INCIDENT RESPONSE

```
                              ┌─────────────────┐
                              │      ALARM      │
                              └────────┬────────┘
                                       ↓
                   NO           ╱─────────────╲
              ┌────────────────│   INCIDENT    │
              │                 ╲─────────────╱
              │                       │ YES
              │                       ↓
              │              ┌──────────────────┐
              │              │ DETERMINE NATURE │
              │              │   OF INCIDENT    │
              │              └────────┬─────────┘
              │                       ↓
              │     ┌──────→┌──────────────────┐──────────┐
              │     │       │PERFORM ASSESSMENT│          │
              │     │       └────────┬─────────┘          │
              │     │                ↓                    │
              │     │       ┌──────────────────┐          │
              │     │       │  DETERMINE TYPE  │          │
              │     │       │   OF RESPONSE    │          │
              │     │       └────────┬─────────┘          │
              │     │                ↓                    │
              │     │       ┌──────────────────┐          │
              │     │       │IMPLEMENT RESPONSE│          │
              │     │       └────────┬─────────┘          │
              │     │                ↓                    │
              │     │       ┌──────────────────┐          │
              │     └───────│MONITOR CONDITIONS│          │
              │             └────────┬─────────┘          │
              │                      ↓                    │
              │             ┌──────────────────┐          │
              │             │  ADJUST RESPONSE │←─────────┘
              │             └────────┬─────────┘
              │                      ↓
              │             ┌──────────────────┐
              │             │  END OF INCIDENT │
              │             └────────┬─────────┘
              │                      ↓
              │             ┌──────────────────────┐
              └────────────→│ NORMAL SYSTEM STATUS │
                            └──────────────────────┘
```

Figure 1. Incident Management Decision-Making.

3

operating speed as the determining variable. However, most electronic surveillance systems can also use occupancy data for incident detection.

For example, in Los Angeles, changes in either the lane occupancy or percentage of time period that vehicles spend over a particular detector location will provide an indication about congestion when an incident has occurred. Normally, computer software can calculate the difference in the measurements between adjacent detector stations. In some cases, the mainlane vehicle detectors may be spaced at half-mile intervals. Here, the incident alert condition can be signaled automatically by the computer when a relative percent change between the present occupancy and that of the preceding samples for the downstream detectors exceeds a certain threshold value through algorithmic analysis.

As additional traffic information immediately upstream of the incident is obtained, control operators can make decisions to activate appropriate responses. The advantage of detector-based surveillance is that it can continuously monitor the network at a relatively low operating cost with minimal human supervision. The information can be used for other traffic control tasks, such as establishing metering rates for traffic responsive ramp metering systems. The main disadvantage of the system is the nature of the incident cannot be readily identified, and some other types of surveillance are often required to determine what type of response is needed.

INCIDENT CONFIRMATION

When the alarm goes off, it is necessary to identify the triggering factors of the incident and confirm it through other available means. In particular, the freeway incident system should:

1. Determine whether an operational failure in the surveillance, communication, and control system has led to the alarm,
2. Identify the reasonableness of the incident alarm and point out the locations of the incident, and
3. Establish a level of confidence in the alarm by confirming the incident through other available field identification techniques.

INCIDENT IDENTIFICATION

Given that a freeway incident has already occurred and been confirmed in the field, it is necessary to determine the nature of the freeway incident before any further control action can be made. With a number of unknown factors, the overall incident identification process should be made in terms of the incident location, incident type, and incident severity.

1. Location of the Incident,
   o Freeway Mainlane,
   o Freeway Shoulder,
   o Freeway Medium,
   o Freeway On-ramp,
   o Freeway Off-ramp,
   o Interconnecting Service Road.

4

2. Type of Incident,
   o Accident,
   o Stalled vehicle,
   o Cargo spill, or
   o Environmental condition.

3. Severity of the Incident,
   o Number and size of vehicles involved,
   o Number of lanes blocked,
   o Property damage only/injury/fatality,
   o Type of cargo involved, and
   o Exploration potential.

INCIDENT ASSESSMENT

Next, the control center operator would have to assess the overall operating condition along the freeway corridor and the nature of the incident. It is important to identify the available design elements involved for timely decision-making. Comprehensive incident assessment must consider the following requirements:

1. The capabilities of the organization, in terms of,
   o Equipment availability, status, and location,
   o Personnel availability, and
   o Operating Procedures, i.e., who has agreed to do what.

2. The likely duration of the incident,
   o Acquired from historical experience,
   o Computed from incident prediction algorithm, and
   o Assessed similar incidents.

3. The potential impact on traffic flow, and
   o Route,
   o Time of day, and
   o Traffic volumes.

4. The status of the primary and diversion routes,
   o For a potential freeway diversion, and
   o For releasing traffic information.

INCIDENT RESPONSE

It was noted that what control responses can be taken depends highly on locally established practice and operating procedures. If the control response is multi-jurisdictional, there is the potential for turf problems among different operating agencies. Historically, operators contacted the police or highway patrol, who determined the need for a response. In establishing an incident management system, it is important that relationships and mutual trust be developed among all participating agencies responsible for the incident. Then, the incident assessment can lead to determining the type of control responses required for the different incident conditions. The incident response involves immediate decisions relating to:

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1. Personnel and equipment,
   o Who is at the scene,
   o Who else should be sent to the scene,
   o Who to inform,

2. Real-time motorist information,
   o Signs,
   o HAR,
   o Radio,
   o TV broadcasts,

3. Off-site traffic control for diversion,

4. Available traffic control strategy.

In the United States, freeway management agencies have used various coordination schemes among the different levels of freeway agencies, highway patrols, and local policies to manage freeway corridor traffic. For example, in Chicago, service patrols of the freeway management team take care of disabled vehicles without calling the police. However, in the event of an accident, the police become involved. In Los Angeles and Long Island, the police must be present to remove a disabled vehicle. Either way a response should be implemented, conditions monitored and assessed. As necessary, the incident response will be adjusted, based upon feedback from freeway monitoring systems.

CONDITION ANALYSIS

This analysis addresses the needed control decisions and determines the types of responses available to both control operators and field personnels. These condition analyses will assess the basic data elements that describe the nature and extent of the freeway incident occurs.

DATA ELEMENTS

The condition analysis focuses on identifying the overall system data requirements that can feed the information flowchart developed during the freeway incident management process. The data elements mainly include:

1. Type of data,
2. Amount of data,
3. Form of the data base input,
4. Source of data, and
5. How the data are acquired.

The realistic availability and suitability of the basic data elements depend on the overall freeway management system designs. Therefore, it is important to investigate the basic data needs, system information process, and communication requirements while planning traffic control strategies. The proper design considerations must be made during the planning, design, and development of the computerized freeway corridor traffic management systems.

MICROCOMPUTER SYSTEM

Incident Management Expert System (IMES) is a microcomputer-based expert system environment developed by the Texas Transportation Institute of the Texas A&M University System. The IMES system provides an intelligent, user-friendly expert system framework by applying several state-of-the-art computer programming techniques. As illustrated in Figure 2, the system includes the graphics user interface, a mouse supporting function, and an expert system inference processor for microcomputer operation.

As illustrated in Figure 3, the graphics user interface displays were created to illustrate the different portions of highway from which users can directly identify targets. A mouse allows the user to easily select menu items from the screen. Instead of using conventional keyboard input, mouse clicking creates a convenient user input media. Expert system is the heart of this expert system. Expert system serves as a consultant helping the user make appropriate decisions according to different situations. The system software also contains the reasoning mechanism or interface engine that will perform the forward-chaining analysis to provide advice to the user.

To provide the maximum system expansion capability, built-in flexibility was designed during the software development. As shown in Figure 4, the user can easily manipulate the IMES by modifying the existing production rules, changing the important study variables, as well as adding new production rules to the existing expert system without recompiling IMES. In addition, the user can also change the menu items on the display screen using the common word processor in the ASCII file. This user manual will demonstrate the details about how to change the menu in the last section.

IMES ENVIRONMENT

This section describes the overall expert system environment including the system design configuration, the CLIPS expert inference engine, and recommended operating procedure. The discussion covers how to maintain and execute the IMES system. The IMES environment section describes the operating environment that IMES runs under and lists the files that IMES needs to access. The section on the user-defined conditions describes how users may modify the menu items on the screen. The section on user-defined responses demonstrates how users can modify system responses to fit different application needs. Lastly, some basic syntax for writing the CLIPS expert system is adopted from the CLIPS manual for further reference.

SYSTEM CONFIGURATION

The IMES system will run on IBM PC or IBM PC compatible machines with either EGA, VGA, or Hercules graphics adapter. IMES runs well in a machine with or without a mouse installation. When the IMES runs in a machine without a mouse, keyboard input will be effective. To run the IMES system properly, make sure that all the major program modules are included as shown on Table 1. The system has simplified user's instructions for the needed program analysis as shown in Figure 5.

Configuration for IMES
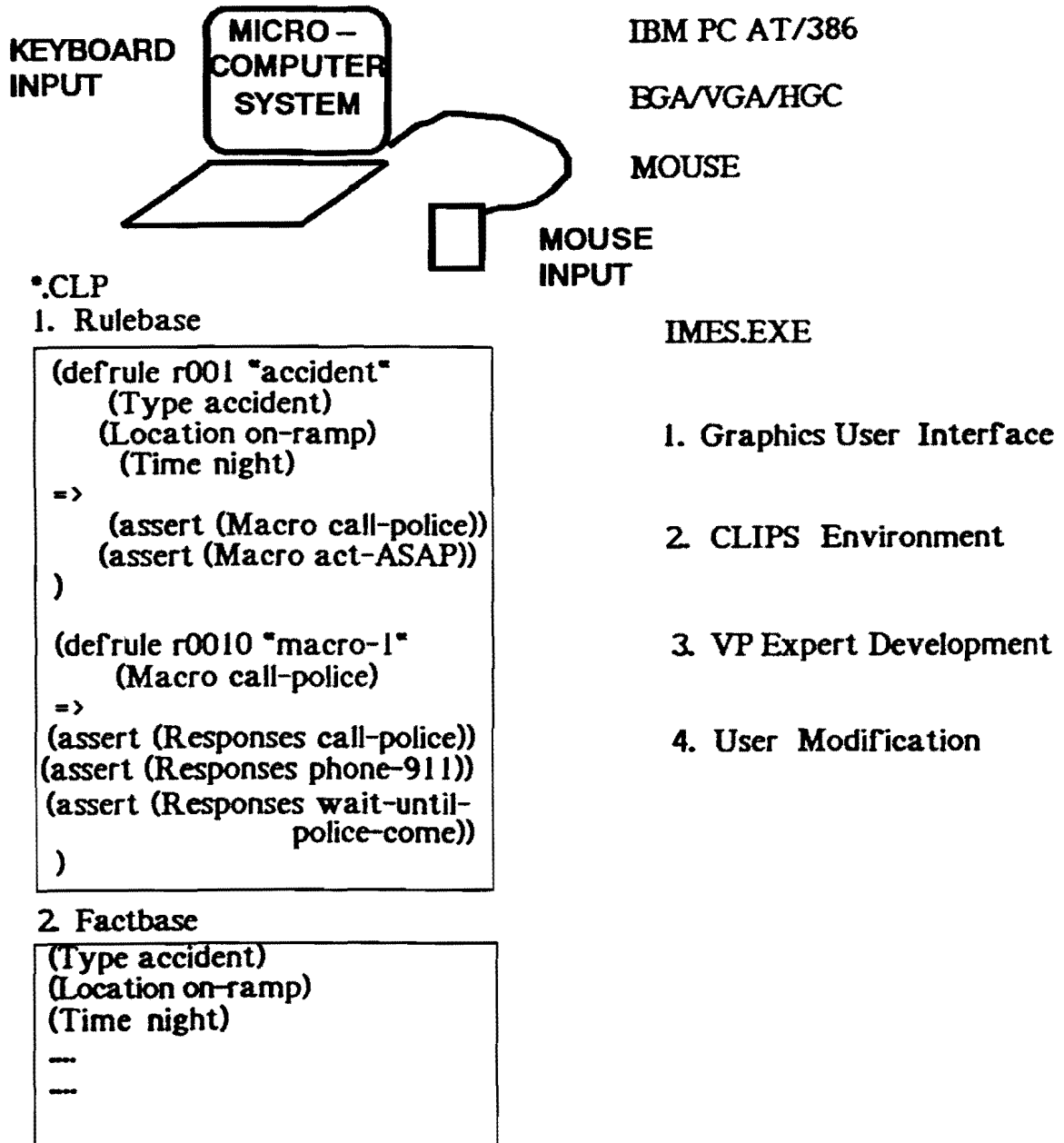# (Incident Management Expert System)

KEYBOARD INPUT   MICRO – COMPUTER SYSTEM

IBM PC AT/386

EGA/VGA/HGC

MOUSE

MOUSE INPUT

*.CLP

1. Rulebase

```
(defrule r001 "accident"
        (Type accident)
        (Location on-ramp)
        (Time night)
=>
        (assert (Macro call-police))
        (assert (Macro act-ASAP))
)

(defrule r0010 "macro-1"
        (Macro call-police)
=>
(assert (Responses call-police))
(assert (Responses phone-911))
(assert (Responses wait-until-
                    police-come))
)
```

2. Factbase

```
(Type accident)
(Location on-ramp)
(Time night)
---
---
```

IMES.EXE

1. Graphics User Interface

2. CLIPS Environment

3. VP Expert Development

4. User Modification

Figure 2. Microcomputer-based Expert System Design.

8
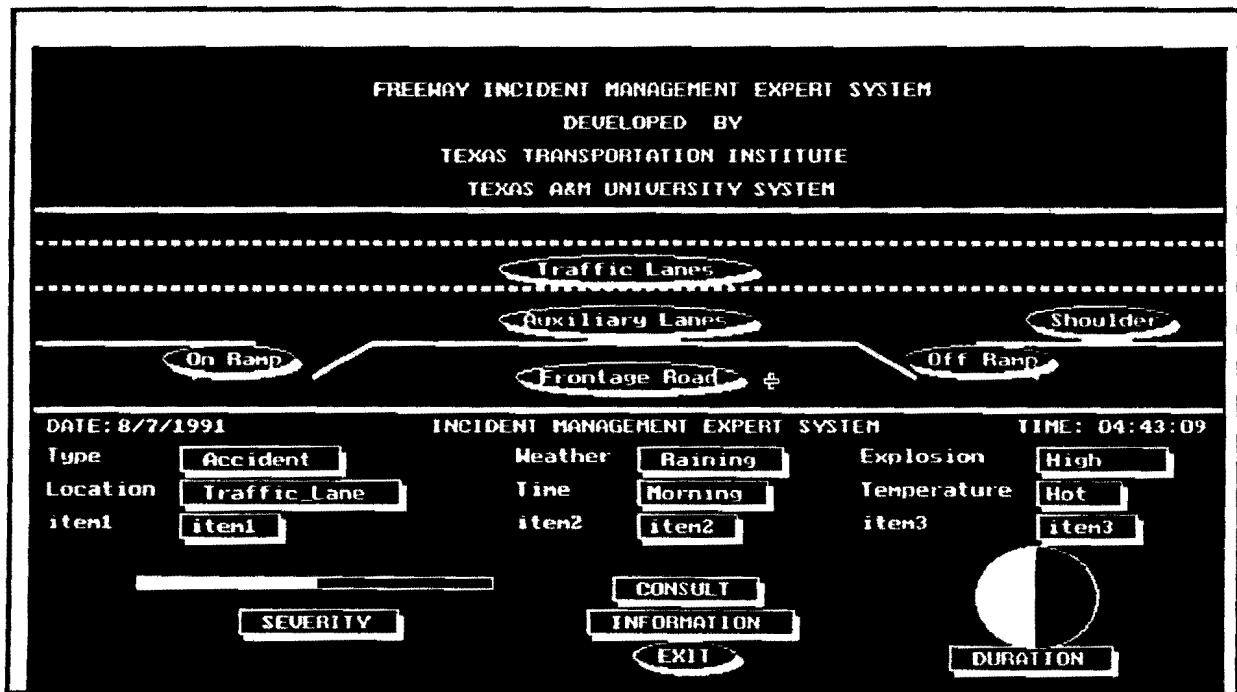
Figure 3. System Initial Screen.

Data Dictionary for IMES
(Incident Management Expert System)

1. Type
   Accident
   Spilled Load
   Disabled Vehicle
	5. Time
	   Morning
	   Afternoon
	   Evening
	   Night

2. Location
   Traffic Lane
   On Ramp
   Off Ramp
   Shoulder
   Auxiliary Lane
	6. Temperature
	   Hot
	   Fair
	   Cold
	   Freezing

3. Weather
   Raining
   Windy
   Snowing
   Fine
	7. Duration(1-60)
	
	8. Severity(1-10)

4. Explosion
   High
   Medium
   Low
	9. Conditions
	   First
	   Second
	   Third

Figure 4. Data Input Elements.

FRONTAGE ROAD AND PARALLEL FACILITIES

In Texas, there are continuos frontage road as additional freeway facilities. In addition, the parallel arterials can be used for alternative routes during incidents

Traffic Lanes

Auxiliary Lanes

Shoulder

On Ramp

Off Ramp

Frontage Road

DATE: 8/7/1991   INCIDENT MANAGEMENT EXPERT SYSTEM   TIME:

Type   Accident   Weather   Raining   Explosion   High
Location   Traffic_Lane   Time   Morning   Temperature   Hot
item1   item1   item2   item2   item3   item3

SEVERITY   CONSULT   INFORMATION   EXIT   DURATION

Figure 5. System Help Information.

TABLE 1.   PROGRAM MODULES OF IMES.

Name	Description
cond.txt	user-defined conditions
response.dat	user-defined responses
ega.bgi	graphics interface file
imes.exe	executable file
imes.clp	knowledge base

CLIPS

CLIPS (C Language Production System) is a public domain expert system building tool and programming language developed and maintained by the National Aeronautics and Space Administration (NASA).   The system was developed in C programming language.   The major advantage of the CLIPS system is that it can be integrated and embedded within any computer program written in C language.   Users can easily expand CLIPS to quickly develop any expert system shell that matches the user's requirements.   The CLIPS module was set up to provide the inference engine for inferring the rules according to the facts and a control strategy for controlling the sequence of the rules being fired.   The facts will be acquired from the user's input data, and the results from CLIPS will be shown on the initial screen.

CLIPS is an expert system building tool built by the Artificial Intelligence Section at NASA/Johnson Space Center.   CLIPS was developed to tackle three major problems caused by Artificial Intelligence programming languages like LISP.   However, the LISP language provides low portability on conventional computers, and poor integration with other programming languages. In addition, LISP machines cost more than conventional ones.   CLIPS was designed to provide high portability, low cost, and easy-to-integrate environment for development of expert systems.

CLIPS is a rule-based programming tool using forward-chaining based on Rete algorithm.   In CLIPS, the major way of representing knowledge is a rule. A rule is a collection of pre-conditions and post-conditions.   Once the pre-conditions are matched, the post-conditions will be executed.   The whole set of rules in an expert system is called rule base. CLIPS provides a mechanism, called inference engine, to check the matching of pre-conditions of rules, and to execute the corresponding post-conditions.   Fact is the essential way of representing data in CLIPS.

Once the rules are created and the facts are prepared, CLIPS is ready to execute the rules.   Unlike conventional programming, CLIPS does not need to specify the sequence of operations explicitly.

The basic execution cycle is described as follows.

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1. CLIPS examines rules to see if pre-conditions of the rules are met.

2. All rules whose pre-conditions are met are activated and put into the agenda. The agenda functions like a stack. Once the rules are activated, they are pushed onto the agenda. Then the top rule is selected and fired. The post-conditions of the rule are executed.

3. CLIPS package was written in the C programming language. The system can be fully integrated and embedded with the C conventional language.

Source and Ordering Information

CLIPS is available through the Computer Software Management and Information Center (COSMIC). The program number is MSC-21208. Further information can be obtained from:

> COSMIC
> 382 E. Broad St.
> Athens, GA 30602
> (404) 542-3265

User Group and Bulletin Board

CLIPS user group was formally established during August 1991. User group plans to support activities such as an electronic mail system for the COSMIC users, a newsletter, and so on. Users can send questions, answers, and editorials via the electronic mail services.

In addition, NASA has a software support bulletin board. The login telephone number is TEL:(713) 280-3896 or (713) 280-3892. The software support bulletin board provides services for communicating with other users, application abstracts, answers to problems and general CLIPS information.

OPERATING PROCEDURE

First, the user should make sure that the program files have been copied to the user's working directory. The user should install the mouse drivers if so equipped. If not equipped for a mouse, the user can skip that step and use the cursor keys to assess various program functions.

To run the IMES, user simply types "IMES" after the command prompt, and hits <return>, and the initial screen of IMES will show up on the screen. Then, the user proceeds with his/her inputs and waits for the study results. After invoking the IMES analysis, the user can operate through the IMES initial screen. The user can use the mouse or keyboard to move the cursor to a specific area and select the needed elements by clicking the mouse or hit <return> through the pull-down menu user-interface design.

The basic procedure of interacting with the IMES system can be described in Figure 6. Users can select menu items from the inital screen. There are a number of menu selection and sets of user-definable selection elements.
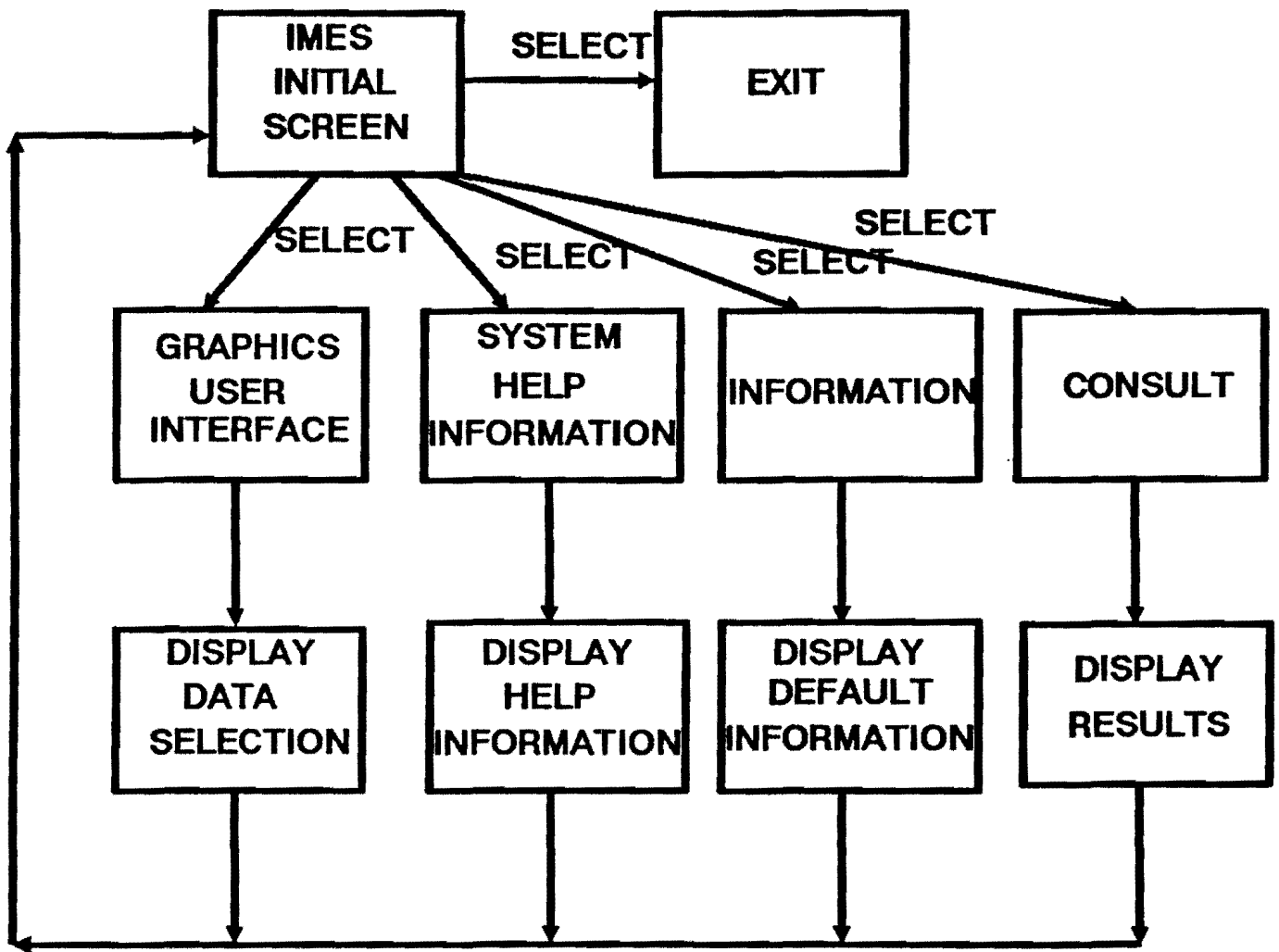
Figure 6.   The Basic Procedure of Interacting with IMES.

Help information can also be invoked by clicking data input items, such as the On Ramp, Traffic Lanes, Auxiliary Lanes, Frontage Raods, Off Ramp, and Shoulders. The help information will be display on the top half of the screen. Graphics screen and mouse indications provide another forms of menu user interface facility. When users select any item such as Type, Location, Weather, Time, Explosion, or Temperature of the incident, the related information will be selected.

As illustrated in Figure 7, when users select item Location, the pop-up menu will display Traffic_Lane, On_Ramp, Off_Ramp, Shoulder, Aux_Lane, and Unknown for users to pick. When users select any one of them, the information will be sent to the fact base of the expert system in IMES for later reference. After the users' selection, the display will return to the initial display screen. Similarly, menus Severity and Duration are for users to input the degree of severity of the incident and the duration of the incident. The graphics display will change according to users' input. After the users finished their input, the display will return to the initial screen.

The user can select any item by clicking the mouse or hitting <return>. IMES will assert these items as facts to the expert system. When user selects any item from the initial screen, the corresponding part of the freeway system will be flashed on the upper part of the initial screen. Figures 8 and 9 illustrates the example menu and system responses for selecting the incident severity and incident durations, respectively. When users select menu INFORMATION, the top half of the screen will display the default information for IMES. When users select menu EXIT, users will exit from IMES system back into the DOS environment. When users select menu CONSULT, IMES will take all the facts input by users to infer the results, which are displayed on the top half of the screen. After users observe the results, users hit any key to return to the initial screen.

After selecting all the necessary input information, the user may click "CONSULT" to request the system to infer the result of the possible recommendations from the expert system responses are shown in Figure 10. After the inference engine infers the heuristic rules according to the facts, the results will be shown on the upper part of the initial screen.
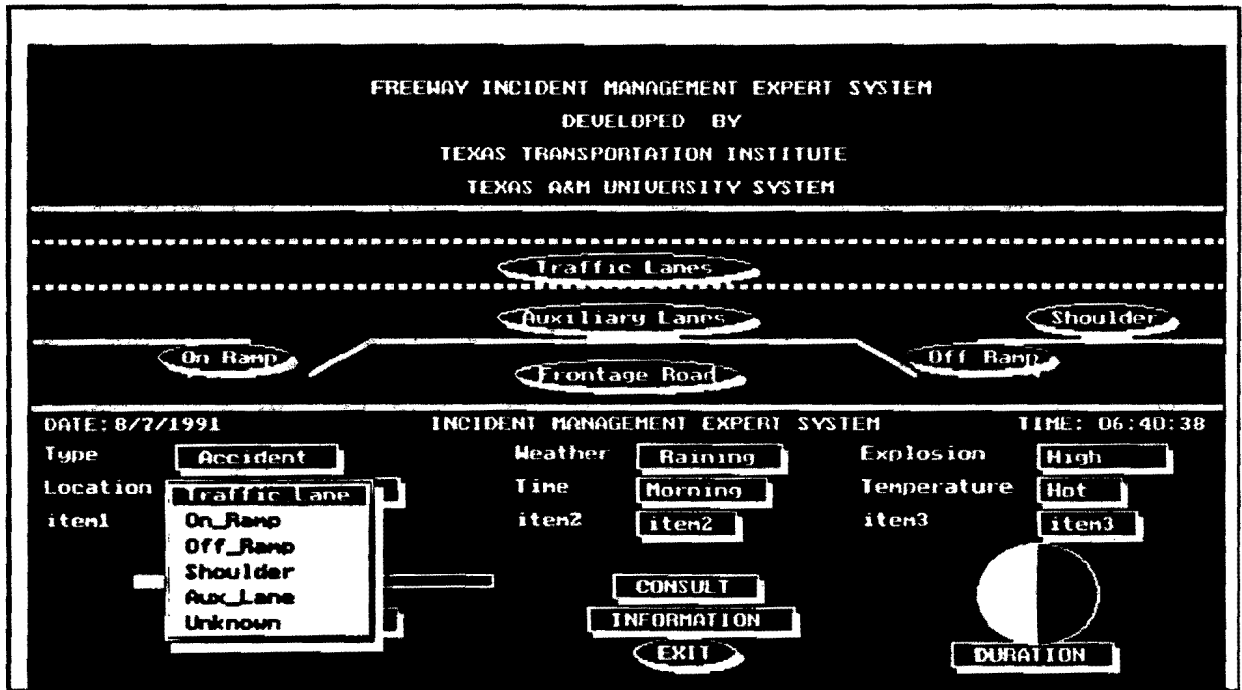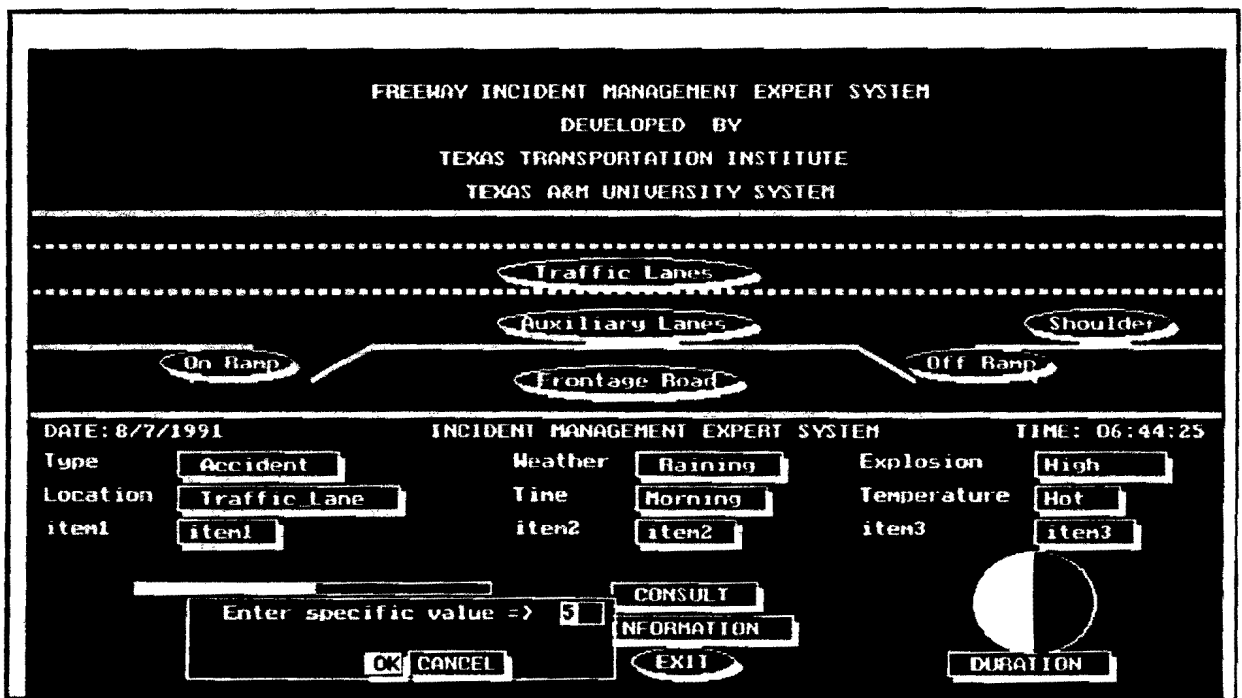
Figure 7. Example of Graphics User Interface.

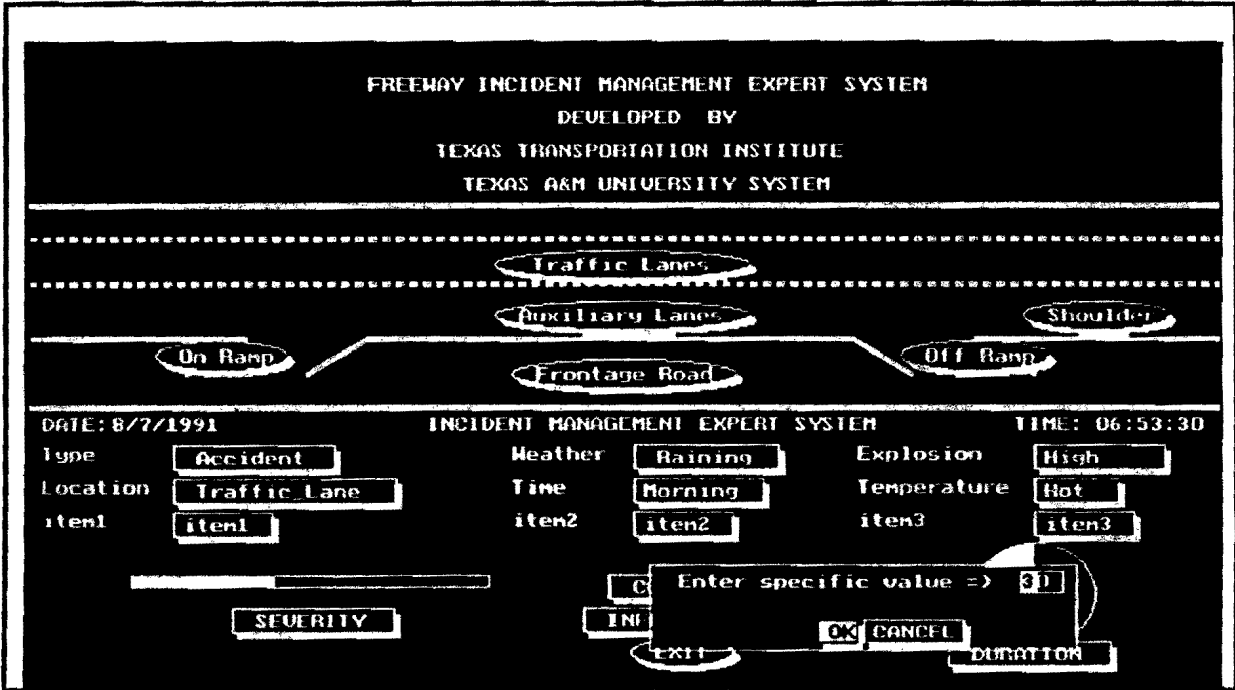Figure 8. Example of Incident Severity.
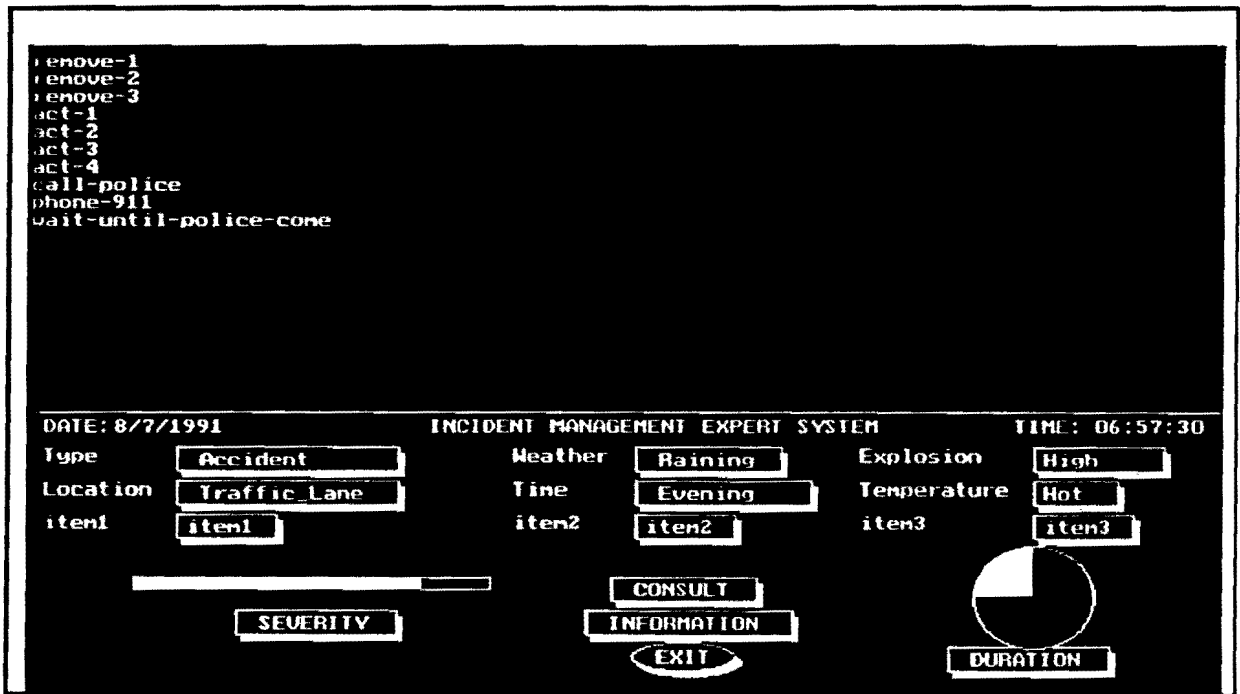
Figure 9. Example of Incident Duration.

Figure 10. Example of Expert System Response.

USER-DEFINABLE OPERATIONS

This expert system is a realistic implementation of the rule-based expert system. The basic system can be used intuitively through graphics-based user interface. Several facilities were designed to allow the user to enhance the system knowledge representation. In particular, the system has been designed uniquely with three user-definable features:

1. The decision-making production rules are defined in the external text files so users can easily make system modifications without requiring program recompiling through an editor.
2. The control responses are also specified in the external text files so that each agency can provide the agency-specific responses.
3. Besides the commonly recognized decision variables used in incident management, the user can also create additional study variables for the site specific analysis and local policy requirements.

By defining these operating conditions as well as allowing the revision of the needed control responses, the user can reflect the operational requirements without requiring any internal program modifications.

USER-DEFINED CONDITIONS

IMES allows users to define new conditions as needed. Users are able to categorize their conditions into three groups, each with five conditions. So there is a total of 15 additional conditions available in addition to IMES's built-in conditions as shown in Figure 11. To specify these new conditions, users only need to change the ASCII text file, named **cond.txt**, by using any word processors that can edit ASCII files. The format of **cond.txt** is described in Table 2. Note IMES only reads the first eight characters in each line for the graphic display layout.

USER-DEFINED RESPONSES

IMES is a generalized expert advise system for managing freeway incidents. If there are no specific response plans available, a set of generic control responses was provided initially. Users can then design their own response messages. IMES will display the messages according to user-defined responses. For illustration, there are seven types of response messages in IMES: call-point-authority, call-police, act-ASAP, remove-incident, investigate-off-the-site, call-citizen-groups, and call-Texas-SDHPT. Each type of response message is a primitive response message. Users are free to define several response messages under each type of response message. For example, users may initially define call-police, phone-911, wait-until-police-come, etc., and expand detailed responses themselves as needed.

The file RESPONSE.DAT is described as follows. Each control response message is preceded by a "Macro" followed by the user defined response messages. Each type of response message is iteratively defined as described with a "Macro" added as the end of file.
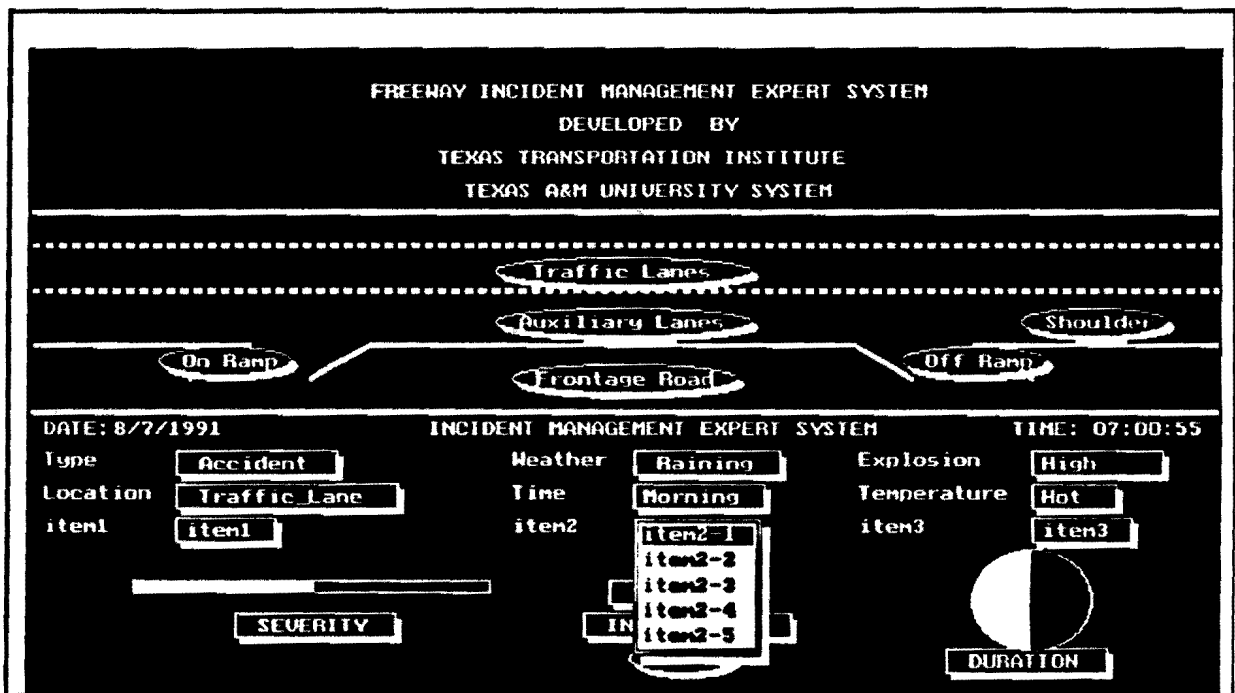
20

Figure 11. Example of User-Definable Inputs.

TABLE 2. THE FORMAT OF COND.TXT.

Line	Purpose
1	Label of Group 1
2	Condition 1 of Group 1
3	Condition 2 of Group 1
4	Condition 3 of Group 1
5	Condition 4 of Group 1
6	Condition 5 of Group 1
7	Label of Group 2
8	Condition 1 of Group 2
9	Condition 2 of Group 2
10	Condition 3 of Group 2
11	Condition 4 of Group 2
12	Condition 5 of Group 2
13	Label of Group 3
14	Condition 1 of Group 3
15	Condition 2 of Group 3
16	Condition 3 of Group 3
17	Condition 4 of Group 3
18	Condition 5 of Group 3

The following section provides a simplified description of the potential control responses. As indicated, every word of a recommended set of control actions or response message is connected by a dash. If the user wishes to change the name of the type of response message, the user needs to change the name in file response.dat as well as that in the file imes.clp. To change the response message, the user only changes the name in file response.dat. Besides, the user can add more response messages under each type of response message. To achieve this, the user adds the items under that type of response message in the file response.dat.

```
Macro call-point-authority
       call-authority-1
       call-authority-2
       call-authority-3

Macro call-police
       call-police
       phone-911
       wait-until-police-come

Macro act-ASAP
       act-1
       act-2
       act-3
       act-4

Macro remove-incident
       remove-1
       remove-2
       remove-3

Macro investigate-off-the-site
       investigate-1
       investigate-2
       investigate-3

Macro call-citizen-groups
       call-local-citizen-group
       call-city-citizen-group
       call-state-citizen-group

Macro call-Texas-SDHPT
       call-Texas-SDHPT

Macro
```

If the user is familiar with CLIPS programming, it is easy to add more types of response messages into the system without requiring system recompilation. In addition, the user can also modify the rules in the expert system, as illustrated in the next section.

DEVELOP NEW RULES

Writing the rule-base for CLIPS is rather straightforward. Though the rules could be very complicated, only a simple format is needed for IMES. The format of the rules is described as follows.

PRODUCTION RULES

The production rule is the primary method of representing knowledge in this expert system. This system uses the rules from the CLIPS package.

Syntax:
```
(defrule <name> ["<comment>"]
     [ (<<first pattern>>)
                  .
                  .                        Left-Hand Side
                  .
       (<<mth pattern>>) ]
=>
       [ (<<first action>>)
                  .
                  .                        Right-Hand Side
                  .
         (<<nth action>>) ]
)
```

Example:
```
(defrule r001
       "This is an example of a simple rule"
       (data color red)
       (data size large)
       (data shape circle)
=>
       (assert (data match))
)
```

Left-Hand Side

Syntax:
```
(test (<defined-function> [ <<arguments>> ]))
```

Example:
```
(defrule r0001
       (data size-1 ?x)
       (data size-2 ?y)
       (test (> ?x ?y))
=>
          .
          .
          .
```

Variable

Pattern on LHS	Facts	?x is bound to
(data color ?x)	(data color red)	red
(data size ?x)	(data size 50)	50

Logical & Relation Operator

Symbol	Function
! or not	not
&& or and	and
|| or or	or
=	equal (numeric)
eq	equal (any)
!=	not equal (numeric)
neq	not equal (any)
>=	greater than or equal
>	greater than
<=	less than or equal
<	less than

Arithmetic Operator

Symbol	Function
/	division
*	multiplication
+	addition
-	subtraction

Right-Hand Side

Syntax:

```
(assert (<<pattern>>)
        [ (<<additional patterns>>) ]
)
```

Example:
```
(assert (data color red))
```

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Syntax:

```
(retract ?<fact-var> [ ?<<fact-vars>> ] )
```

Example:
```
(defrule r0001
        ?p1 <- (data color red)
        ?p2 <- (data size 50)
   =>
        (retract ?p1 ?p2)
```

Syntax:

```
(bind ?<var-name> <value> or <variable>)
```

Example:
```
(defrule r0001
        (data size ?x)
   =>
        (bind ?y 5)
        (bind ?z ?x)
        (bind ?a (+ 3 5))
        (bind ?b (read))
)
```

Syntax:

```
(open "<file-name>" <logical-name> ["<mode>"])
(close [<logical-name>])
(readline [<logical-name>] )
```

Mode	Meaning
r	read only
w	write only
r+	read and write
a	append only

Example:
```
(defrule r0001
        (data size 50)
   =>
        (open "data.in" file-1 "r")
        (open "data.out" file-2 "w")
        (bind ?x (readline file-1))
        (bind ?a (+ ?x 10))
        (fprintout file-2 ?a crlf)
        (close file-1)
        (close file-2)
)
```

Syntax:

```
(if (<predicate> [<<args>>])
then
        [(<<action 1>>)
        .
        .
         (<<action n>>)]
[else
        (<<action 1>>)
        .
        .
        (<<action n>>)]
)
```

<u>Example</u>:

```
(defrule r0001
        (data size ?x)
        =>
        (if (< ?x 40)
        then
                (format t "%d less than 40" ?x)
        )
)
```

The above example illustrates how the decision rules may be modified from the initial knowledge base as provided by the current system. The user can refer to the CLIPS Reference Manual for more detailed information concerning the background of the CLIPS system development, if needed.

MODIFY EXISTING RULES

The objective of IMES design is to build a maintainable and user-friendly system. To be a maintainable system, the entities of IMES were designed as loosely coupled as possible, i.e. the interconnection of entities were minimized. Once the rules are changed, IMES need not be re-compiled since the rule base is treated as an input file of IMES. Different rule bases are just different input files to IMES, and they do not affect IMES at all. For the same reason, when users modify user menus, IMES needs no re-compilation. IMES takes the user definable menus as an input file. Each time IMES reads the different menus and display the different menus correspondingly. So IMES becomes maintainable and easy to use.

To add a new rule or to modify a rule in IMES is fairly straightforward. Users can add new knowledge directly to the rule base, replacing old knowledge. There is no CLIPS development environment needed for compiling the new rule base since IMES itself embeds CLIPS. After modification, the user needs only re-run IMES. IMES will re-compile the new rules and generate the new results corresponding to the new rule base.

For example, under the given decision rule describing how to handle an incident: the incident type is an accident; the incident location is on ramp; the time is in the morning; and the duration is less than 10 minutes, user needs to call police and act as soon as possible. The scenario can be described in a decision rule as follows.

```
(defrule rule-01
     "Test rule"
     (Type accident)
     (Location on-ramp)
     (Time morning)
     (Duration ?x)
     (test (<= ?x 10))
=>
     (assert (Macro call-police))
     (assert (Macro act-ASAP))
)
```

If there is no rule like this in the existing rule base, the user can directly add this rule in the rule base. If this rule has already existed in the rule base, and the user wants to modify one of its pre-conditions or post-conditions, the user directly replaces the old knowledge with the new knowledge. Provided the user wants to change the happening time from morning to evening, the user just replaces 'morning' by 'evening' in the rule base. And the rule could be modified as follows:

```
(defrule rule-01
     "Test rule"
     (Type accident)
     (Location on-ramp)
     (Time evening)
     (Duration ?x)
     (test (<= ?x 10))
=>
     (assert (Macro call-police))
     (assert (Macro act-ASAP))
)
```

As illustrated by the examples above, the modification of IMES is straightforward by the users under the user-definable conditions. After modifying the rule base, the user can re-run IMES, and new results will be generated according to the new rule base. However, the correctness of the results will still be based on the correctness of the new rule base.

CONCLUSIONS AND RECOMMENDATIONS

Non-recurring incidents 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, incident management is especially important while freeways are operating near, at, or beyond their physical capacities. Engineers often need to 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 necessary for determining when and how computerized traffic control systems should respond.

This report documents a microcomputer-based expert system being developed which includes a graphical user interface, decision-making rules, and knowledge inference mechanism to automate freeway incident management applications. Overall, the microcomputer user's manual explains the design and implementation issues of the expert system that can assist control operators in identifying and recommending alternative solutions using microcomputers. The expert system can be used as a decision-making assistance to help potential users determine the different actions needed to handle specific freeway incident management problems. The system software can be further implemented along with 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 lead to future implementation of new generations of advanced traffic control concepts to the arterial street network and freeway corridor systems to automate on-line, real-time traffic responses and management strategies.

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APPENDIX. DESCRIPTION OF DATA FILES.

<u>RESPONSE . DAT</u>
1. Macro call-point-authority
2. call-authority-1
3. call-authority-2
4. call-authority-3
5. Macro call-police
6. call-police
7. phone-911
8. wait-until-police-come
9. Macro act-ASAP
10. act-1
11. act-2
12. act-3
13. act-4
14. Macro remove-incident
15. remove-1
16. remove-2
17. remove-3
18. Macro investigate-off-the-site
19. investigate-1
20. investigate-2
20. investigate-3
21. Macro call-citizen-groups
22. call-local-citizen-group
23. call-city-citizen-group
24. call-state-citizen-group
25. Macro call-Texas-SDHPT
26. call-Texas-SDHPT
27. Macro

<u>DOND . TXT</u>
1. item1
2. item1-1
3. item1-2
4. item1-3
5. item1-4
6. item1-5
7. item2
8. item2-1
9. item2-2
10. item2-3
11. item2-4
12. item2-5
13. item3
14. item3-1
15. item3-2
16. item3-3
17. item3-4
18. item3-5