A DSS FOR “DYNAMIC TUNNEL” TRAFFIC AND INCIDENT MANAGEMENT

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ABSTRACT
Traffic incidents in tunnels can have dramatic consequences and can prove extremely costly in terms of human lives, increased congestion, pollution and repair costs. Traffic incident management is the primary tool in minimizing the impact and reducing the probability of secondary incidents. It primarily includes incident detection, verification, response, clearance and recovery operations. Besides these operations, traffic management in the post-incident scenario is a crucial step to minimize the negative consequences on network efficiency and safety. Traffic management includes the dissemination of information to drivers and the activation of proper traffic control measures at the incident site and on the roadway infrastructures affected by the traffic incident.

This paper describes the current development, within the SITI project, of a DSS (TRIM-Traffic and incident management) designed to assist traffic control centre (TCC) operators to effectively and safely mitigate traffic congestion associated with incidents in tunnel and on the surrounding road network.

In particular TRIM is designed to support on-line and off-line tasks of TCC operators required to define, implement and control the appropriate traffic response plans on the basis of the incident severity level, the predicted duration, the estimated delay and extension of the impact area and the current/predicted traffic demand approaching the incident site.

The basic elements of a response plan are the traffic channelling and control schemes to regulate traffic flow past the incident site, the traffic diversion on appropriate routes to relieve traffic demand at the incident site and the dynamic dissemination of information to drivers using various output devices and regarding traffic conditions, changes in roadway geometry, operating traffic speeds and routing.

BACKGROUND
The Italian roadway and motorway network is characterized by a high density of traffic and tunnels. In recent years the risks of incidents have increased as many road infrastructures, including tunnels, were designed several decades ago to carry lower traffic volumes than the current traffic levels and were built with technical requirements that with time have become outdated.

Currently all the main Italian roadway and motorway companies are involved in the process to improve the tunnel safety levels according to the recent EU directive that defines minimum harmonised organisational, structural, technical and operational safety requirements for all tunnels longer than 500 meters in the Trans-European Road Network.

The SITI project co-financed by the MIUR (Ministry of Education, University and Research) aims to study, develop and demonstrate a set of innovative technologies in order to improve the traffic monitoring process and the safety level inside the road tunnels. SITI introduces a new approach, the “Dynamic Tunnel” vision, which considers the tunnel as a whole with the road network before and after the tunnel itself, like a complex system in continuous evolution.
A SITI objective is the implementation of a DSS for the selection and best implementation of traffic management measures in response to the occurrence of an incident to alleviate serious traffic congestion, minimize substantial queue back-up and reduce potential secondary incidents. The main functions of the DSS are aimed at preventing crisis situations and at making more effective the traffic control operations during the emergency events, both at local and wide area.

**POST-INCIDENT TRAFFIC MANAGEMENT STRATEGIES**

An incident represents any unpredictable occurrence that disrupts traffic flow for a period that lasts longer than the incident itself and, temporarily, reduces roadway capacity. An incident can range from disabled vehicles or debris dropped along the side of the roadway up to major collisions involving fatalities, fires or hazardous material spills. Severe incidents involving significantly damage to roadway and structures, such as multi-vehicle collisions, tanker truck explosion and fire in tunnels, can cause severe disruptions in the flow of traffic including even disturbances in the economy of a whole region. However minor incidents, such as disabled vehicles, are responsible for the majority of the total delay caused by incidents.

The occurrence of incidents, besides its direct impacts in terms of property damage, injuries and fatalities, can quickly lead to congestion and associated travel delay, wasted fuel, increased pollutant emissions and higher risk of secondary incidents. The amount of delay and impacts that results from the incident depends on the duration of the following five distinct phases often overlapping:

1. **Detection** that determines the occurrence of the incident;
2. **Verification** that defines the precise location and nature of the incident;
3. **Response** that concerns the activation and dispatching of personnel and equipment to the incident site;
4. **Clearance** that includes the removal of vehicles, debris and spilled material from the roadway to restore the complete roadway capacity;
5. **Recovery** that consists of dissipating the queue at the site of the incident once the roadway is cleared in order to restore as quickly as possible the normal traffic conditions.

Together the first four phases represent the total duration of the incident or the period of time ranging from the occurrence of the incident to the complete restoring of the roadway capacity. The recovery phase largely depends on the extent of the disruption to traffic flow caused by the incident and on the effectiveness of the traffic management measures implemented soon after the occurrence of the incident.

Traffic management includes the implementation of a range of traffic control measures at the incident site and on the roadway infrastructures affected by the incident aimed at minimizing traffic disruption, reducing the probability of secondary collisions and protecting responders working on the incident.

The control at the incident site is required to facilitate the orderly and safe movement of traffic past the incident by channelling traffic with flares, cones, delineators and warning signs into the lanes that remain open to traffic.

Typical techniques implemented for the on site control are:

1. roadway shoulder utilization to provide additional capacity around the incident scene;
2. ramp diversion from the exit ramp immediately preceding the incident site, to divert traffic temporarily off the roadway onto a nearby parallel street and back onto the affected roadway downstream of the incident scene.
3. contra flow lane diversion (for major incidents causing the full closure of the carriageway for several hours) to allow upstream trapped traffic to utilize a travel lane from the opposing roadway direction;
4. alternate one-way movement when two-way traffic is reduced to one-way traffic and traffic in both directions must use a single lane. Alternate one-way traffic control may be affected by means of temporary traffic signal or by flagmen.

Traffic management may also requires the implementation of measures that temporarily limit traffic demand approaching the incident location to prevent congestion or vehicle queuing upstream of the incident. In this context typical traffic control strategies are traffic diversion on alternative routes and ramp metering.
By effectively controlling entering vehicle volumes with traffic signals at the entrance ramps located upstream from the incident site, the ramp metering strategy can help keep the traffic density below the critical level and provide a smooth flow of traffic on the section of roadway immediately upstream of the incident.
The diversion of the traffic flow approaching the incident area on appropriate alternative routes is the only way to alleviate congestion especially in the occurrence of major incident requiring the long-term closure of multiple lanes or full closure of the roadway. However the effectiveness of traffic routing depends on the availability of alternate routes and their level of congestion.
A diversion strategy involves the determination of where and how much traffic should be diverted and the sequence of roads forming the diversion routes that are best suited to handle this increased traffic demand. A diversion strategy may also involve the modification of signal timing and the activation of guide signs along the diversion routes to allow the effective and safe passage of diverted traffic.
A major element of traffic management in post-incident scenario is the dissemination of information to drivers approaching the incident area regarding traffic condition, changes in roadway geometry, operating traffic speeds and routing by deploying various output devices (variable message signs, lane control signals, radio broadcasts, etc). Drivers’ response to the provided incident-related information is crucial for successfully diverting traffic, reducing secondary incidents and improving responders’ safety on the incident scene.
In conclusion by reducing the duration of the incident and maximizing the use of the available roadway capacity during incidents, both the economic cost of congestion and the associated aggravation can be reduced. The result is more reliable travel, shorter trips and an ability to accommodate more trips within the existing roadway infrastructures.

BASIC REQUIREMENTS AND FUNCTIONS
In this context a DSS with the capability of storing, analyzing, and displaying geographically referenced information and data on network characteristics, traffic and incidents, predicting incident duration and traffic delay, generating and implementing appropriate traffic response plans to different incident scenarios and controlling their effectiveness in reducing traffic disruption and related impacts, appears to be the perfect tools to greatly increase the efficiency of incident and traffic management.
Particularly the main requirements that TRIM should be able to meet are:
- to integrate and display information flowing from the surveillance and control devices, installed inside the tunnel and on the surrounding road network, to the TCC (i.e.: traffic flow sensors, traffic signs, VMSs, meteo sensors, AVL, etc.);
- to perform traffic simulation studies at macro/micro scale to evaluate feasible traffic response plans under different traffic conditions and incident scenarios;
to store, query and analyse network characteristics data, incident scenarios and historical traffic data, needed to define possible diversion routes and control strategies and to feed traffic simulation and prediction models;

• to select on the basis of predefined rules the most appropriate traffic plan in response to an incident and suggest to the TCC operators the needed steps for its implementation;

• to provide during the incident management period reliable estimates of the network traffic conditions to verify the effectiveness of the proposed traffic response plan.

Based on these requirements TRIM design is aimed to make available a new software tool suitable to help the TCC operators in their tasks, especially when they face dramatic traffic congestion caused by major incidents inside or in the proximity of a tunnel, involving long duration clearance operations and affecting high traffic volumes.

In particular TRIM is designed to help the TCC operators to effectively perform:

➢ off-line tasks, concerning the study and design of a set of traffic response plans to face possible incident scenarios through the use of micro/macro traffic simulation and prediction tools;

➢ on-line tasks during the incident management process, concerning the selection, implementation and follow-up of the most appropriate traffic response plan, in relation to the incident severity level and the traffic volumes approaching the incident site.

The main off-line and on-line functions of the TRIM system are outlined in the flowchart illustrated in figure 1.

![Flowchart of TRIM basic functions](image)

**Figure 1:** Flowchart of TRIM basic functions

The flowchart shows the different steps followed from the occurrence of the incident to the implementation and control of the traffic response plan.
After an incident has been detected and verified through information coming from the different available sources (traffic sensors, CCTVs, police patrol, etc.), the incident details (i.e.: type, location, time of occurrence, vehicle involved, injuries involved, fatalities involved, etc.) are input by the TCC operator into TRIM through a convenient graphical user interface.

Once TRIM has received the input information describing the incident, the first step is to predict the incident duration on the basis of the incident characteristics and the operational experience accumulated from previous incident management operations. Duration prediction refers to the expected time interval ranging from the incident occurrence to the end of clearance operations.

Starting from the predicted incident duration and taking into consideration the amount of the road capacity reduction and the prevailing traffic conditions, TRIM estimates delays and impact area extent that will be caused by the incident.

These estimates are then used to select a preliminary traffic response plan that includes the set of strategies chosen to manage traffic flow (such as diversion points, diversion volumes, termination points, diversion routes, timing for traffic signals, emergency signals, messages to be displayed on the VMSs etc.). The selection is performed on the basis of rules pre-defined by the traffic experts.

According to the selected traffic response plan, TRIM proposes to the TCC operators, step by step, the predefined traffic management measures to be implemented. The traffic response plan is integrated with information about the best paths to be taken by the involved emergency response vehicles to reach the incident site more quickly and vice versa.

Traffic micro-simulation is then performed starting from the preliminary estimates about the incident duration, the current traffic data received from sensors, the diversion routes and the traffic control measures taken by the TCC operators. Traffic micro-simulation reproduces in a virtual environment the spatial-temporal evolution of the traffic flow on the roadway network affected by the incident with the final aim to offer an immediate, reliable estimate of the effectiveness of the preliminary traffic response plan.

If the simulation results (such as delays and queue lengths) differ significantly from the expected traffic performance, TRIM helps the TCC operator to select and implement a new, more effective traffic response plan.

On-line traffic micro-simulation can be performed again when updated information on the traffic conditions or the clearance operations duration becomes available in order to verify the effectiveness of the current traffic response plan.

The TRIM off-line functions are aimed to study and evaluate feasible traffic plans in response to possible incident scenarios through the use of micro and macro scale traffic simulation models.

Micro-simulation, that captures the behaviour of vehicles and drivers in great detail, is performed to evaluate traffic congestion evolution at local scale in the proximity to the incident site due to the complicated structure of the models involved.

On the other hand macro-simulation, due to their more aggregate nature, is performed to evaluate the traffic conditions at a wider scale (i.e.: regional/national network), to choose the best diversion points for the specific incident and to determine the best routes for the chosen diversion points.

Finally an off-line function of TRIM is the generation of shortest paths, so that emergency responders can avoid blocked or slow routes and quickly reach the incident site.
GENERAL ARCHITECTURE AND MODULES

TRIM is designed to work inside a motorway or an urban area or a long tunnel traffic control centre (TCC) able to perform traffic surveillance, traffic control and driver information functions. Trim, including macro/micro scale traffic simulators, is designed to support on-line and off-line functions such as the incident duration prediction, the traffic delay estimation, the impact area determination, the formulation, selection and control of appropriate traffic response plans. Traffic simulators will enable traffic control operators during the incident management period to perform detailed real-time analysis of the network traffic conditions under the current control strategies.

The general architecture of the TRIM system is illustrated in figure 2.

TRIM is composed of the following software modules:

- a relational database (MySQL) designed to store, query and update historical incident and traffic data, traffic network characteristics, data exchanged between the various system modules, simulation results and traffic response plans;
- a GIS-based user interface (ArcView) that enables TCC operator to display the roadway network, the real time traffic data and the status of the control devices on a background map, to run on-line and off-line prediction and simulation procedures, to analyse and display the results in multiple views and tables, to define and implement traffic response measures;
- an interface module to gather on-line traffic/meteo data collected by sensors installed inside the tunnel or on the surrounding roadway network;
• a module to predict the duration of the incident ranging from its occurrence to its complete removal. The module incorporates a statistical model that includes variables related to operational and incident-type factors that can be realistically obtained in real time under incident conditions. The model is tailored on the basis of the time experienced in past incidents occurred in the local area;

• a module to estimate the incident delay suffered by drivers and the impact area extent in case of non-intervention. The module incorporates a model, based on deterministic queuing method that calculates the cumulative vehicles hours of delay and the consequent queue length upstream of the incident site. The incident delay is estimated starting from the estimated incident duration, the prevailing traffic demand and the value of the capacity loss;

• a module to select the most appropriate traffic response plan on the basis of a predefined set of rules. The rules-set is formulated by traffic experts who possess specific knowledge and expertise to solve traffic congestion problems. In the rule-formalising process, traffic simulation tools can provides data for deriving consistent rules for the selection of the best traffic plan in response to an incident;

• a module to help step-by-step the TCC operator through its tasks needed to implement the traffic response plan including the provision of incident-related information to drivers and the application of traffic control measures on the network infrastructures affected by the incident;

• a path generation module to enable the shortest, fastest routing of emergency response vehicles from the various key locations, including hospitals, fire and police stations, to the incident scene;

• traffic simulation tools at micro (AIMSUN) and macro scale (MIAURB) to model and evaluate the evolution of the traffic flows associated to different traffic management strategies and incident scenarios.

CONCLUSIONS

Roadway and tunnel agencies are now more frequently asked to develop and improve incident management to expedite response and clearance processes and to minimize the traffic flow disruption and the potential for secondary incidents.

Traffic management is a key step of the complex incident management process as it can greatly reduce the amount and duration of the resulting congestion. Traffic management embraces the selection of the most appropriate traffic control strategies, such as signal modification and traffic diversion, and the dissemination of incident-related information to drivers to avoid the incident and adjust driving behaviour.

The paper has presented a DSS (TRIM) to assist traffic control centre personnel involved in determining the appropriate strategies to effectively and safely manage traffic in post-incident scenario and support execution of steps required for their implementation and control. TRIM has the capability to use both historical and real time sensor data, to collect and categorize incident information, to simulate all candidate traffic response plans prior to their implementation, to perform the immediate preliminary estimate of incident impacts in terms of duration, delay and geographic extent, to select and implement the most appropriate response plan and, finally, to model and control real time traffic conditions during incidents. The proposed DSS will be soon tested under real conditions in the interurban high congested corridor extending from the southern neighbourhoods of Naples to the town of Sorrento. The corridor is defined by the “SS 145” roadway (named Sorrentina) suffering from relatively high incident rates and including a 1400 meters long tunnel.
REFERENCES


