ASSESSMENT OF INCIDENT MANAGEMENT STRATEGIES USING AIMSUN

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ABSTRACT

PRIME (Prediction of Congestion and Incidents in Real Time, for Intelligent Incident Management and Emergency Traffic Management) is a project of the 5ht Framework Program of the European Union which objectives are to develop: methods for estimating incident probability in real-time, which can activate traffic management strategies to reduce the likelihood of incidents, improved systems and algorithms for detecting incidents, an improved integration of incident verification to increase the reliability of incident management, and the integration of aspects of motorway and urban-network incident management strategies to increase the effectiveness of incident and traffic management strategies in urban / interurban areas. This paper deals with the use of microscopic simulation to assess the potential impacts of the incident management strategies. A methodological scheme on how to use simulation to achieve these objectives is presented and the experimental plan for the test site in Barcelona is described and the preliminary testing results are presented

INTRODUCTION

PRIME (Prediction of Congestion and Incidents in Real Time, for Intelligent Incident Management and Emergency Traffic Management, reference IST 13036) builds on recent achievements (1) in the management of incidents and road emergencies in EU projects, and enhances weak links in the incident and road emergency management chain. This paper is partially based on materials from project Deliverables 3.1, 3.2, 6.1 and 6.2. The objectives of PRIME are to:

- Develop Methods for **estimating incident probability** in real-time, which can activate traffic management strategies to reduce the likelihood of incidents
- Develop improved systems and algorithms for **detecting incidents**
- Improved integration of incident verification to increase the reliability of incident management
- Integration of aspects of motorway and urban-network incident management strategies to increase the effectiveness of incident and traffic management strategies in urban / interurban areas.

The project is developing models of incident probability to estimate the likelihood of occurrence of incidents in real time. Estimation is based on geometric, weather and traffic characteristics. The operator can use the output from the models to support traffic management decisions that seek to reduce the probability of incident occurrence. Reducing this probability is expected to benefit the system, even if the immediate benefit may not always be visible to the drivers. For instance, the operator may activate traffic management and control strategies that increase the delay for certain drivers in the urban network but improve flow in the motorway. Other strategies may request certain drivers to divert away from their route, to achieve improved overall performance that reduces the likelihood of incidents.

An incident is defined as any non-recurrent event, which causes reduction of roadway capacity or increase of risk to drivers. For instance, apart from collisions or spilled load, incidents may also include vehicle breakdown at the shoulder. Incident or congestion prediction comprises the estimation of the potential for occurrence of incidents or congestion in real time. Congestion in this context concerns incident related emergence or growth of queues, also denoted as 'non-recurrent congestion' or 'incident related congestion'. Incident detection is the activity of monitoring traffic with the aim of (automatically) recognising the occurrence of an incident. This can be done either directly by spotting the vehicles involved in the incident or indirectly by analysis of deviant behaviour of other traffic that is reacting to the incident. The incident verification aims at confirming that an incident has actually occurred and at collecting information about the incident that is needed to organise appropriate incident response, including dispatching of emergency services and deployment of traffic management measures.

THE INCIDENT MANAGEMENT FUNCTIONS

Non-recurring congestion, is caused by traffic incidents which are unplanned physical events, such as accidents, spilled cargoes, disabled vehicles and debris on the road, occurring randomly in time and space and resulting in reduction of road capacity and safety. Incident Management is the co-ordinated, pre-planned and/or real-time use of human resources and equipment to reduce the duration and impact of incidents. Incident management signifies the co-ordinate, planned real-time use of human and technical resources, which aim to the reduction of the duration and consequences of incidents. Incident management involves a systematic approach for establishing accurate and reliable incident detection and verification, reducing the time it takes to detect and verify an incident occurrence, deploying the appropriate response resources, clearing the incident, managing the oncoming traffic until normal flow is restored, and reducing the overall time from detecting an incident until normal flow is restored. More specifically, incident management includes:

1. ***Detection***: Incident Detection includes all methods, techniques and actions needed to identify all spatial, temporal and severity characteristics of an incident.
2. ***Verification****:* Includes all methods and actions for ascertaining that a detected incident is to be accepted by the rest of the system.
3. ***Response:*** Includes all actions for determining agencies involved in the Incident Management operations, dispatching of appropriate response units, and guiding the response units to travel from their initial location to the incident site. It also includes incident clearance, i.e., all procedures and techniques for removing injured people, spilled cargoes and disabled vehicles, and restoring roadway capacity.

The objective of an incident management system is to reduce incident related delay and its adverse impacts. The incident management system includes a number of complex and strongly interrelated actions, and involves different agencies with different objectives, training, expertise and instrumentation.

INCIDENT DETECTION

Fast and reliable *incident detection* is instrumental in reducing traffic delay and increasing safety. In particular, with the information from incident detection, optimal control strategies guide the traffic flow toward smooth operation by preventing additional vehicles from entering upstream of the incident and by communicating traffic information to the travellers. In addition, incident detection constitutes the cornerstone for prompt incident management and safety improvement near the incident location. Automatic incident detection (AID) involves two major elements: A *traffic detection system* that provides the traffic information necessary for the detection and an *incident detection algorithm* that interprets the information and ascertains the absence or presence of an incident. Local presence detectors embedded in the motorway pavement are used extensively to obtain traffic data, primarily on occupancy and volume. Wide-area machine-vision detectors and other detector types can also be used for data collection. Incident detection algorithms can detect capacity reducing incidents, and safety reducing incidents. A number of incident detection algorithms have been developed. Their structure varies in the degree of sophistication, complexity and data requirements. Depending on their structure and detecting logic existing AID algorithms can be classified as comparative, time series, probabilistic, dynamic modelling, neural-network based, filtering algorithms, algorithms based on the fundamental traffic diagram, and algorithms based on wide-area detection by machine vision.

The minimum data requirements for detecting an incident automatically, using data from road-side monitoring equipment are:

Name	**Description**
Equipment Location	Ideally this information will be provided as distance in kms from designated marker posts however not all equipment will be able to provide this and it may be necessary to approximate the incident location using the location of the road-side equipment. It must also be possible to derive the road identifier either directly from the Equipment Location or by cross referencing the Equipment Location.
Carriageway	It must be possible to derive the Carriageway, where the incident occurred either directly from the Equipment Location or by cross referencing the Equipment Location.
Detection Code	This code will identify the source or method of the incident detection which for road-side equipment will be the equipment identifier and type of equipment which detected the incident.
Date and Time of Detection	The date and time of the incident detection to an accuracy of within 2 minutes.
Traffic Flow	% Occupancy every 30-secs in each lane
	% Occupancy every 60-secs in each lane
	Volume every 30-secs in each lane
	Volume every 60-secs in each lane
	Speed (km/hr) every 30-secs in each lane
	Speed (km/hr) every 60-secs in each lane
	% Occupancy every 30-secs on each entry/exit ramp
	% Occupancy every 60-secs on each entry/exit ramp
	Volume every 30-secs on each entry/exit ramp
	Volume every 60-secs on each entry/exit ramp

	Speed (km/hr) every 30-secs on each entry/exit ramp
	Speed (km/hr) every 60-secs on each entry/exit ramp

The output provided by the incident detection will be an Incident Alarm, warning to the operator identifying that an incident has been detected at a given position.

TWO ALGORITHMIC MODELS IN PRIME

Incident detection algorithms provide the logic for evaluating and processing the information obtained from electronic surveillance. Detection of traffic incidents has typically been based on models that determine the expected Traffic State under normal traffic conditions and during incidents. Two of the algorithms that are being object of testing in PRIME are respectively based on complex traffic models (Persaud and Hall) and in statistical analysis. Both try to establish predetermined incident patterns in traffic measurements and attempt to identify these patterns by comparing detector output against pre selected thresholds.

PERSAUD

The objective is to incorporate a mechanism for distinguishing between recurrent and incident-related congestion. The algorithm is based on a model derived from the one by Persaud and Hall, (2),(3),(4) elaborated on the catastrophe theory to describe the relationships between flow, occupancy and speed. The detection logic works in two step. In the first step the principle of the congestion detection logic is that a congestion flag can be given by operation in certain areas of the flow/occupancy diagram, or by a slow speed. If a flag is given for P consecutive periods congestion is present and hence a potential incident is indicated. The logic is designed for a system that provides speed and flow-occupancy data. The efficiency increases if data is for single lane. In the second step an analysis of the downstream detector is performed trying to identify the causes of the detected congestion to distinguish between recurrent congestion and congestion generated by an incident.

The algorithm's global idea can be expressed in the form of a template drawn on a flow-occupancy diagram, defining four different states of traffic. The template is composed of 4 areas, which are divided by the lower bound of uncongested data (LUD), the critical occupancy (Ocrit), and the critical volume (Vcrit). Area 1, above the LUD, is uncongested data. The area below LUD and Vcrit and to the left of Ocrit is Area 2, one type of congested traffic operation. The area to the right of Ocrit and below Vcrit is Area 3, more heavily-congested traffic operation compared with data in Area 4, which is below LUD but above Vcrit. The procedure for identifying the LUD line is to start identifying the data corresponding to uncongested conditions and then fitting a non-linear function through the uncongested data by means of regression, and then to plot the function against the data. Parameters should be calculated for different lower limits of uncongested speeds, in other words, lower bound on uncongested flows for a given occupancy should be defined. The other parameters should also be identified though an empirical analysis. Ocrit is simply the occupancy at which the highest observed volume occurs. Vcrit may be harder to establish. To properly identify it requires some congested data, and it must be possible to identify the volume that is normal within recurrent congestion, as opposed to that which occurs only during capacity reductions. The raw data received from the loop detectors are compared with the appropriate template values. A persistence check is used, such that the same state needs to be maintained for a certain number of intervals for a change condition to be finished. For the testing this persistence check has been set at three intervals. Any data falling bellow LUD for longer than three intervals are considered to be congested. The algorithm then attempts to identify the cause. If the cause can be identified as one of two categories, then the congestion is not considered to be from an incident. If the cause cannot be placed in one of these categories, then the congestion is deemed to be caused by an incident. The simplest of the two nonincident categories is secondary congestion, representing the extension of primary congestion to the next station in sequence, either further upstream as a consequence of queue growth, or further downstream when queue discharge effects carry on further than expected.

THE LOGIT MODEL TO ESTIMATE INCIDENT PROBABILITY

The aim of the Incident Probability Estimation is to establish the association between traffic conditions, weather conditions and road geometry and incident occurrence. The association is established according to statistical models based on traffic and weather conditions and road geometry as explicative variables and the presence of incidents, as a response variable, given as a result the probability of incident occurrence for each segment that constitutes the road network for which data are available.

The statistical approach adopted has been based on a Hierarchical Logit Model (called HLOGIT), a statistical model consistent of a set of observed explicative variables either continuous (called covariates) or categorical variables (called factors). For technical reasons, for each model component (variable) the following possibilities have been considered:

1. The variable is a continuous variable (or considered as a continuous variable), that is a covariate, then only 1 parameter is related to this model component.
2. The variable is a categorical variable, that is a factor, then as many parameters as the number of possible values for the factor must be filled related to the model component.

If $\mathbf{x}_i$ is the vector of explicative variables at section i, then the estimation of the probability of an incident at section i is given by

$$p_i = \frac{\exp(\mathbf{x}_i \beta)}{1+\exp(\mathbf{x}_i \beta)} \quad \textit{for} \;\; \beta \quad \text{the vector of model parameters}$$

The estimated probability can be translated in terms of a qualitative risk estimate defining the appropriate threshold values, as for example those in the following table:

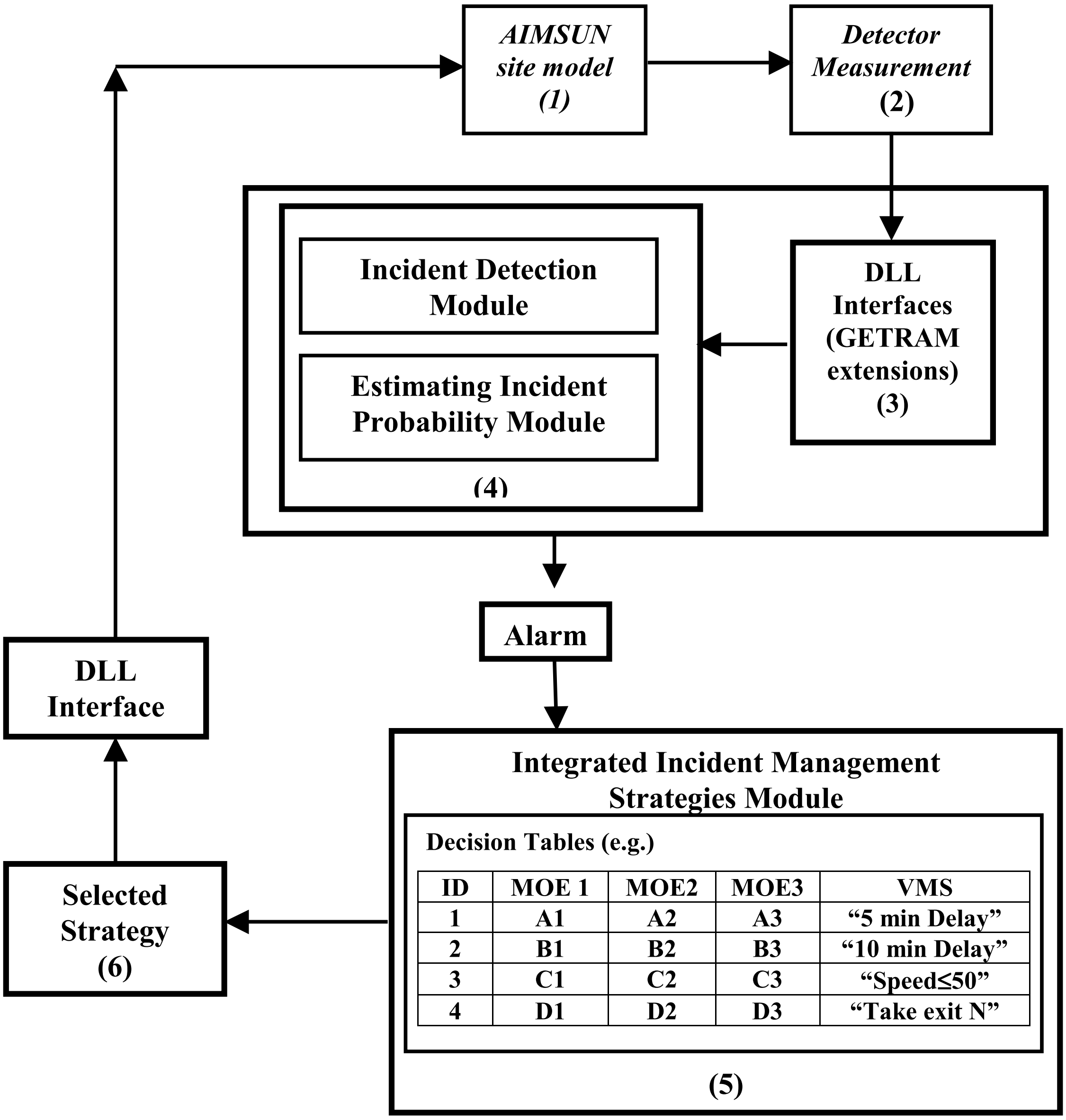
Estimated incident probability	***RISK***
$0< p_i \le 0.2$	*None*
$0.2< p_i \le 0.4$	*Low*
$0.4< p_i \le 0.6$	*Medium*
$0.6< p_i \le 0.8$	*High*
$0.8< p_i \le 1$	*Extreme*

The $\mathbf{x}_i$ vector of current explicative variable values for section i would contain for example variables like: CLOUDCOVER, ENVIRONMENTAL CONDITIONS, NUMBER OF ENTRY RAMPS, NUMBER OF EXIT RAMPS, OCCUPANCY, etc. In this case the vector of parameters would contain 11 values: 1 for intercept parameter, 3 for CLOUDCOVER factor, 4 for factor ENVIRONMENTALCONDITIONS , 1 for NUMBER OF ENTRY RAMPS, 1 for NUMBER OF EXIT RAMPS and 1 for OCCUPANCY.

THE OFF-LINE TESTING IN BARCELONA

The conceptual approach to the Off-line testing workplan at Barcelona site is depicted in Figure 1 and works as follows:

1) An AIMSUN model (Box 1) of the whole test site has been built and calibrated using the traffic data collected from September 2000 until April 2001.
2) Once calibrated, the model emulates the traffic measurements (flow, occupancy, speed and traffic composition, Box 2) that in the real-world are provided by the available on-street detection stations.



ID	MOE 1	MOE2	MOE3	VMS
1	A1	A2	A3	"5 min Delay"
2	B1	B2	B3	"10 min Delay"
3	C1	C2	C3	"Speed≤50"
4	D1	D2	D3	"Take exit N"

Figure 1

3) A specific interface, (built with the available DLL GETRAM library of functions that enables the AIMSUN simulation model to communicate with external applications) , to feed the simulated traffic data into the incident detection/probability estimation models that will work using the simulated data provided by the model.

4) The algorithms, which make up the incident detection and estimating incident probability modules, use the simulated traffic data generated by AIMSUN to predict and identify incidents on the simulated network via the GETRAM extensions (Box 4).

5) When incidents are predicted/detected, the Integrated Incident Management Strategies Module is alerted which chooses traffic control plans and/or information dissemination plans according to the severity of the conditions encountered (Box 5).

6) The selected strategy can then be fed back into the simulator in terms of VMS messages which are designed to divert certain proportions of drivers or control plans which will alter priority at traffic signals. A site specific DLL GETRAM interface feeds the parameters of the strategy back into AIMSUN. The effects of these strategies can then be monitored.

7) The decision tables which make up the IIMS module have been developed off-line. These form a dictionary of traffic control plans and information dissemination plans for each link in the simulated network. These site specific plans are derived by running various incident scenarios (duration and severity) on specific key links in the network.

SITE DESCRIPTION AND TESTING SCENARIOS

In 1992, as part of the completion and improvement of the city road network infrastructure for the Olympic Games a 43Km. long Ring Road was completed. The Ring Roads are functionally split in two parts, the north bound or “Ronda de Dalt” crossing the upper part of the city at the feet of “El Tibidabo” hills, and the south bound, “Ronda Litoral” running parallel to the Mediterranean shore most of its length. They have three lanes on both directions in most of their length, with the exception of the stretch of the “Ronda Litoral” along the harbour that has only two lanes. Traffic monitoring and management on the Ring Road is done from the Traffic Management Centre at the “Collcerola “ Node in the “Ronda de Dalt” which also covers the function of Traffic Information Centre. In case of incidents requiring an intervention of emergency units (urban police, fire brigade, ambulances, etc.) the Traffic Management Centre activates the alarms and sends the available information to the Incident Management Centre, which is the responsible of the intervention. Figure 2 depicts in detail the Barcelona PRIME site as modelled in AIMSUN for the Off-line testing. The Ring Roads are a urban freeway that articulates the main accesses/exits to and from the city, distributes the traffic around the city and canalises the main traffic streams between the two main industrial areas North (from Nus Trinitat) and South (from Nus Diagonal) of the city respectively. The 15 Km of urban motorway between Nus Trinitat and Nus Diagonal have a strong interaction with densely populated urban areas, making that traffic problem in the Ring Road could be easily exported into the neighbour urban arterials and streets and conversely. Figure 2 also identifies the main site areas with an stronger interaction between the Ring Road and the urban/interurban network. Interchange nodes Nus Trinitat and Nus Diagonal, in yellow and fuchsia respectively, are two of such areas. In red and green have been highlighted two other main areas nominated respectively Problem Area 1 and 2. Problem area 1 has three main interaction points: the arterial Via Julia, the Roundabout “Plaza de Karl Marx”, collecting and distributing traffic flows from/to the arterial Valldaura, and the interchange node between the Ring Road and the Rovira Tunnel. Problem Area 2 comprises the section of the Ring Road between to interchanges Nus de Collcerola (where the Traffic Control centre is located) and Plaza de Artós. Problem Area 1 has been the area selected for the off-line PRIME testing exercises. Figure 3 depicts in detail the problem area.

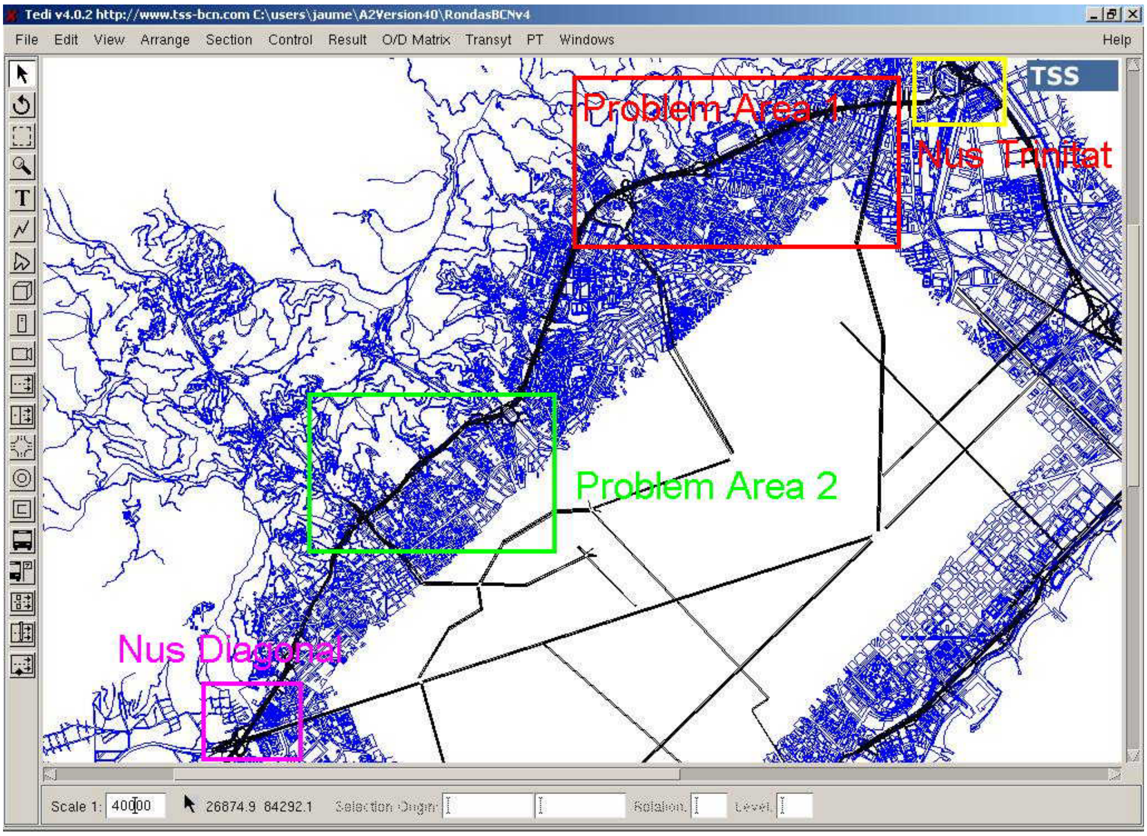


Figure 2: Barcelona PRIME Site. Main interaction areas between the Ring Roads and the Urban and Interurban Networks.

At the selected Problem Area 1 of Barcelona's site there are available three types of strategies (single factors), and their combinations (combined factors):

- Information and route recommendations using the Variable Message Panels
- Speed control on the main sections using the Variable Speed Signs
- Access control based on ramp metering strategies at the equipped entry ramps

The selected Problem Area has: 3 Off-ramps direction Llobregat, 4 On-ramps direction Llobregat, 3 On-ramp direction Besos, 3 Off-ramp direction Besos, 1 VMS panel direction Llobregat, 1 VMS panel direction Besos

The On-ramps in both directions are equipped with traffic lights that could implement ramp metering strategies. The strong interaction between the Ring Road and the urban network trough these service roads makes that any strategy implemented on the Ring Road could potentially have a strong impact on the adjacent urban network, limiting in that way its actions, i.e. a ramp metering at On-Ramp 2, direction Llobregat, could potentially create queues spilling back to the service road and blocking the access to the Roundabout in "Plaza Karl Marx". This implies that the simulation experiments to define and evaluate off-line a strategy including such potential action should take into account limitations in the allowed queue lengths. The strategies defined for the problem area in both directions (ranked from lower to higher levels of intervention) are:

Strategy 1: Display information messages on the VMS informing on the presence of congestion, incidents, etc.; make recommendations on speeds; alternate the information messages with warnings

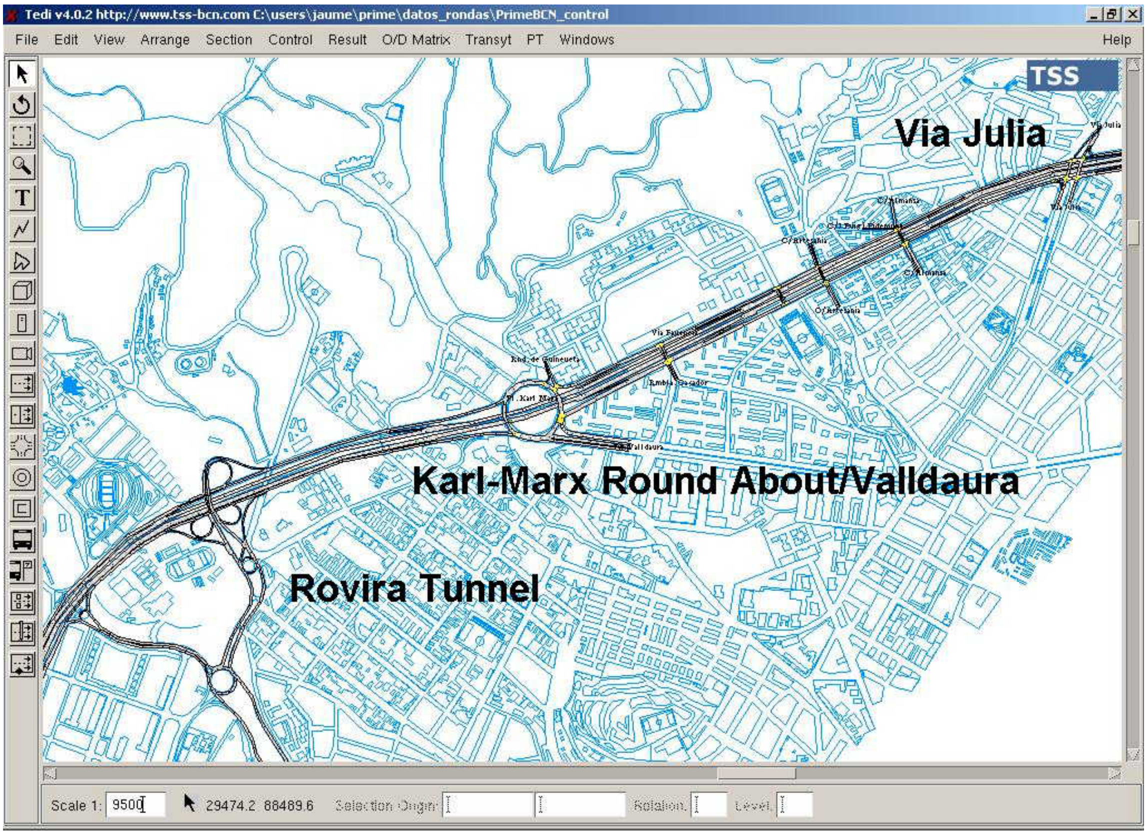


Figure 3: Detail of the problem Area 1 for PRIME Off-line testing.

Strategy 2: Display more dissuasive information messages on the VMS informing on the presence of congestion, incidents, etc; provide also delay and travel time estimates; variable speed limits compulsory **Strategy 3**: The same as Strategy 2 and rerouting information (try to force the use of specific off-rasms leading to alternative routes) **Strategy 4**: The same as Strategy 3, and ramp metering at On-rams upstream of the incident / congestion location. Each experimental scenario has been implement for the Problem Area 1 of the simulation model. The differences between the scenarios depend on the implemented management strategies. The scenarios have been assessed for the traffic conditions used to calibrate the basic simulation model. The main objectives of the simulation experiments have been: Estimate the potential benefits of the single factors and the combination of factors with respect to the do-nothing scenario; estimate the effects of a timely identification of incidents in combination with the design factors and derive rules for establishing management strategies. The results of the simulation analysis and assessment of scenarios will be the basis for a decision making process which could lead to a real-life implementation of the defined management strategies. The core of the decision support system as shown in Box (5) of Figure 1 is a decision table in which the strategies are defined in terms of the factor specified above. Each strategy will be triggered by threshold values for a set of indices of Measures of Efficiency (MOE), i.e.: MOE 1: Degree of saturation on a subset of predefined critical sections in the site; MOE 2: Delays (vehicle-hours) in the entire site; MOE 3: Total travel times (vehicle-hours) in the entire site; MOE 4: Average Queue lengths at critical entry ramps in the site; MOE 5: Total travel (vehicle-kilometers) in the entire site; MOE 6: Speed variance (Km/h) in the mainline

The simulator proposed: AIMSUN (5), (6), (7), (8), (9), (10), is embedded in GETRAM (Generic Environment for Traffic Analysis and Modelling) a simulation environment comprising a traffic network graphical editor (TEDI), a network data base, a module for storing results, and an Application Programming Interface to aid interfacing to other simulation or assignment models. An additional library of DLL functions, the GETRAM EXTENSIONS, enables the system to communicate with external applications, as for example real-time control logic. TEDI is a graphical editor for traffic networks. It has been designed with the aim of making the process of network data entry and model building user-friendly. Its main function is the easy entry of the network feeding the traffic simulators like AIMSUN. To facilitate this task the editor accepts as a background a graphical description of the network area, in terms of a DXF file from a GIS or an AutoCAD system, so sections and nodes can be built subsequently into the foreground. The editor supports both *urban* and *interurban* roads, which means that the level of detail covers elements such as surface roads, entrance and exit ramps, intersections, traffic lights and ramp metering.

PRELIMINARY CONCLUSIONS

The information available from the incidents has been used to replicate them in the calibrated simulation model. Figure 4 illustrates the process of simulating Incident ID=312. The preliminary purpose of the testing exercise has been in this case verify whether the improved detection system can overcome some of the identified drawbacks for the real system (low detection rates due to high distances between detector, lack of sensitivity due to the aggregation time - one minute – for the current detectors, etc.). Table 1 reproduces the preliminary results achieved by simulation for the current version of Persaud, and Table 2 the preliminary results for the EIP algorithm

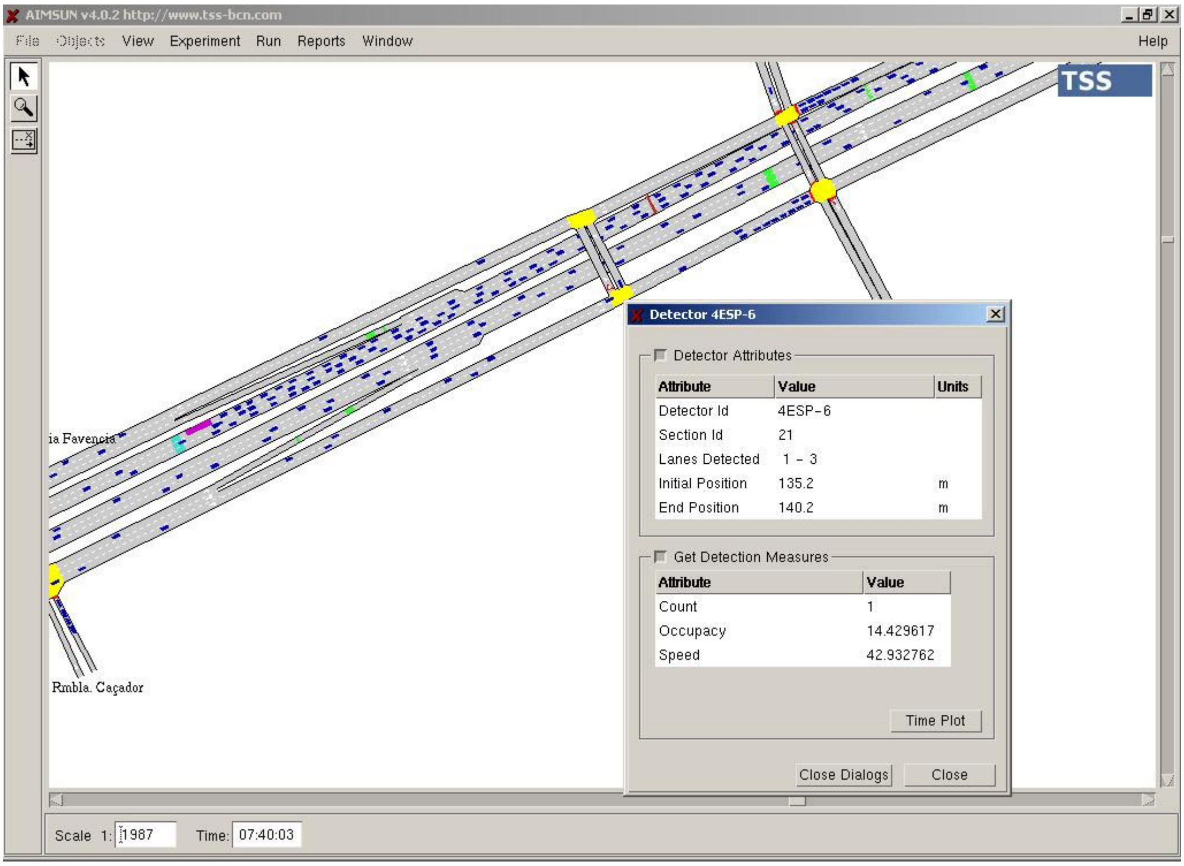
Component	**Measure Of Effectiveness**	**Definition**	**Target/ %**	**Preliminary value**
ID	Detection Rate	Number of Pass results / Total number of incidents in sample	85%	60%
	Detection False Alarm Rate	Number of False Alarms Raised over the total test period / Total number of records in test period	0.2%	0.25%
	Relative Detection False Alarm Rate	Number of False Alarms Raised over the total test period /Total number of incidents which occurred over the test period		35
	Time To Detect	The maximum time taken to detect an incident	Persaud = 120 seconds	180

Table 1

EIP Validation Measure of Effectiveness	*Current Implementation of EIP*	**Target**

Estimation Rate	19 of 22 incidents: 86%	80%
Estimation False Alarm Rate	900 of 2741 registers ,i.e. 32%	10%
Relative Estimation False Alarm Rate	900 of 22 = 40.91	-

Table 2



Detector Attributes

Attribute	Value	Units
Detector Id	4ESP-6	
Section Id	21	
Lanes Detected	1 - 3	
Initial Position	135.2	m
End Position	140.2	m

Get Detection Measures

Attribute	Value
Count	1
Occupacy	14.429617
Speed	42.932762

Scale 1: 1987 Time: 07:40:03

Figure 4

For incident management strategies, the simulation scenario consisted on the full implementation of the conceptual diagram depicted in figure 1. A subset of well identified incidents has been selected and three alternative versions of the scenario, which results are summarized in Table 3, have been simulated: S1: Do nothing scenario (current situation); S2: Scenario with Strategies 2 and 3 as defined above (warnings and speed control); S3: Scenario with Strategy 4 (Warnings, speed control and ramp metering in the affected On ramps)

(1) The initial experiments show an improvement that reduces the overall delay. Although there is reduction in travel times, consequence of the reduction in delays, the increase in total travel times is due to the increase in the total number of vehicles, as can be seen in the increase in MOE3. The simulated scenario assumes that drivers accept the warnings and look for alternative routes when congestions or incidents occur downstream, and follow the speed limit indications.

(2) This scenario requires further analysis. The expected improvements are not achieved, and in fact the conditions deteriorate with respect to the do nothing scenario. A preliminary analysis indicates that metering create queues in some on ramps that strongly interact with

the urban network blocking some critical intersections. The implemented strategy has been of auto-adaptive type, trying to keep the flows in the main section under certain threshold values. For this experiment the threshold values have been the VCRIT volumes of the detector downstream the on-ramp with the objective of trying to keep the main section in uncongested conditions. That means that more complex metering strategies should be taken into account i.e. metering that also uses queue lengths at on-ramps as control variable.

Component	**Measure Of Effectiveness**	**Definition**	**Values S1**	**Values S2 (1)**	**Values S3 (2)**
IIMS	IIMS MOE 1 –	Delays in Vehicle-Hours over the entire modelled network.	21.44	18.56	23.78
	IIMS MOE 2 –	The total travel times in Vehicle-Hours over the entire modelled network.	36.56	38.63	35.27
	IIMS MOE 3 –	Total travel distance in Vehicle-Kilometres over the entire modelled network.	388885	401728	367582

Table 3

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