Real-Time Expert System Approach to Freeway Incident Management

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Fundamental to the operation of most intelligent vehicle-highway system (IVHS) projects are advanced systems for surveillance, control, and management of integrated freeway and arterial networks. A major concern in the development of so-called "smart roads" is the provision of decision support for traffic management center personnel, particularly for addressing nonrecurring congestion in large or complex networks. Decision support for control room staff is necessary to detect, verify, and develop effective response strategies for traffic incidents. These incidents are events that disrupt the orderly flow of traffic and cause nonrecurring congestion and motorist delay. Nonrecurring congestion can be caused by accidents, spilled loads, stalled or broken-down vehicles, maintenance and construction activities, signal and detector malfunctions, and special or unusual events. An attempt was made to implement a novel, artificial intelligence–based approach to the problem of providing operator decision support in integrated freeway and arterial traffic management systems, as part of a more general IVHS. The development of the Freeway Real-Time Expert System Demonstration (FRED), a component prototype real-time expert system for managing nonrecurring congestion on urban freeways in southern California, is discussed. The application of FRED to a section of the Riverside Freeway (SR-91) in Orange County is presented as a case study and illustrates the current capabilities of the system.

As a means to improve road-based mobility and safety, with decreased economic and environmental impacts from traffic, the concept of an intelligent vehicle-highway system (IVHS) is evoking substantial interest in Europe, Japan, and the United States. Relying on advances in electronics, communications, and computing, IVHS technologies would create so-called "smart cars" and "smart roads" to achieve significant areawide traffic operation improvements. A recent report (*1*) classified IVHS technologies in four categories:

1. Advanced traffic management systems,
2. Advanced driver information systems,
3. Freight and fleet control systems, and
4. Automated vehicle control systems.

The following paragraphs focus on advanced traffic management systems because advanced systems for surveillance, control, and management of integrated freeway and arterial networks are fundamental to the operation of most IVHS projects. In addition, implementation of these concepts is beginning. In Los Angeles, for example, the Santa Monica Freeway Smart Corridor Demonstration Project is under way, and other smart corridor projects are likely to follow.

However, a major concern in the development of such smart roads is the provision of decision support for traffic management center personnel, particularly for addressing nonrecurring congestion in large or complex networks. Decision support for control room staff is necessary to detect, verify, and develop effective response strategies for traffic incidents. These incidents are events that disrupt the orderly flow of traffic and cause nonrecurring congestion and motorist delay. Nonrecurring congestion can be caused by accidents, spilled loads, stalled or broken-down vehicles, maintenance and construction activities, signal and detector malfunctions, and special or unusual events. The ultimate objective of this research was to implement a novel, artificial intelligence (AI)–based approach to the problem of providing operator decision support in integrated freeway and arterial traffic management systems, as part of a more general IVHS. Although it is envisioned that for some time vehicles will operate mostly under driver control, in the future automated lateral and longitudinal control of vehicles may be possible. New vehicles, facilities, and vehicle and system control strategies may also be used. Nevertheless, advanced decision support capabilities similar to the concepts being developed in this research are likely to be important to the operation of future IVHS projects.

In previous research (*2*), a conceptual AI–based design was developed. The approach involved a hierarchically defined set of decision support modules within a distributed blackboard framework, emphasizing the use of real-time knowledge-based expert systems (KBESs). In practice these KBESs could be associated with multiple computers, traffic control centers, transportation agencies, and traffic subnetworks, even in one corridor.

The development of the Freeway Real-Time Expert System Demonstration (FRED), a component prototype real-time expert system for managing nonrecurring congestion on urban freeways in southern California, is discussed. The application of FRED to a section of the Riverside Freeway (SR-91) in Orange County is presented as a case study and illustrates the current capabilities of the system.

SYSTEM DEVELOPMENT

Nature of the Domain

In describing the operation of the freeway traffic operations center (TOC) in Los Angeles, the California Department of Transportation (Caltrans) states that the basic goal is to "know what's happening on the freeway system and to get infor-

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mation out to the motoring public." In conjunction with the California Highway Patrol, the TOC currently disseminates information by commercial radio stations and changeable message signs (CMSs) adjacent to the freeway. The TOC can dispatch an operational unit called the "major incident traffic management team" (MITMT) to incident locations, while providing continuous monitoring and coordination functions. The semi-automatic traffic management system (SATMS) includes approximately 700 directional freeway miles, 934 instrumented locations or stations (typically involving a full set of loops across the pavement, plus those at on- and offramps), and about 5,000 detectors providing 30-sec occupancy and volume data.

The city of Los Angeles also maintains a TOC for the signalized surface street system, called the "automated traffic surveillance and control system" (ATSAC). Currently, the system monitors approximately 400 system detectors. The Santa Monica Freeway Smart Corridor Demonstration Project area encompasses over 400 signalized intersections and will likely add 1,000 detectors to the ATSAC system. Inclusion of additional areas may add hundreds of intersections and thousands of detectors to ATSAC in the future.

As the breadth and scope of these systems continue to expand, particularly in conjunction with smart corridor and other IVHS concepts and requirements, the amount of incoming TOC data and the complexity of both the networks and incident management and response functions will make it increasingly difficult, if not impossible, for human operators to function effectively without automated assistance.

Real-time KBESs address situations such as those in which human operators suffer from cognitive overload in time-sensitive environments. In a smart corridor context, a KBES could filter low-level (but voluminous) detector data and present the operator with fewer high-level analyses and recommendations concerning incident detection, verification, and response. Use of the system would reduce the operator involvement needed to focus on true operational problems, permit rapid development of optimal and consistent response plans, and facilitate coordination among all relevant agencies, thereby reducing delays associated with nonrecurring congestion.

System Functions

The objective of the envisioned system is to provide decision support to TOC staff in the traffic surveillance and control functions required in a smart corridor context, potentially as part of a more general IVHS. Five integrated modules are proposed (*2*):

1. Incident detection,
2. Incident verification,
3. Identification and evaluation of alternative responses,
4. Implementation of selected responses, and
5. Monitoring recovery.

Emphasis is placed on the initial development of FRED, which, as a component of an overall decision support system, is limited to a freeway TOC to assist in managing nonrecurring congestion on urban freeways. FRED is currently being developed for a 6-mi section of the Riverside Freeway (SR-91) in Orange County, California. To assist in the development of FRED, detector data containing several major incidents have been supplied by Caltrans for this section of freeway, which is located between two other major freeways (I-5 and SR-57).

The overall functions of FRED are presented in Figure 1. In this figure Smart Central, or SCC, refers to a proposed real-time KBES that would attempt to optimize corridor or areawide traffic conditions and would coordinate response actions among all relevant agencies. Associated with Smart Central would be a major relational data-base system to facilitate the networked linking of all agencies and their control systems. Further details are provided by Ritchie (*2*).

Hardware and Software

FRED is being developed using G2 real-time expert system development software (*3*). G2 has been designed specifically for real-time applications and provides a powerful software development environment. In FRED external functions to G2 are being written in C (G2 is LISP-based). G2 also permits a highly graphical and easy-to-use window-based operator interface to be constructed. The hardware platform being used is a color Sun SPARCstation 1 workstation and a RISC-based Unix machine with 16 Mb of random access memory.

Knowledge Acquisition

To date, the knowledge embodied in FRED has been acquired from the authors, from a variety of professional papers and

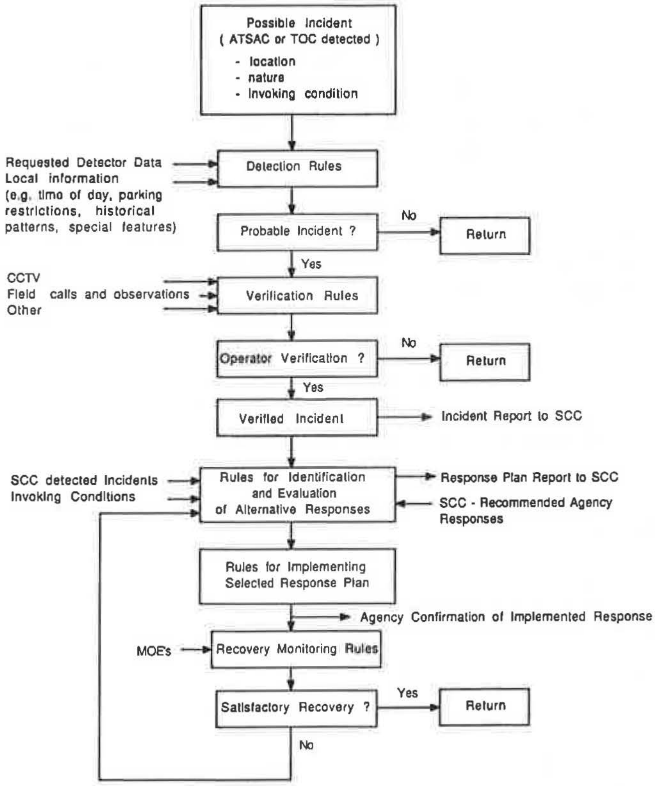


FIGURE 1 Freeway TOC overview.

reports (*4,5*), from Caltrans traffic operations specialists in Los Angeles and Orange County (Districts 7 and 12, respectively), and from many individuals and colleagues involved in the Santa Monica Freeway Smart Corridor Demonstration Project. Further research is clearly required to develop fundamental traffic operations and control system knowledge to be captured in FRED for identifying optimal control and motorist information response strategies in an integrated freeway and arterial traffic system. Such research could be pursued parallel to the development of tools such as FRED.

Knowledge Representation and Inference

Any expert system, real-time or otherwise, requires knowledge and data. Knowledge is usually embodied as a set of rules that act on data and facts to accomplish the objectives of the system. Real-time expert systems differ from conventional static expert systems in that they must respond to data that are continually changing. The nature of traffic is such that its behavior can change rapidly, particularly if an incident occurs. A real-time expert system for traffic monitoring and control must respond reliably and quickly to changes in incoming data.

In FRED knowledge is represented as a series of production rules, examples of which are given in Figure 2. An English-style format is used to make writing and interpreting rules less taxing. Each rule has an antecedent and a consequent. If the conditions embodied in the antecedent are satisfied, then the actions within the consequent are executed. Actions encompass a whole range of tasks that can be performed by the system, including graphic displays, posting of messages to the operator and external systems, setting of attributes, and so on. To behave as a real-time system, FRED examines all active rules each second. Thus, changing data can be responded to every second, which is sufficiently fast for traffic control conditions, particularly when loop data are often only available every 30 sec. The structure of the rules depends greatly on the structure of the data, of which a brief description follows.

RULE 1 - This rule states that if there is a confirmed incident on the eastbound section of the freeway then the direction of CMS control is east - ie. CMS rules will only be applied to eastbound signs.

```
if the status of any incident i1 is confirmed and
       the ir_direction of i1 = 'E/B'
then
       conclude that the direction of cms-control is east
```

RULE 2 - This is an example of a rule to determine whether the MITMT should be dispatched to the scene of an incident. If the incident is an orange alert type incident and the expected duration is greater than 2 hours and the number of lanes blocked is greater than 2 then the response team should be sent. If the team is to be sent, the consequent part of this rule creates a message and displays it to the operator.

```
if the status of an incident i1 is confirmed and
       the ir_type of i1 is a member of the text list orange-alert-list  and
       the ir_duration of i1 >= 2.0 and
       the ir_lanes of i1 >= 2.0
then
       conclude that resp-mitmt is correct
```

RULE 3 - This rule is a good example of the effects of forward chaining. The rule states that whenever a message is posted to any CMS the icon display should change to red to notify the operator that a message is currently displayed.

```
whenever the line1 of any cms-sign c1 receives a value
then
       change the sign icon-color of c1 to red.
```

FIGURE 2 Typical FRED system rules.

Data in FRED are organized as sets of objects, and in this sense the system can be described as object-oriented. Each object contains a set of attributes in which data are stored. For example, in FRED each incident is represented as an object with such attributes as location, type, and expected duration. All objects belong to an object class, and all classes are arranged in a hierarchy that incorporates downward inheritance. A characteristic of real-time expert systems in general, and of FRED in particular, is that of transient (or dynamic) objects. When the need arises to store data, an object of the appropriate predefined class can be created and data stored in its attributes. Rules can then operate on this object. In FRED, this idea is appropriate for the various stages of an incident. Once an incident is detected, an incident object is created and its attributes are assigned values. When an incident has terminated, its corresponding object is deleted. By this method, any number of incident objects corresponding to multiple freeway incidents can exist at any one time, and rules can operate on all of them together. For example, Rules 1 and 2 in Figure 2 have in their antecedents the clause "if the status of an incident i1 is confirmed. . ." This clause translates as "if the status attribute of any incident object has the value confirmed." Here the incident is the object class, of which there may be any number of instances, each representing a different freeway incident.

Having established how knowledge and data are represented, the inference process, that is, the procedure for examining and executing (firing) rules, can be considered. Most expert systems incorporate either forward or backward chaining, and usually both. Most real-time expert systems would rely on forward chaining to respond to events, and FRED is no different. Forward chaining is an inference method that attempts to match the antecedents of rules against available facts (or events) to establish new facts that will eventually lead to a goal or conclusion. The major event in the FRED system is the confirmation, by the operator, of an incident that, by forward chaining, fires a series of rules designed to formulate responses.

An important aspect of real-time expert system development is to avoid unnecessary processing so as to maintain a fast system. FRED uses the capabilities of the G2 system to invoke a set of rules only when they are needed. The system completely ignores rules that are not invoked, so the invoking of rules is a means of controlling the amount of knowledge that needs to be applied to any particular stage of the overall incident management process.

PROTOTYPE FEATURES

System Structure

Figures 3 and 4 show, respectively, the external and internal layout of the FRED system. External system components include incident detection algorithms and a communications

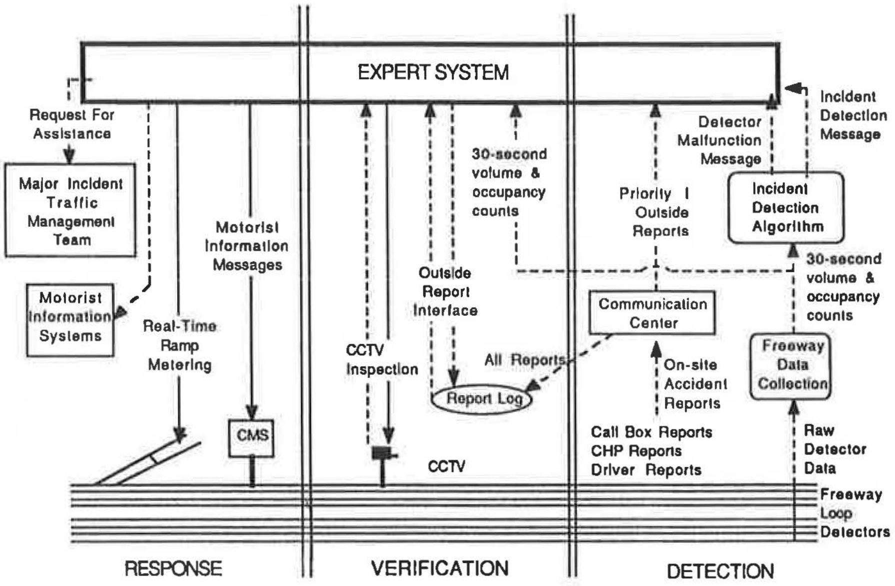


FIGURE 3 FRED external system overview.

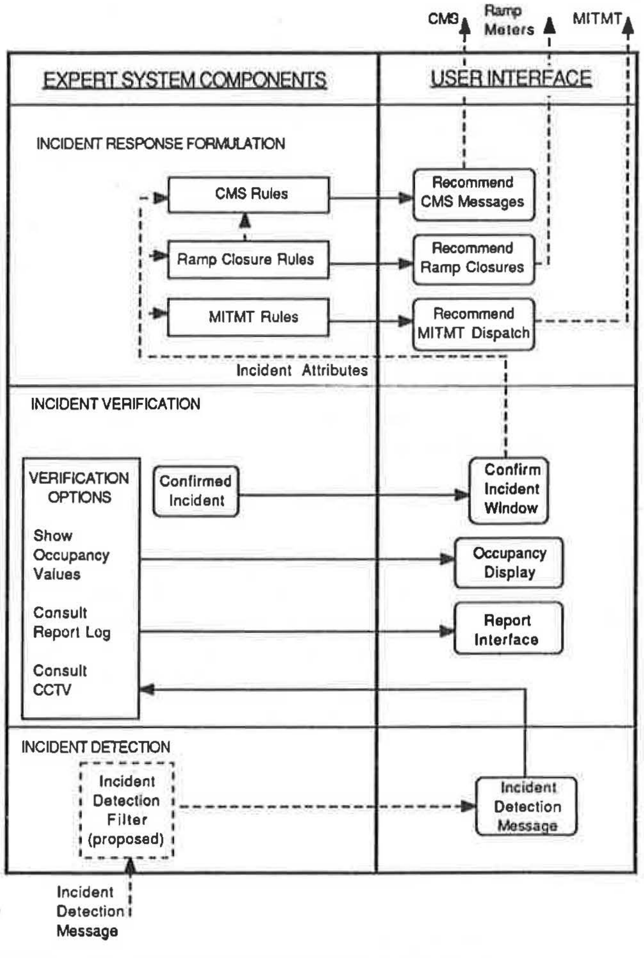


FIGURE 4 FRED internal system overview.

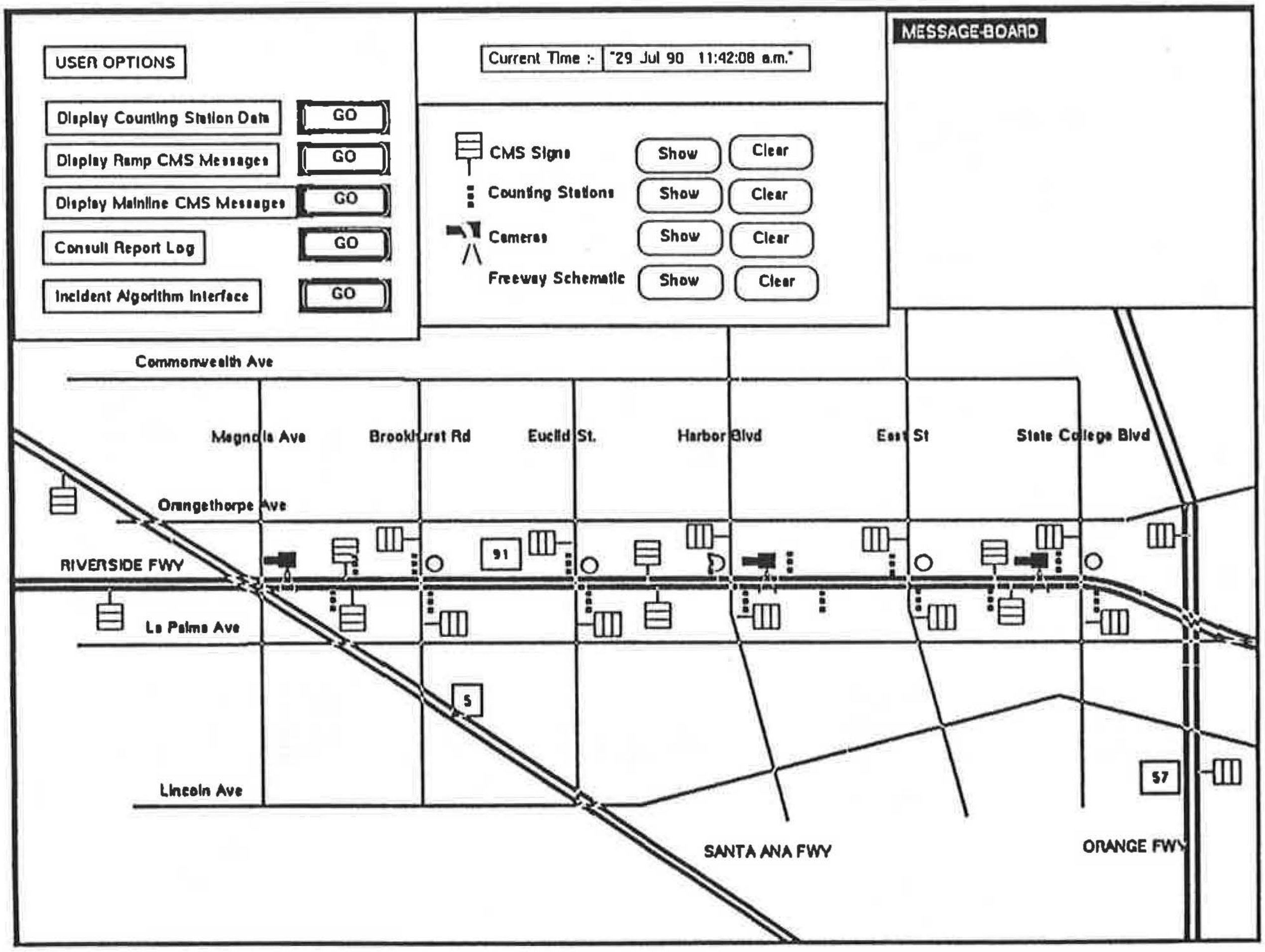
center to aid in the detection of incidents, as well as various incident response mechanisms. The role of both the internal and external components is discussed in later sections.

A vital requirement of any system designed for operator support is the user interface. FRED uses the sophisticated built-in screen management facilities of G2 to provide the operator with a series of separate windows containing either graphic data displays or messages. The operator interacts with the expert system by way of mouse-driven action buttons or keyboard-driven type-in boxes.

Figure 5 shows the screen that is presented to the operator when no incidents have been detected (actual screens employ different colors that do not appear in the figures). The central part of the display is the location map, depicting the section of SR-91 under study, along with two adjacent freeways (I-5 and SR-57) and major arterial streets. At the top center of the screen is a panel of display action buttons, allowing the operator to selectively view the location of counting stations, CMSs, and closed circuit television (CCTV) cameras. In Figure 5 all these symbols are displayed. Figure 5 shows the location of hypothetical CCTV cameras placed above this section of SR-91 to provide the operator with visual images of traffic conditions, as well as CMSs.

Action buttons perform a prescribed action when the operator clicks the mouse on the button icon. For example, Figure 6 shows a message that appears when an incident is detected. Next to the message is a CONFIRM action button. When the operator clicks the mouse on this button, the system records that the operator received the message.

Another visual aid to the operator is shown in Figure 6. A schematic of the freeway layout appears at the bottom of the screen, showing lane configurations, ramp designs, and the precise locations of counting stations and CMSs. The icons representing CMSs and ramp meters can be changed to denote



Current Time :- "29 Jul 90 11:42:08 a.m."

FIGURE 5 System display board.

different operating conditions. For example, the two lights on a ramp meter icon are changed to red if the corresponding ramp is closed in response to an incident.

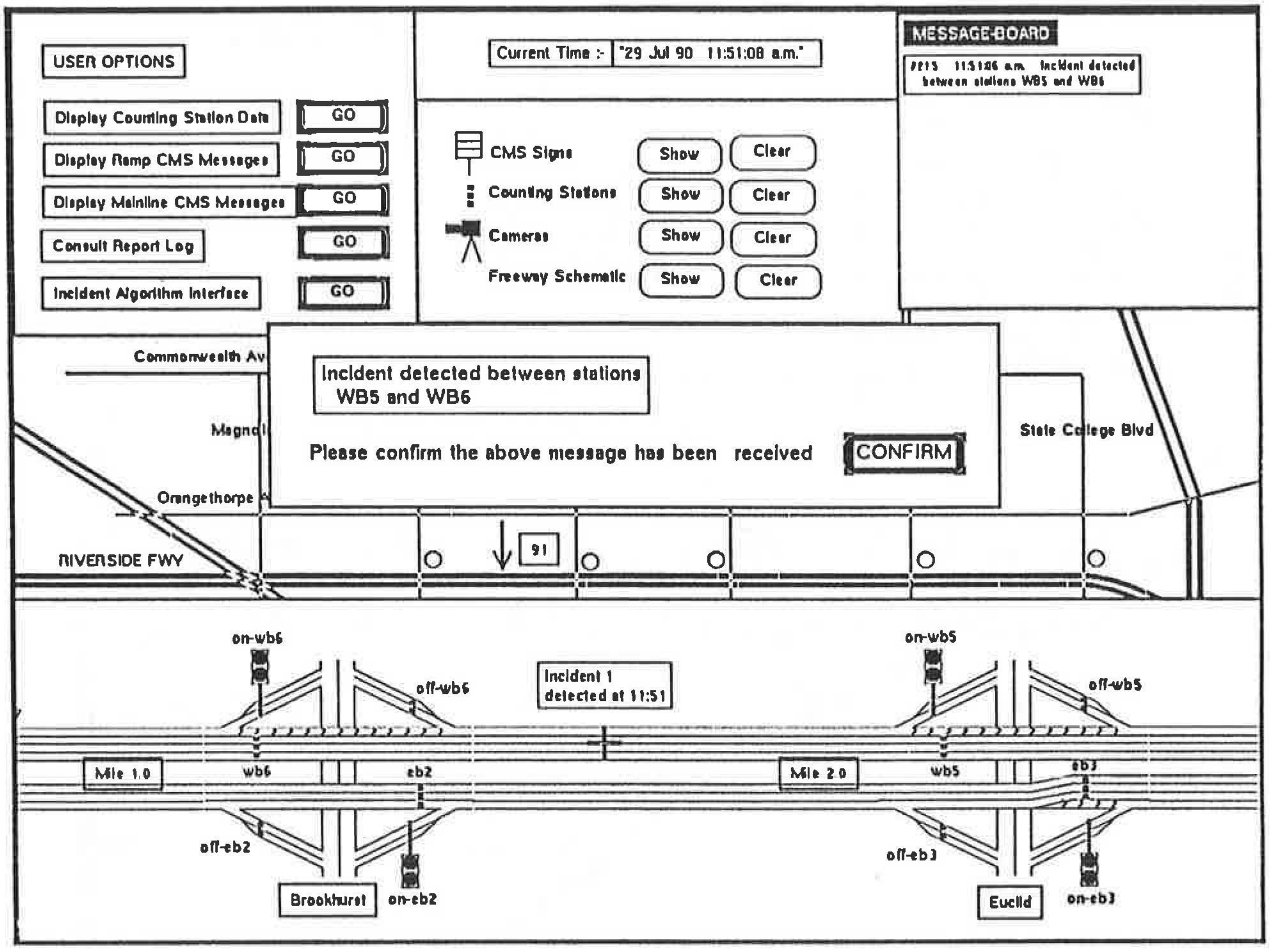
Incident Detection

The first step in incident management is the detection phase. Attempts to manage incidents are ineffective if incidents are not detected quickly and reliably. In the FRED environment, incidents are detected in two ways: (a) from applying an incident detection algorithm to loop detector data and (b) from outside reports.

Considerable research has been undertaken on developing effective computer algorithms for the detection of freeway incidents using main-line loop detector data. In the FRED system, a version of the California algorithm reported by Payne and Knobel (*6*) is implemented. The algorithm reads 30-sec occupancy counts from a series of counting stations on the freeway main line. The stations are processed as a series of sections, with each section having an upstream and a downstream station. A number of parameter values are derived from the occupancy counts at the upstream and downstream stations. If these values lie outside some predetermined range, an incident is said to be detected. A separate option in FRED allows the operator to interactively select the algorithm to be used and its sensitivity.

Once an incident has been detected, a signal is sent to FRED that a possible incident exists between the upstream and downstream stations that triggered the detection. A message window is placed in the center of the screen to notify the TOC operator, who is then required to acknowledge the message (see Figure 6). On the central map display, the color of the freeway section in which the suspected incident is located changes from green to flashing red, and an arrow appears next to it. The suspected incident is only known to lie between the two counting stations that triggered the detection, and, until an on-site report is received, its location remains approximate.

The second method of detecting an incident is by way of outside reports, which are usually on-site reports of an incident from freeway motorist call-boxes, police officers, cellular car phones, aerial observers reporting on traffic conditions, or Caltrans maintenance personnel. It is assumed that all such reports are first received by a communications center manned by operators who enter the reports into a data base in a predetermined format. Information such as incident location, nature of incident, number of lanes blocked, and presence of



Current Time :- "29 Jul 90 11:51:08 a.m."

#215 11:51:06 a.m. Incident detected between stations WB5 and WB6

Incident detected between stations WB5 and WB6

Please confirm the above message has been received

Incident 1 detected at 11:51

FIGURE 6 Incident detection message.

injuries and fatalities is supplied. If the incident is a major one, such as an overturned truck, then more detailed information may be required, such as a description of the load, whether flammable or toxic materials are involved, and whether specialized assistance is required.

In FRED the communications center is simulated by an external program that accepts incident reports and checks to see if they match a particular protocol before entering them onto a report log. The report program examines the type of incident to determine whether extra information is required, and, if so, the communications center operator is prompted for the information. Each report is allocated a priority ranging from 1 to 5, depending on the nature of the incident and the source of information. For example, a report originating from a police officer at the scene of an incident would receive the highest priority of 1. Priorities become important when considering whether or not the report should be passed on to the freeway TOC. Only Priority 1 incidents are communicated to FRED; all other incident reports are written to a report log that can be consulted by the TOC operators when needed (see the following section).

For a number of reasons, it is important that FRED receives reports only after preliminary processing. First, the operators at the freeway TOC should not be overwhelmed with unreliable reports or multiple reports of the same incident. Second, reports should be received by FRED in a recognizable format to allow them to be easily understood by the operator and to enable the development of rules that operate on the reports. For example, the type of incident (such as overturned truck or two-car accident) must appear on a list of incident types recognized by FRED so that rules such as Rule 2 in Figure 2 can function properly.

FRED deals with outside incident reports in the same way as incident detection reports—a message requiring acknowledgment is placed in the center of the screen.

An important aspect of the incident detection phase is the prevalence of false incident reports, that is, reports of incidents that either do not exist or are not severe enough to warrant response. A role of any system that aims to reduce the cognitive load of its operators is to reduce this false alarm rate to manageable levels. The preliminary processing of outside reports is one means of reducing the level of false alarms from this source. However, reducing false alarms triggered by loop detector data is more difficult. More incident detection algorithms involve a trade-off between detection rate (percentage of true incidents detected) and false alarm rate (percentage of false alarms over a certain period of time). Increasing the detection rate by altering threshold parameters necessarily increases the false alarm rate. Currently, FRED leaves this trade-off problem to the external detection algorithm, but it is hoped that heuristics can be incorporated into FRED to act as a further filter of incident-detection reports.

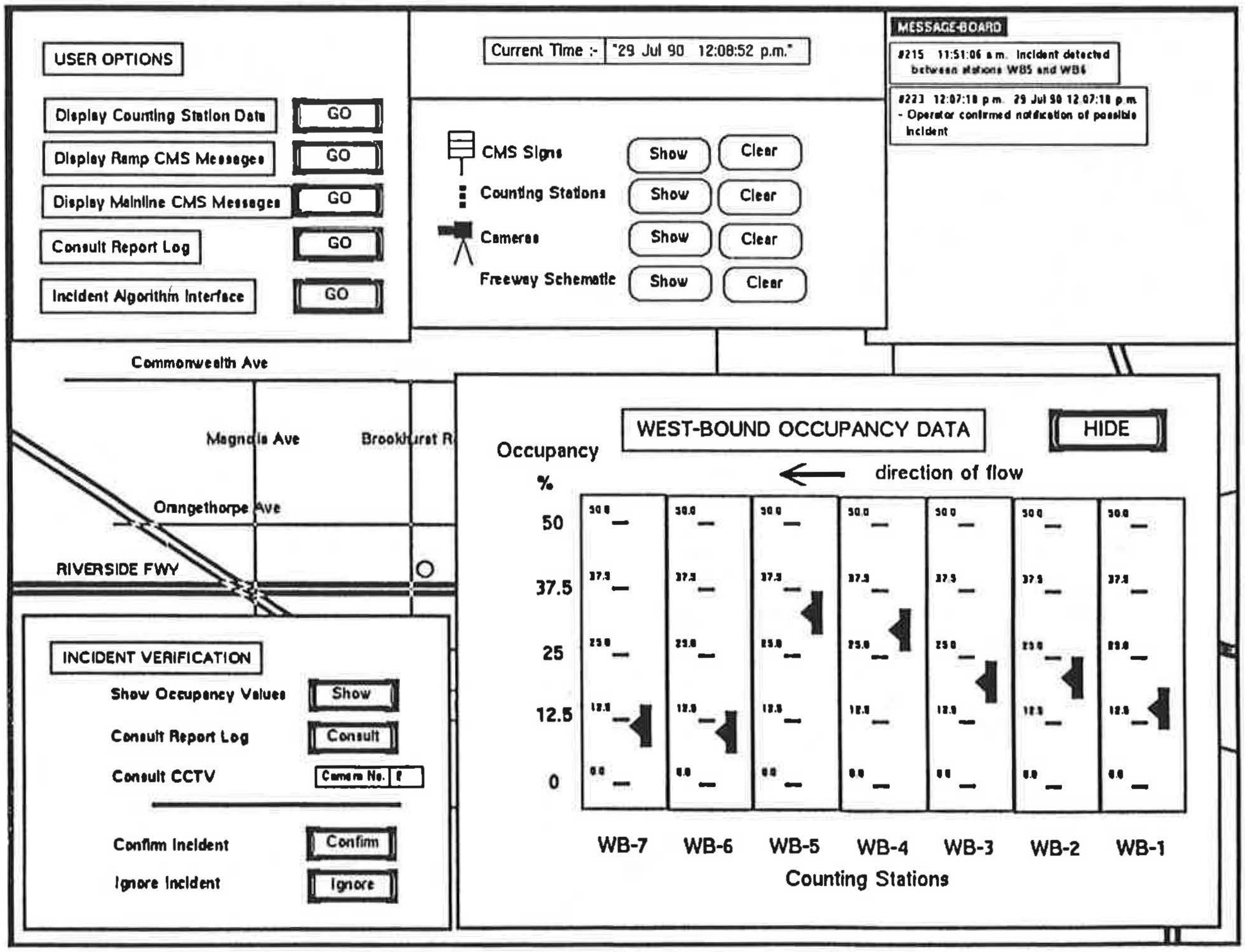
Incident Verification

Once an incident has been detected or reported to the freeway TOC operator, it is the operator's task to verify the incident before any incident responses are formulated. In the current FRED system, there are three verification methods available: (a) CCTV, (b) inspection of loop data, and (c) consultation of the report log. Figure 7 shows the incident verification window (in the bottom left corner of the screen) that is presented to the operator as a summary of the verification options.

The incident verification window in Figure 7 displays the identification number of the camera closest to the suspected incident location. Although it is technically feasible for FRED to directly control the positioning and zooming of the camera, this action is not simulated, partly because of the uncertainty surrounding the incident's location. If CCTV is available and visibility is sufficient, the use of a CCTV camera is the primary means of verifying an incident. However, under poor visibility conditions or in sections where CCTV is unavailable, the operator must rely on other methods.

The graphic display of current values of traffic parameters, such as occupancy and volume, may help operators recognize an incident. Figure 7 shows a display of occupancy counts for the seven counting stations located on the westbound section of the freeway (see Figure 5 for the location of counting stations). The sudden discontinuity of occupancy between Stations WB5 and WB6 suggests a major disruption of flow between these two stations. Stations downstream of WB6 show low occupancy values, suggesting more freely flowing traffic, whereas the upstream values are higher, indicating the onset of congestion. Experienced operators may be able to recognize certain patterns in traffic conditions that indicate the presence of nonrecurring congestion. Such expertise could be encoded into FRED as a separate knowledge base and used in filtering false alarms. Graphic displays of traffic conditions can also be useful during incident monitoring, particularly when deciding if an incident has terminated.

As mentioned in the section on outside reports, a log of all reports is maintained external to the FRED system, with only high-priority reports being sent directly to TOC operators. In the incident verification phase, the operator is able to interrogate the report log for reports relevant to the time and location of the incident being verified. A standard data-base query procedure is followed, with the operator providing values for certain fields (e.g., all reports with a time stamp be-



Current Time :- "29 Jul 90 12:08:52 p.m."

#215 11:51:06 a.m. Incident detected between stations WB5 and WB6

#223 12:07:18 p.m. 29 Jul 90 12:07:18 p.m. - Operator confirmed notification of possible incident

FIGURE 7 Incident verification.

tween 8:30 and 8:50 a.m. and a location between Magnolia and Euclid streets). Details of relevant reports, if any, are displayed on the screen. The operator may decide that an incident detection report combined with a low-priority outside report is sufficient to confirm the presence of an incident.

If an operator verifies an incident, an incident confirmation window is displayed, as shown in Figure 8. Examples of type-in boxes are shown in this figure. The operator is required to enter, among other incident attributes, the type of incident (determined perhaps from a CCTV camera). The string entered by the operator becomes an attribute of the current incident object. Thus, objects can receive values of attributes from external sources, internal inferences, or the operator. If the operator has visual contact with the scene of the incident via CCTV, details relating to the incident can be entered into FRED simply by typing the values into the appropriate boxes contained within the incident confirmation window. Additionally, the operator is allowed to move a marker denoting the approximate position of the incident to a more precise location. The position of the marker is recorded and used in the response stages.

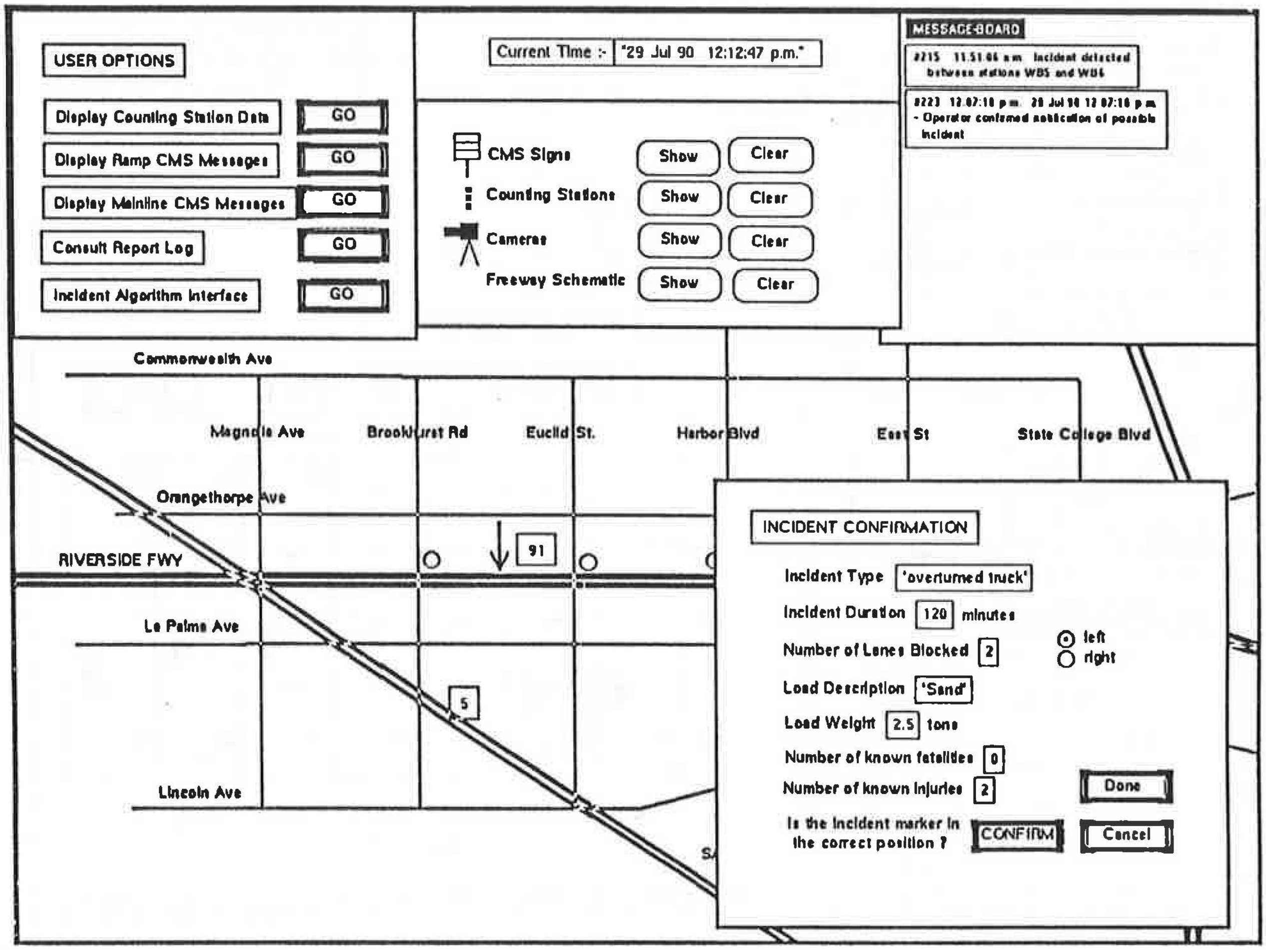
Incident Response

The formulation of incident response strategies is the major area in which a sophisticated expert system approach is warranted. In the FRED system, there are currently three main response elements: (a) the MITMT, (b) real-time ramp metering, and (c) CMSs.

MITMT Response

As explained previously, the Los Angeles district of Caltrans instituted the MITMT. The team's primary purpose is "to furnish, as rapidly as possible, equipment and manpower to aid in management of traffic at or near major traffic incidents on freeways." Currently, the team's equipment consists of 12 sedans and 11 mobile CMSs. Personnel include 5 primary and 18 standby members, and the team is available 24 hr a day.

The role of FRED in invoking the MITMT is to determine whether or not an incident is major and, if so, to provide necessary information about the nature of the incident to the response team. Both these tasks are achieved by a set of rules, of which Rule 2 in Figure 2 is an example. In effect, the rule states that, if a so-called "orange-alert" incident is confirmed, if the expected duration is 2 hr or more, and if the number of lanes blocked is two or more, the MITMT should be sent. This rule is drawn from the existing guidelines for operation of the MITMT. Incident types are arranged in lists according to their severity. Orange-alert incidents include spilled loads or jack-knifed trucks. Red-alert incidents include overturned trucks, bomb threats, and hazardous material spills. If the



Current Time :- '29 Jul 90 12:12:47 p.m.'

#215 11:51:06 a.m. Incident detected between stations WB5 and WB6

#223 12:07:10 p.m. 29 Jul 90 12:07:10 p.m. - Operator confirmed notification of possible incident

Incident Type 'overturned truck'

Incident Duration 120 minutes

Number of Lanes Blocked 2 ● left ○ right

Load Description 'Sand'

Load Weight 2.5 tons

Number of known fatalities 0

Number of known injuries 2

Is the incident marker in the correct position ?

FIGURE 8 Incident confirmation.

operator confirms the response, an incident report is sent to the MITMT dispatch office providing such details as location, type, expected duration, lanes blocked, number of injuries and fatalities, and description of any spilled load. Further work on FRED should provide recommended diversion strategies to be implemented by the on-site team.

Ramp Metering and Closure

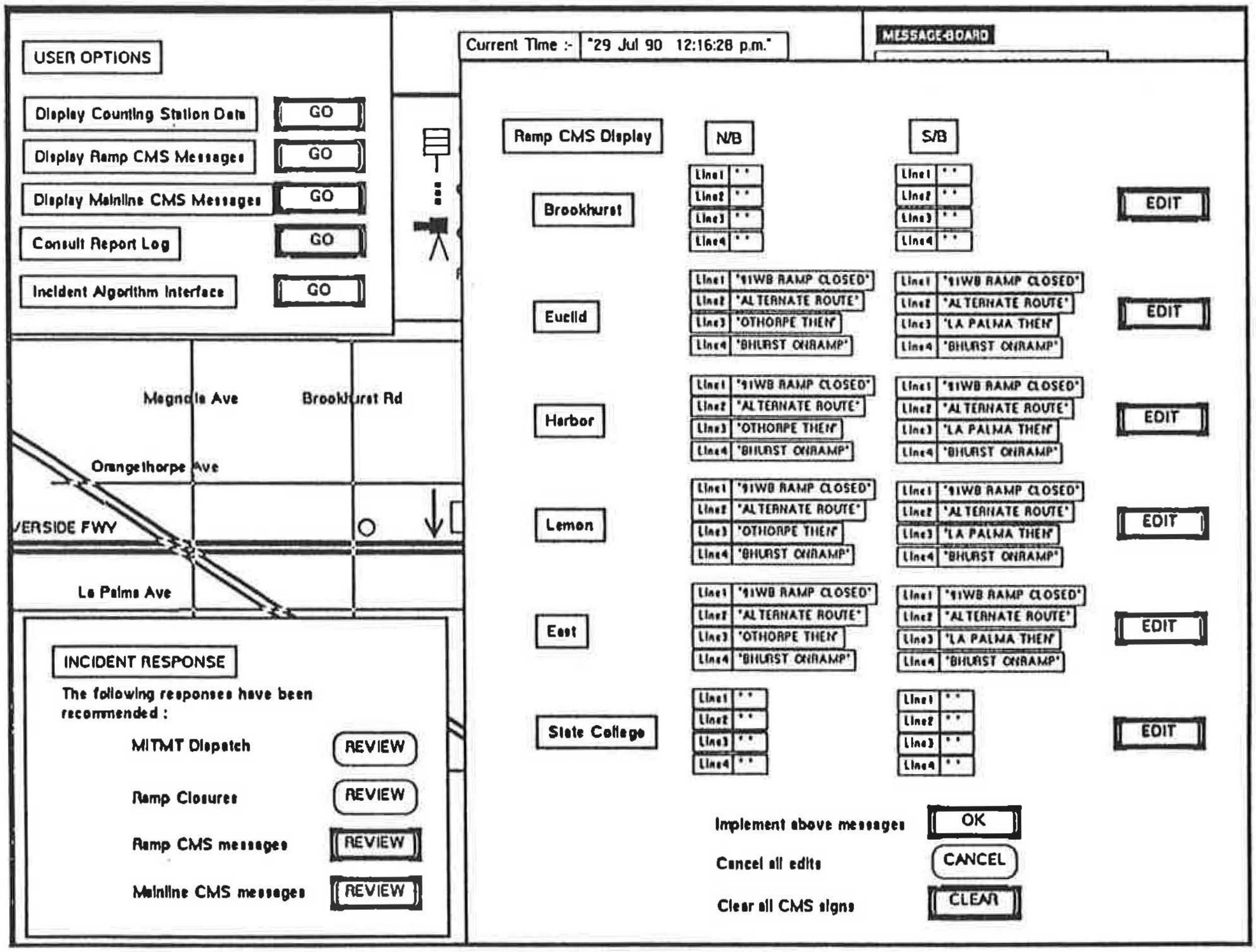
A simplified version of a real-time ramp metering algorithm developed for use in Seattle, Washington (7), is implemented as a module external to the FRED system. This algorithm computes optimal metering rates every 30 sec in an attempt to maintain a high level of service for traffic downstream of each ramp. It is assumed that all entrance ramps on the case study section are metered and that real-time control of these meters is possible.

The FRED system allows the ramp metering algorithm to operate independently and only intercedes when the capacity of a section of the freeway has been drastically reduced by an incident. To reduce demand at the incident site, ramps upstream may be recommended for closure. This task is performed in stages. In this initial version of FRED, an estimate is made of the capacity at the incident site using such information as number of lanes blocked. Flow conditions upstream of the incident are then examined to determine the expected demand on the freeway at the incident site. The severity of the incident is determined to be the extent to which expected demand exceeds capacity at the incident site. If the severity of the incident is above a specified threshold, all ramps within a certain distance upstream of the incident are recommended for closure. The threshold and upstream distance values can be modified by TOC operators.

Arterial Street CMS Information

If ramp closure is to be an acceptable response mechanism, advance information must be provided to motorists intending to use the entrance ramps. Such information should indicate which ramp is closed and, more importantly, provide an alternative route. The formulation of messages to be posted on CMSs on arterial streets near entrance ramps is the responsibility of another section of FRED. Each major arterial street with an interchange to SR-91 within the case study section was assumed to have a CMS positioned on the north and south approaches. Thus, each entrance ramp was provided with two CMSs that could provide information about closure.

The major task in formulating the messages is to determine an alternative route around the incident site using arterial streets. Two street names were provided: (a) the entrance ramp immediately downstream of the incident and (b) the arterial street parallel to the freeway leading to the entrance ramp. Figure 9 shows the set of messages recommended for the arterial street CMSs for an incident on SR-91 westbound



Current Time :- "29 Jul 90 12:16:28 p.m."

The following responses have been recommended :

Ramp CMS Display	N/B	S/B
Brookhurst	Line1 " " Line2 " " Line3 " " Line4 " "	Line1 " " Line2 " " Line3 " " Line4 " "
Euclid	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "OTHORPE THEN" Line4 "BHURST ONRAMP"	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "LA PALMA THEN" Line4 "BHURST ONRAMP"
Harbor	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "OTHORPE THEN" Line4 "BHURST ONRAMP"	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "LA PALMA THEN" Line4 "BHURST ONRAMP"
Lemon	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "OTHORPE THEN" Line4 "BHURST ONRAMP"	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "LA PALMA THEN" Line4 "BHURST ONRAMP"
East	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "OTHORPE THEN" Line4 "BHURST ONRAMP"	Line1 "91WB RAMP CLOSED" Line2 "ALTERNATE ROUTE" Line3 "LA PALMA THEN" Line4 "BHURST ONRAMP"
State College	Line1 " " Line2 " " Line3 " " Line4 " "	Line1 " " Line2 " " Line3 " " Line4 " "

Implement above messages OK

Cancel all edits CANCEL

Clear all CMS signs CLEAR

FIGURE 9 Incident response—CMS messages.

between Brookhurst and Euclid. Four ramps have been closed—at the Euclid, Harbor, Lemon, and East interchanges. The entrance ramp immediately downstream of the incident site is at Brookhurst. The parallel arterial street for northbound traffic is Orangethorpe Avenue, and the one for southbound traffic is La Palma. The operator is allowed to edit any of the messages before implementation or to cancel them all.

This formulation of an alternative route via arterial streets will, in practice, require some assessment of the capacity of the alternative streets and entrance ramps. An appropriate approach is to coordinate the diversion of traffic from the freeway, as determined by FRED, with the arterial street system to improve the flow of traffic through the entire corridor.

Main-Line CMS Information

If nonrecurrent congestion is expected due to a detected incident, information should also be provided to motorists on the freeway approaching the incident site. In the case study, motorists are notified via CMSs located on SR-91 as well as on connecting freeways I-5 and SR-57. The location of the incident and the number of lanes blocked are given. This information is derived directly from the incident parameters provided in the verification stage, with some message composition processing.

For each incident response, the operator is presented with the recommended action, if any, and asked for confirmation. Figure 9 shows the incident response window displayed in the bottom left corner of the screen after the formulation of all responses. The operator is allowed to review each response before implementation, as illustrated in the discussion of arterial street CMS messages.

CONCLUSIONS

The response of traffic operations specialists in southern California to initial demonstrations of FRED has been most favorable. However, much research remains to be done to incorporate the proposed additional decision support functions in FRED. This work is ongoing.

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REFERENCES

1. *Report to Congress on Intelligent Vehicle-Highway Systems.* Office of Economics and Office of the Assistant Secretary for Policy and International Affairs, U.S. Department of Transportation, 1990.
2. S. G. Ritchie. A Knowledge-Based Decision Support Architecture for Advanced Traffic Management. *Transportation Research*, Vol. 24A, No. 1, 1990.
3. *G2 User's Manual.* Gensym, Inc., Cambridge, Mass., 1988.
4. *Traffic Control Systems Handbook.* Publication LP-123. Institute of Transportation Engineers, Washington, D.C., 1985.
5. *Traffic Operations Center Operator's Manual.* District 7, California Department of Transportation, Los Angeles, 1989.
6. H. J. Payne and H. C. Knobel. *Development and Testing of Incident Detection Algorithms, Volume 3: User Guidelines.* Report FHWA-RD-76-21. Technology Service Corporation; FHWA, U.S. Department of Transportation, 1976.
7. L. N. Jacobson, K. C. Henry, and O. Mehyar. A Real-Time Metering Algorithm for Centralized Control. Presented at 68th Annual Meeting of the Transportation Research Board, Washington, D.C., 1989.

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