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A Real-Time Expert System Approach
To Freeway Incident Management

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Working Paper, No. 88

A REAL-TIME EXPERT SYSTEM APPROACH TO FREEWAY INCIDENT MANAGEMENT

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ABSTRACT

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 such Smart Roads, and the focus of this paper, is the provision of decision support for traffic management center personnel, particularly for addressing non-recurring congestion in large or complex networks. Decision support for control room staff is necessary to effectively detect, verify and develop response strategies for traffic incidents. These are events that disrupt the orderly flow of traffic, and cause non-recurring congestion and motorist delay. Non-recurring congestion can be caused by accidents, spilled loads, stalled or broken down vehicles, maintenance and construction activities, signal and detector malfunctions, and special and unusual events. The ultimate objective of our research is to implement a novel artificial intelligence-based solution approach to the problem of providing operator decision support in integrated freeway and arterial traffic management systems, as part of a more general IVHS. In this paper, we present and discuss the development of FRED (Freeway Real-Time Expert System Demonstration), a component prototype real-time expert system for managing non-recurring congestion on urban freeways in Southern California. 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.

INTRODUCTION

As a means to improve road-based mobility and safety, with decreased economic and environmental impacts of traffic, the concept of Intelligent Vehicle-Highway Systems (IVHS) is evoking substantial interest in Europe, Japan and the U.S. Relying on advances in electronics, communications and computing, IVHS technologies would create Smart Cars and Smart Roads to achieve significant areawide traffic operations improvements. A recent report (1) classified IVHS technologies in four categories:

-- Advanced traffic management systems
-- Advanced driver information systems
-- Freight and fleet control systems
-- Automated vehicle control systems

The concern of the research on which this paper is based is with advanced traffic management systems, because fundamental to the operation of most IVHS projects are advanced systems for surveillance, control and management of integrated freeway and arterial networks. In addition, implementation of these concepts is now beginning. In Los Angeles, for example, the Santa Monica Freeway Smart Corridor Demonstration Project is underway, and other Smart Corridor projects are likely to follow.

However, a major concern in the development of such Smart Roads, and the focus of this paper, is the provision of decision support for traffic management center personnel, particularly for addressing non-recurring congestion in large or complex networks. Decision support for control room staff is necessary to effectively detect, verify and develop response strategies for traffic incidents. These are events that disrupt the orderly flow of traffic, and cause non-recurring congestion and motorist delay. Non-recurring congestion can be caused by accidents, spilled loads, stalled or broken down vehicles, maintenance and construction activities, signal and

detector malfunctions, and special and unusual events. The ultimate objective of our research is to implement a novel artificial intelligence (AI)-based solution approach to the problem of providing operator decision support in integrated freeway and arterial traffic management systems, as part of a more general IVHS. While 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 also likely to be important to the operation of future IVHS projects.

In previous research (2), a conceptual AI-based design was developed for the present problem. 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 (KBES). In practice, these KBES could be associated with multiple computers, traffic control centers, transportation agencies and traffic sub-networks, even in one corridor.

In this paper, we present and discuss the development of FRED (Freeway Real-Time Expert System Demonstration), a component prototype real-time expert system for managing non-recurring congestion on urban freeways in Southern California. 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 information out to the motoring public." In conjunction with the California Highway Patrol, this TOC currently disseminates information via commercial radio stations, and changeable message signs (CMS) adjacent to the freeway, and can dispatch a Major Incident Traffic Management Team (MITMT) to incident locations, while providing continuous monitoring and co-ordination functions. The system (called the Semi-Automatic Traffic Management System, or 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/off ramps), and about 5000 detectors providing 30 second 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 1000 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 continues 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 KBES address situations like these where human operators suffer from cognitive overload in time-sensitive environments. In a Smart Corridor context, such a system could filter the low-level but voluminous detector data, and present the operator with fewer high-level analyses and recommendations concerning incident detection, verification and response. This would reduce the operator involvement needed to focus on true operational problems, permit rapid development of optimal and consistent response plans, and facilitate co-ordination amongst all relevant agencies, thereby reducing delays associated with non-recurring congestion.

SYSTEM FUNCTIONS

The objective of the envisioned system is to provide decision support to TOC staff in their 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):
- incident detection
- incident verification
- identification and evaluation of alternative responses
- implementation of selected responses
- monitoring recovery.

In this paper, we focus on the initial development of a freeway real-time expert system demonstration (FRED) which, as a component of an overall decision support system, is limited to a freeway TOC to assist in managing non-recurring congestion on urban freeways. FRED is currently being developed for a section of the SR-91 Riverside Freeway (approximately 6 miles in length) in Orange County in 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).

In general terms, the overall functions of FRED are presented in Figure 1. In this figure, "Smart Central" refers to a proposed real-time KBES that would attempt to optimize corridor or areawide traffic conditions and co-ordinate response actions amongst all relevant agencies. Associated with Smart-Central would be a major relational database system to facilitate the networked linking of all agencies and their control systems. Further details are discussed in (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 very 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, a RISC-based Unix machine with 16 Mb of RAM.

KNOWLEDGE ACQUISITION

To date, the knowledge embodied in FRED has been acquired from the authors, from a variety of professional papers and reports such as (4) and (5), from traffic operations specialists in Caltrans 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 upon 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 quite 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. Rules are formatted in an English-style format that makes 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. In order to behave as a real-time system, FRED examines all active rules every 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 seconds. The structure of the rules depends very much upon the structure of the data, of which a brief description follows.

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 attributes such 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 such as location, type, and expected duration 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.." which translates as "if the status attribute of any incident object has the value confirmed". Here "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 we can consider the inference process, i.e. the procedure for examining and executing (firing) rules. Most expert systems incorporate either forward or backward chaining and usually both. Most real-time expert systems would rely upon forward chaining in order 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 which, via 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 where 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 center to aid in the detection of incidents, and various incident response mechanisms. The role of both the internal and external components will be 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 presented to the operator when no incidents have been detected (screens are displayed employing different colors which do not appear in these Figures). The central part of the display is the location map, depicting the section of the SR-91 freeway 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, changeable message signs 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 the 91 freeway to provide the operator with visual images of traffic conditions, as well as changeable message signs.

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, and next to the message appears 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 appears 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 changeable message signs. The icons representing changeable message signs and ramp meters can be changed to denote 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: from applying an incident detection algorithm to loop detector data, and from "outside reports."

Considerable research has been undertaken on developing effective computer algorithms for the detection of freeway incidents using mainline loop detector data. In the FRED system, a version of the California algorithm reported in (6) is implemented. The algorithm reads 30-second occupancy counts from a series of counting stations on the freeway mainline. The stations are processed as a series of sections with each section having an upstream and downstream station. A number of parameter values are derived from the occupancy counts at the upstream and downstream stations and if these values lie outside some predetermined range then 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 is changed 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 will remain approximate.

The second method of detecting an incident is by way of outside reports. These 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 staffed by a group of operators who enter the reports into a report database in a predetermined format. Information such as incident location, nature of incident, number of lanes blocked, presence of 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 such 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 Incident Verification below).

It is important that FRED receives reports only after preliminary processing for a number of reasons. 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 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 2-car accident, etc.) must be a member of a list of incident types recognized by FRED in order for rules such as rule 2 in Figure 2 to function properly.

FRED deals with outside incident reports in the same way as incident detection reports: a message requiring acknowledgement 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. Most incident detection algorithms involve a tradeoff between detection rate (percentage of true incidents detected) and the 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 tradeoff problem to the external detection algorithm, but it is hoped that heuristics could 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: closed circuit TV (CCTV), inspection of loop data and consultation of the report log. Figure 7 shows the incident verification window (in the bottom left corner of the screen) 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 technically feasible for FRED to directly control the positioning and zooming of the camera, this is not simulated, partly because of the uncertainty surrounding the incident's location as outlined earlier. If CCTV is available and visibility sufficient, the use of a CCTV camera will be the primary means of verifying an incident. However, under poor visibility conditions or in sections where CCTV is unavailable the operator will have to rely upon 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 the occupancy counts for the seven counting stations located on the westbound section of the freeway (see Figure 5 for location of counting stations). The sudden discontinuity of occupancy between stations WB5 and WB6 is suggestive of a major disruption of flow between these two stations. Stations downstream of WB6 show low occupancy values suggesting

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more freely flowing traffic, while the upstream values are higher indicating the onset of congestion. Experienced operators may in fact be able to recognize certain patterns in traffic conditions that indicate the presence of non-recurring congestion. Such expertise could be encoded into FRED as a separate knowledge base and be 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 or not.

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 database query procedure is followed with the operator providing values for certain fields, for example all reports with a time stamp between 8:30 and 8:50 am and 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. Here the operator is required to enter, amongst 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 from the operator. If the operator has visual contact with the scene of the incident via CCTV, then details relating to the incident can be entered into FRED by simply 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.

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INCIDENT RESPONSE

The formulation of incident response strategies is the major area in which a sophisticated expert system approach is warranted. Currently in the FRED system there are three main response elements: major incident traffic management team, real-time ramp metering and changeable message signs.

MITMT Response

The Los Angeles District of Caltrans has instituted an operational unit called the Major Incident Traffic Management Team (MITMT), whose 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 CMS's. Personnel include five primary and 18 standby members and the team is available 24 hours a day.

The role of FRED in invoking the MITMT is to determine whether an incident is "major" and if so to provide necessary information regarding 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 was an example. In effect, the rule states that if an incident is confirmed and of type "orange-alert," the expected duration is two hours or more, and the number of lanes blocked is two or more, then the MITMT should be sent. This rule is drawn from the existing guidelines regarding the operation of the MITMT. Incident types are arranged in lists according to their severity. Orange-alert incidents include spilled loads or jackknifed trucks. Red-alert incidents include overturned trucks, bomb threats and hazardous material spills. If the operator confirms the response, an incident report is sent to the MITMT dispatch office providing details such 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 expert system. This algorithm computes optimal metering rates every 30 seconds in an attempt to maintain a high level of service for traffic downstream of each ramp. It has been assumed that all the 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 the demand at the incident site, ramps upstream may be recommended for closure. A series of rules perform this task in the following stages. In this intial version of FRED an estimate is made of the capacity at the incident site using information such as the number of lanes blocked. Then the flow conditions upstream of the incident are 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 will indicate which ramp is closed, and more importantly, provide an alternative route. The formulation of such messages

to be posted on CMS's on arterial streets near the entrance ramps is a responsibility of another section of FRED. It was assumed that each major arterial street with an interchange to SR-91 within the case study section had a CMS positioned on the north and south approaches. Thus, each entrance ramp was provided with two CMS's that could provide information regarding 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 - the entrance ramp immediately downstream of the incident and the arterial street parallel to the freeway leading to the entrance ramp. Figure 9 shows the set of messages recommended for the arterial street CMS's for the incident on 91 westbound between Brookhurst and Euclid. Four ramps have been closed - at Euclid, Harbor, Lemon and East interchanges. The entrance ramp immediately downstream of the incident site is at Brookhurst and the parallel arterial street for northbound traffic is Orangethorpe Ave and for southbound La Palma. The operator is allowed to edit any of the messages before implementation or 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, and possibly incorporation of Caltrans pre-planned emergency detour routes. An appropriate approach is to co-ordinate 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.

Mainline CMS information

If any non-recurrent 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 this is done via CMS's located on the 91 freeway as well as connecting freeways I-5 and SR-57. The form of

information consists of the location of the incident and the number of lanes blocked. This is derived directly from the incident parameters provided in the verification stage with some message composition processing.

For all of the above responses 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-hand corner of the screen after the formulation of all responses. The operator is allowed to review each of the responses before implementation, as was seen for the case of the arterial street CMS messages.

CONCLUSIONS

This paper has presented and discussed the development of FRED (Freeway Real-Time Expert System Demonstration), a component prototype real-time expert system for managing non-recurring congestion on urban freeways, as part of the application of IVHS concepts in Southern California. The application of FRED to a section of the Riverside Freeway (SR-91) in Orange County was presented as a case study, and illustrated the current capabilities of the system. 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 on-going.

ACKNOWLEDGEMENTS

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LIST OF FIGURES

Figure 1   Freeway TOC Overview

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                    ┌─────────────────────────────┐
                    │      Possible  Incident     │
                    │   ( ATSAC or TOC detected ) │
                    │                             │
                    │    - location               │
                    │    - nature                 │
                    │    - invoking  condition    │
                    └─────────────────────────────┘
                                   │
                                   ▼
Requested Detector Data  ──►  ┌──────────────────┐
Local  information        ──► │  Detection Rules │
(e.g. time of day, parking    └──────────────────┘
restrictions,   historical            │
patterns,  special  features)         ▼                   No
                              ┌──────────────────┐   ┌──────────┐
                              │ Probable Incident? │──►│  Return  │
                              └──────────────────┘   └──────────┘
                                    │ Yes
CCTV                     ──►         ▼
Field   calls and observations ─► ┌──────────────────┐
Other                    ──►      │ Verification Rules│
                                  └──────────────────┘
                                         │
                                         ▼                 No
                              ┌────────────────────┐   ┌──────────┐
                              │ Operator Verification?│─►│  Return  │
                              └────────────────────┘   └──────────┘
                                    │ Yes
                                    ▼
                              ┌──────────────────┐      Incident Report to
                              │ Verified Incident│ ──►  Smart Central
                              └──────────────────┘
                                    │
Smart Central                       ▼
detected incidents  ──►   ┌─────────────────────────┐   Response Plan Report to
                          │ Rules  for  Identification│─► Smart Central
Invoking Conditions ──►   │      and Evaluation       │
                      ──► │ of Alternative Responses  │◄── Smart Central - Recommended
                          └─────────────────────────┘       Agency Responses
                                    │
                                    ▼
                          ┌──────────────────────┐
                          │ Rules for Implementing│
                          │ Selected Response Plan│
                          └──────────────────────┘
                                    │
                                    └──► Agency Confirmation of Implemented Response
                                    ▼
MOE's  ──►                ┌──────────────────────┐
                          │Recovery Monitoring Rules│
                          └──────────────────────┘
                                    │
                                    ▼                Yes
                          ┌──────────────────────┐   ┌──────────┐
                          │ Satisfactory Recovery ?│─►│  Return  │
                          └──────────────────────┘   └──────────┘
                                    │ No
```
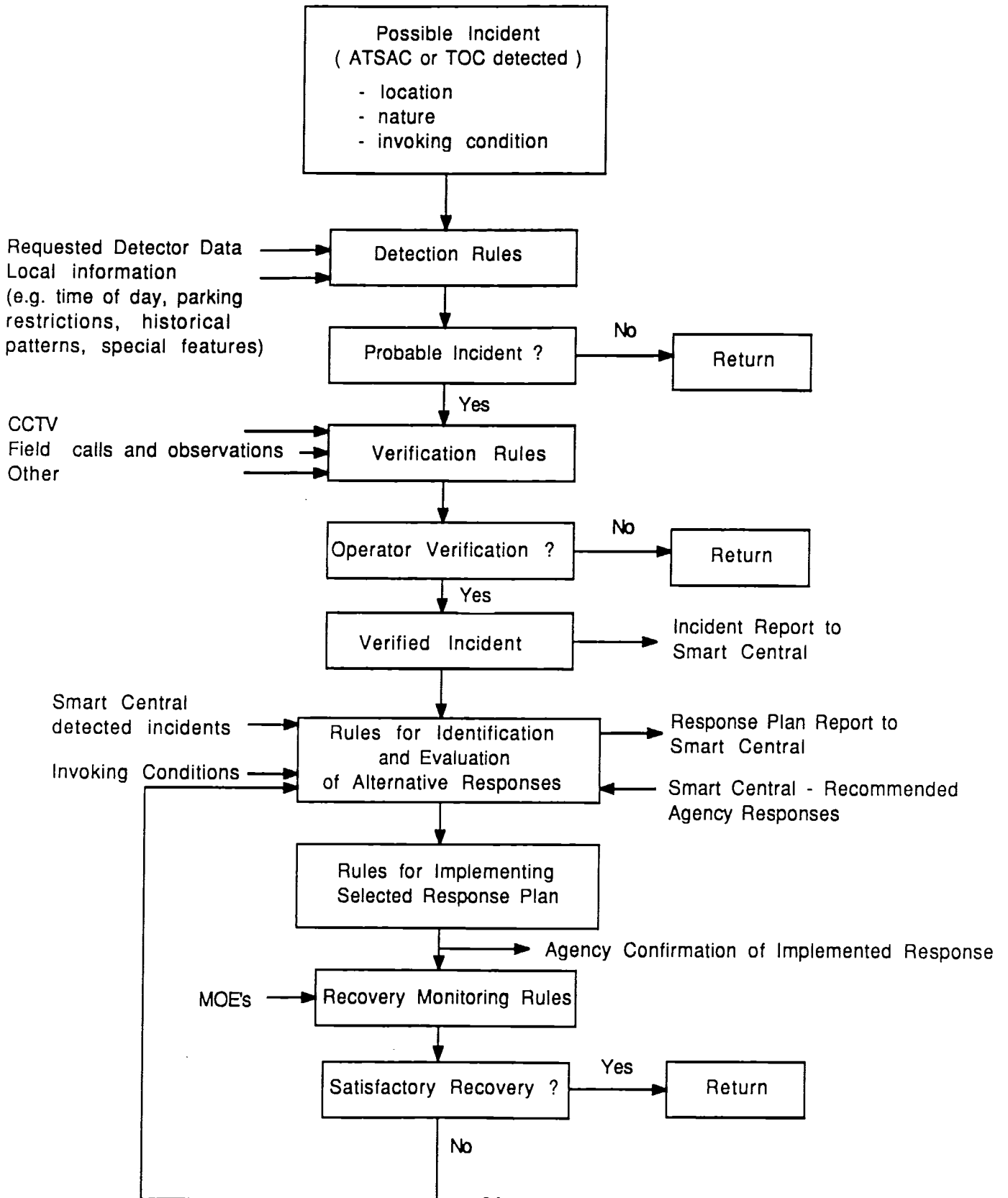
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Figure 2 Typical FRED System Rules

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 or equal to 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 3 FRED External System Overview

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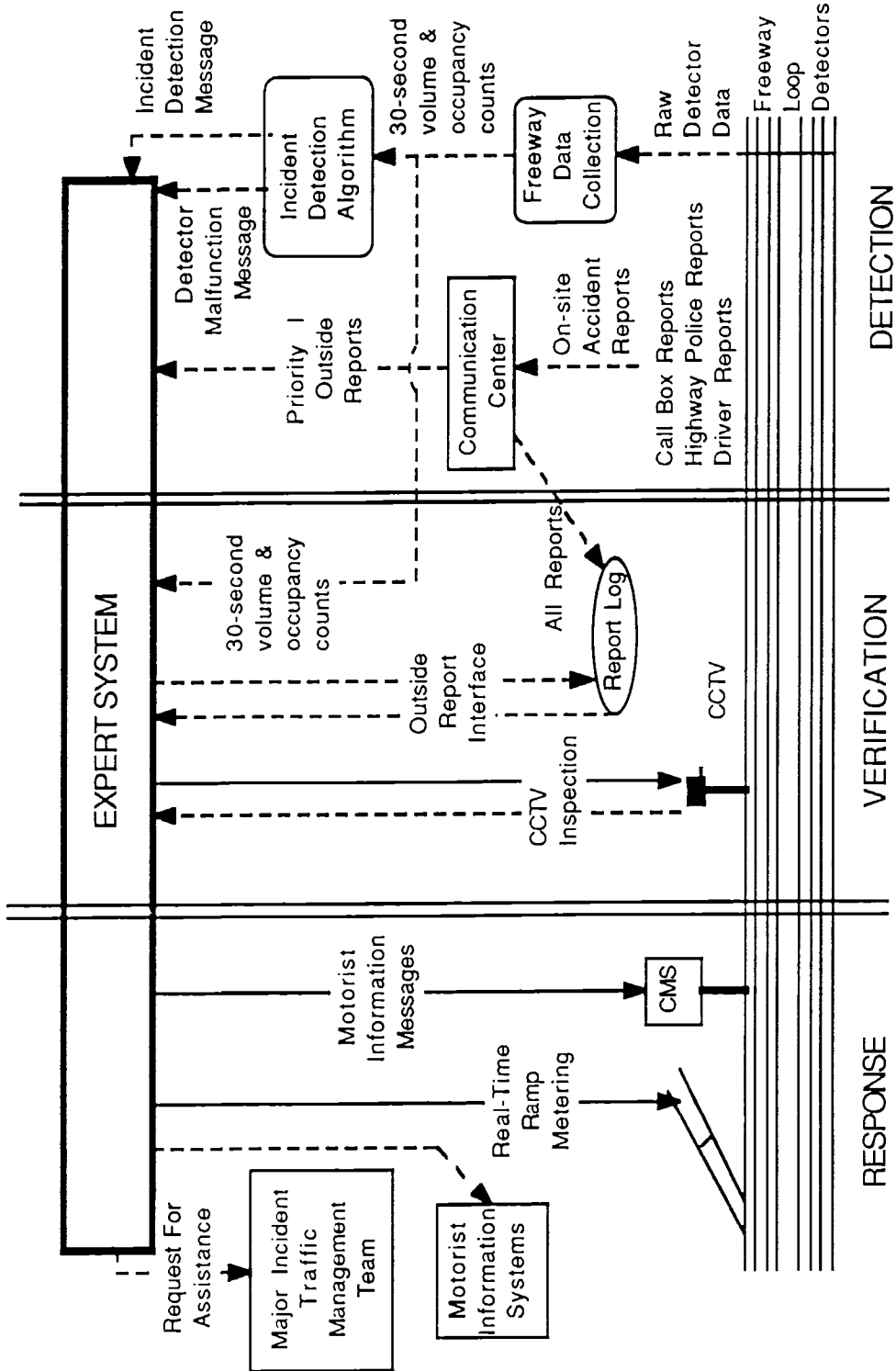
Figure 4 FRED Internal System Overview

CMS   Ramp Meters   MITMT

EXPERT SYSTEM COMPONENTS | **USER INTERFACE**

INCIDENT RESPONSE FORMULATION

- CMS Rules → Recommend CMS Messages
- Ramp Closure Rules → Recommend Ramp Closures
- MITMT Rules → Recommend MITMT Dispatch

Incident Attributes

INCIDENT VERIFICATION

VERIFICATION OPTIONS

Confirmed Incident → Confirm Incident Window

Show Occupancy Values → Occupancy Display

Consult Report Log → Report Interface

Consult CCTV

INCIDENT DETECTION

Incident Detection Filter (proposed) → Incident Detection Message

Incident Detection Message

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Figure 5 System Display Board

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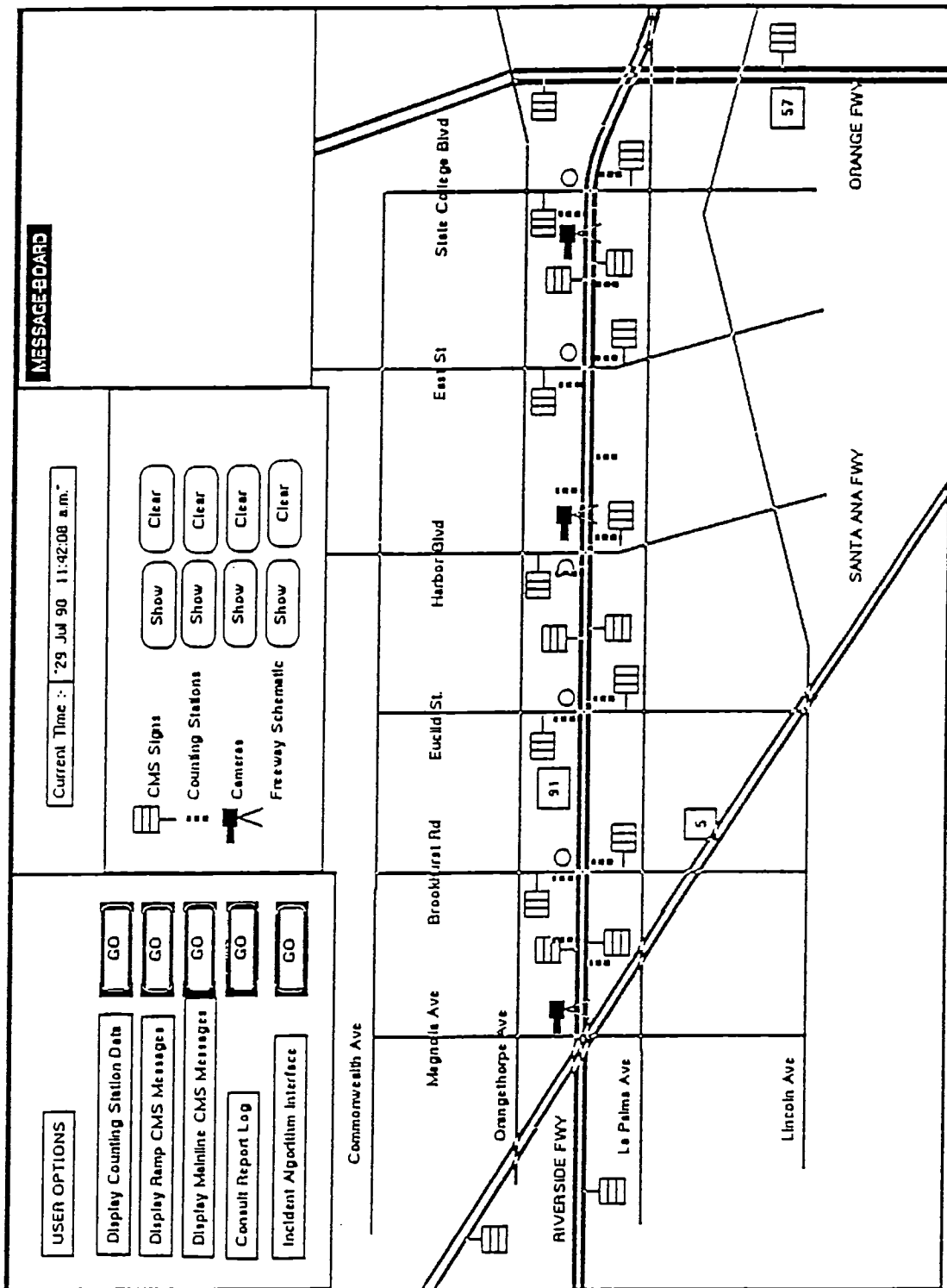
Figure 6 Incident Detection Message
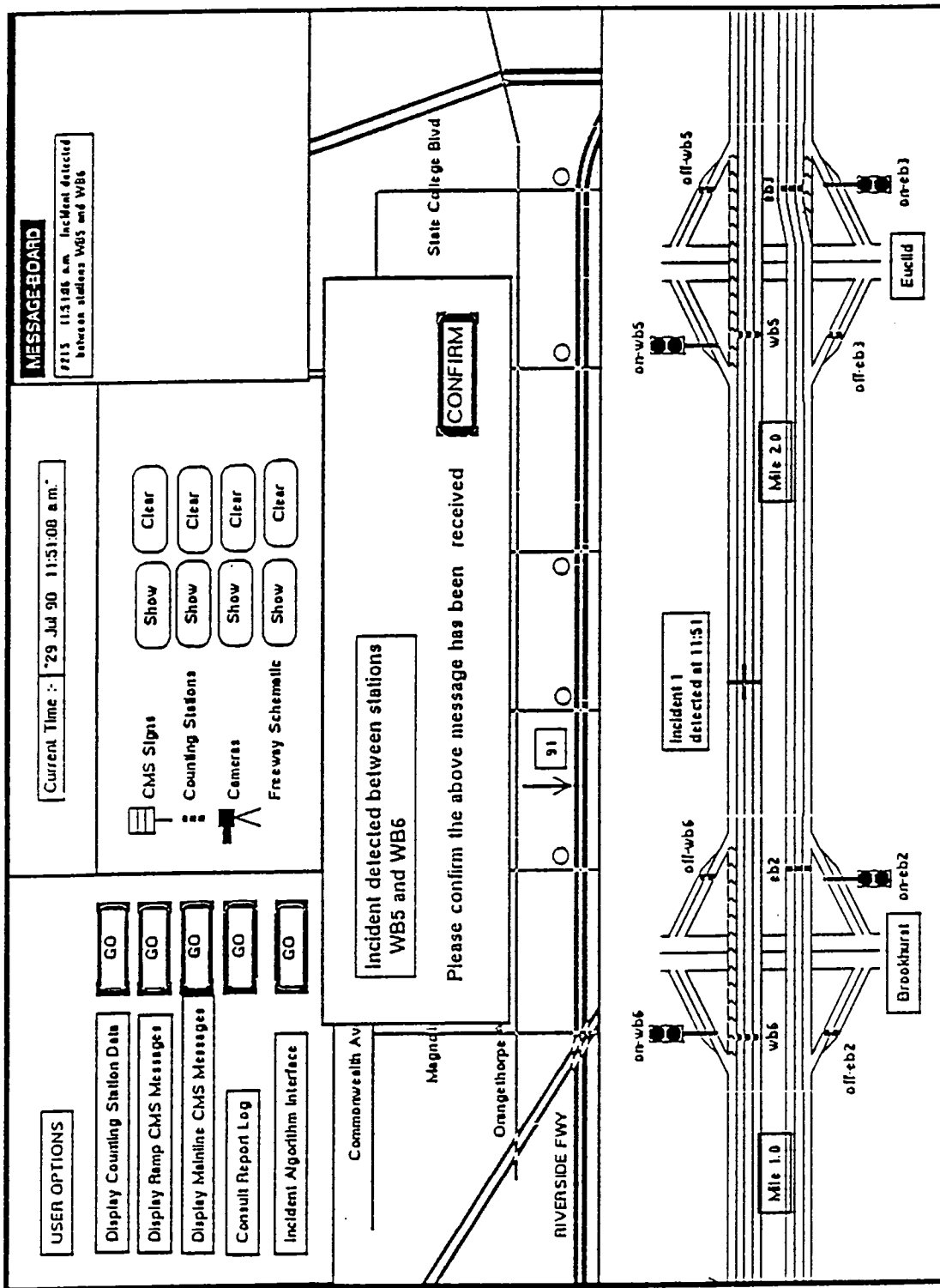
Figure 7 Incident Verification
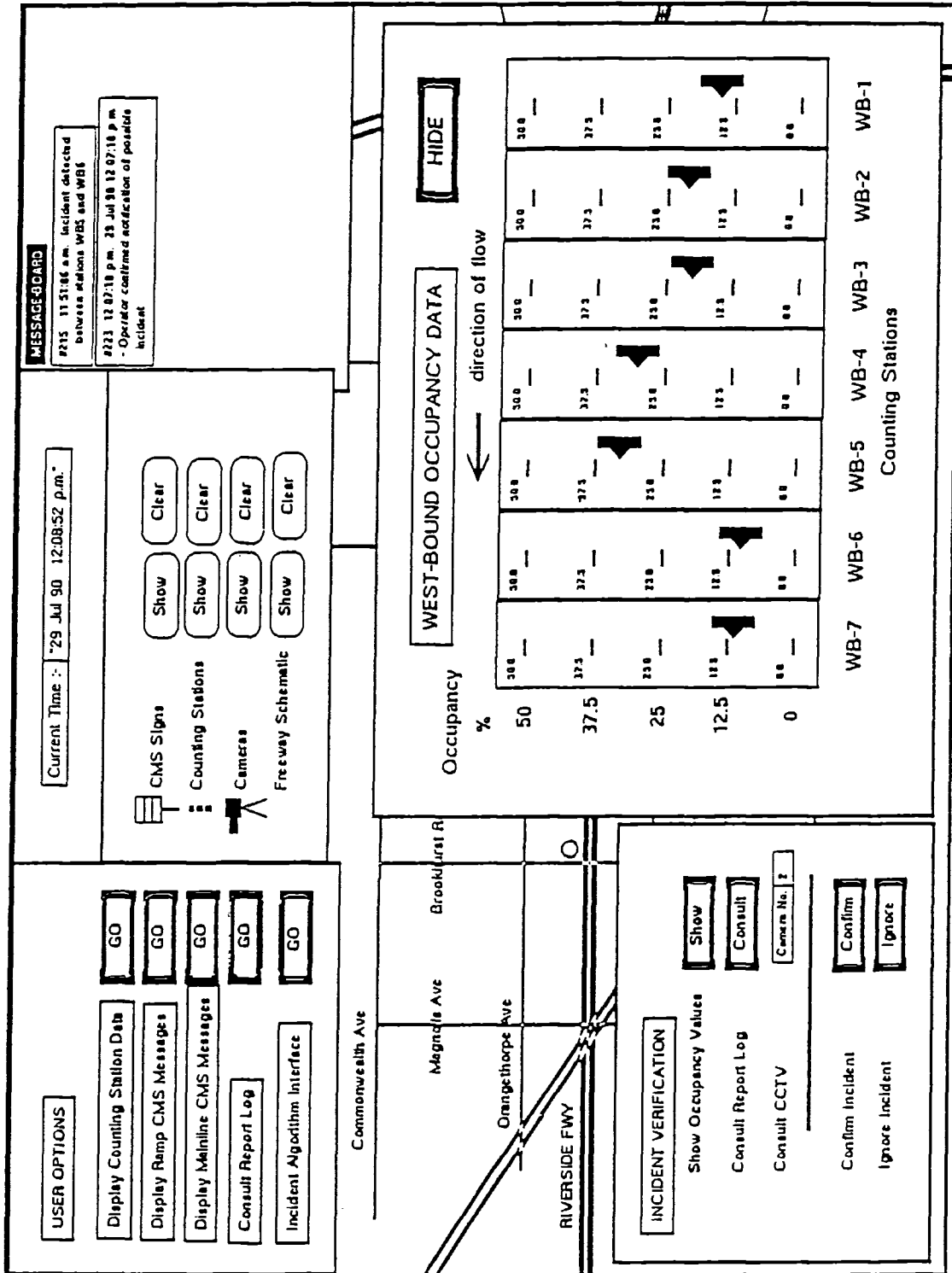
Figure 8 Incident Confirmation

Figure 9 Incident Response - CMS Messages