Freeway Traffic Control Strategy with dynamic allocation of traffic lanes; the application on Mestre-Venice beltway

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Summary

This paper describes the innovative traffic control strategies embedded within the integrated telematic system implemented by the “Società delle Autostrade di Venezia e Padova” on Mestre-Venice beltway. This system is the most advanced among those that in Europe have faced the problem of using in a dynamic way the hard shoulder lane as third traffic lane. The paper describe the Software tools developed and the preliminary results of the assessment performed.

The issue addressed

The Mestre-Venice beltway is one of the most critical stretch of the overall Italian Motorway network. It has the double role of serving mobility on long distance trips connecting north Italian region through the east-west corridor, and local mobility gravitating around Venice area. For many hours during the day the traffic flow reaches the carriageway capacity generating severe congestion which may result in flow blockage as incident occurs.

Società delle Autostrade di Venezia e Padova decided, since beginning of ’90, to invest for enhancing the situation with the introduction of ITS systems. A first ITS intervention was in ’92 with the EASY-DRIVER system, a second ITS in 2000 was the “Motorway Access Regulation and Control” system (MARCO) which adopts Ramp Metering techniques as the key element for controlling traffic flow.

In 2001 the Third ITS which start from the consideration that hard shoulder can be used as third traffic lane by means of dynamic allocation of traffic lanes, but to avoid compromising safety, additional measures have to be taken, and integration of several subsystems: Automatic Incident Detection (AID), Lane Control Sign (LCS), Ramp Metering (RM), Re-Routing (RR) and Multi-agency Incident Management (MIM), under the coordination of a “supervisor” (SV) are the key factors for successful implementation of the solution.
Implemented solution

The MARCO initiative were only the first step in a process aimed at resolving the problem of the “Mestre bottleneck”. Considering that hard shoulders on motorway have very low efficiency because they are just used in exceptional situation the system which has been now implemented and since 14/4/2003 in operation is a large ITS with many components, but where the key idea is to allocate in a totally dynamic and automatic way the traffic on two or three lanes depending on traffic condition and safety level to be granted.

Strategy for dynamic lane allocation is a complex task due to the conflicting requests originated by capacity and safety needs. In fact when the traffic is high, shoulder lane should be open for traffic, but if an incident occurs it is necessary to move traffic out of this lane for allowing fast rescue intervention. Prompt notification of alarm, fast process of them with coordinated implementation of speed advice, lane recommendations and rerouting actions are the main issues that ITS system has to address.

Innovation

Main innovative topics of this system are the integration concept adopted and the level of automation requested in managing traffic control strategy. This requires a suitable system architecture and a robust and flexible SW tool for managing the overall integrated system and its control strategies.

The ITS implemented is very large and comprises several subsystems:

- Traffic Monitoring System with 31 motorway and beltway sections equipped with IR&radar sensors (Siemens/ASIM DT281), 33 sections on ramps equipped with loop sensors and 147 sections coming from UTC system of Mestre for monitoring traffic on alternative routes. Automatic Incident detection on beltway ( sensors every 250 mt) which grant a full coverage of carriageways, including 22 “emergency
bay”. 105 TV sensors are mounted on gantries and poles;

- Speed and lane recommendation by means of 23 LCS every 700 mt on beltway;

- 61 VMS, 20 of them are located on urban road network, 8 on access ramps and 33 on motorway and beltway carriageway. Some of these are used to provide alternative route recommendation on diversion points

- 37 digital CCTV for the Surveillance system to cover also alternative routes;

- 8 ramps equipped with traffic lights for Ramp metering;

- Incident management with a multiagency approach (Integration of different Centres: Police, Carabinieri, Hospital, etc.);

- User information with an Internet web site with live data and images;

- multiagency Rescue fleet management.

System Architecture has been designed using FRAME (Reference European Architecture).

**Control strategies**

Objectives of the Control strategy is to define LCS configuration (speed and lane recommendation, including open/closure of the shoulder lane to traffic flow), Ramp Metering parameters and rerouting actions both for normal traffic situation or in reaction to unexpected events like incidents, sudden speed drops, vehicle exiting “safe haven” etc.

The strategies have been designed after having identified a well defined set of scenarios. These scenarios have been built on the basis of 2 “operational condition” and 3 “situation type”. The following matrix clarified the concept:

<table>
<thead>
<tr>
<th>operational condition</th>
<th>standard (two lane)</th>
<th>special (three lane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>situation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>normal with events</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>with emergency</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

For each cells of the matrix a well defined set of operation which the system hast to do has been defined, moreover all the rules for “transition” from two to three lane and vice versa for each “situation” have been defined. All this have been coded within the System Data Base.
Under the rules set by the scenarios the strategy works with two levels:

- At first level (Dynamic control) the speed limit are defined automatically on the basis of actual traffic condition which are update every 60". The way to set these speed limit is based on the concept that vehicle has to be slowed down to a speed which is compatible with their passage through the “critical section” (where density is 95% of the critical density). Of course there can be several critical section which have to be managed in a suitable way as well as soft changing both in space and in time of speed limitation have to be properly handled.

- At second level (Event reaction) there are all the speed and lane limitation configuration which are defined as reaction to unexpected events (like incidents, accidents, road works, etc.). Basic idea for this strategy is to implement a “cells protection” strategy, where cells are the minimum element on which an event can be associated (could be the AID zone).

![Cells and AID sensors](image)

In the following picture an example of configuration-scenario is shown.

<table>
<thead>
<tr>
<th>Zone type</th>
<th>LCS configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CS (Left lane cells)</strong></td>
<td>LCS on cells or first LCS before the protected zone</td>
</tr>
<tr>
<td></td>
<td>second LCS before the protected zone</td>
</tr>
<tr>
<td></td>
<td>Third LCS before the protected zone</td>
</tr>
</tbody>
</table>

The engine which implement the strategy has the task of solving, for each VMS, all the conflict rising from all the requests of speed limitation coming from “Dynamic control” or “event reaction” module.
Software Tool

The high level of automation requires a suitable SW tool both for managing strategies but also for helping user in understanding what the system does and allowing operator for easy, fast and reliable interaction with the system.

SW architecture is object oriented, it has been developed in C++ MFC, using SQL server as DBMS; The SW is organised around 4 main module each of them is split in several treehead.

The 4 main module are:

- **Traffic Observer**: using traffic data coming from competent subsystem has the task to make data validation, data aggregation and update historical traffic data profile for type of day;

- **SV_Timer**: which implement strategies both for normal operation and for Incident management. It is in charge of managing events, both automatically detected by the system, like traffic events or incident detected by means of AID subsystem or manually introduced into the system by the operators; it is also in charge of generating VMS messages solving conflict and deciding for all VMS which is the massage to be displayed.

- **Traffic Models**: This is a crucial part of the system. It has the task of completing traffic state observation for those part of the network which has no sensors in such a way the “picture” of traffic were complete. Moreover is in charge of making traffic forecast for next time interval. This is obtained applying suitable traffic models (assignment as well as OD matrix estimate);

- **GUI (graphical User Interface)**: which allow the operator to interact with the system by means of them it is possible to click on each object (road and/or equipment) to know everything about them; it is possible to mange equipment like VMS, TVCC or sensors. It is possible to handle Incident management by means of powerful tool
which allow operator in selection of the most useful action to be implemented and guiding the system in performing all the actions which are part of the decision taken by the operator. By means of this GUI, operator is helped in exchanging messages with other Actors which are involved in emergency management, like police, fire brigade, rescue services, etc.

**First results**

This paragraph shows some results of the application of the control concepts before presented. Starting on 14/4/2003 the system is in operation. Road work on east direction has forced 2 lane configuration on this carriageway, so only on west direction (to Milan) the switching lane configuration strategy is really in operation.

In accordance with the strategy the three lane configuration is set once the density within the “critical section” exceed the threshold of 22 V/Km/lane. With increasing trend, while the 2 lane configuration is set when the density per lane goes below 14 V/km/lane with decreasing trend. The results of the application of the strategy on one average day (namely the 6/5/2003) are presented in the following table where data are compared with the situation before the operation of the system:

<table>
<thead>
<tr>
<th></th>
<th>before</th>
<th>now</th>
<th>delta%</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-mar</td>
<td>59,90</td>
<td>76,26</td>
<td>+27,32</td>
</tr>
<tr>
<td>06-may</td>
<td>13,13</td>
<td>5,05</td>
<td>-61,54</td>
</tr>
<tr>
<td>Speed Coef. of var.</td>
<td>0,22</td>
<td>0,07</td>
<td>-69,80</td>
</tr>
</tbody>
</table>

It is easy to see the dramatic gain in average speed (average within the space, 11 section, and the time, 24 hours) which move from less than 60 Km/h to around 80 Km/h which also mean that, in average, we move from “risk area” (looking at traffic stability) to more “quiet” situations.

It is also interesting to see the standard deviation parameter which move from 13 to 5 which means that there is more homogenous speed along space and time which in turn means that we have an improvement of traffic safety.
If we look in details on temporal evolution of speed along the entire beltway stretch we can see the benefit of having three lane available especially in peak hour when the speed drops below 50 km/h.

It is also interesting to note the different distribution of traffic along lane (taking into account that heavy traffic account for more than 25%. With 2 lane configuration 83% of light vehicles are on left lane while with 3 lane configuration only 60% still use left lane, 30% use middle lane and 10% right lane. With two lane configuration 83% of Heavy traffic use right lane while 17% uses left lane (which is one of the main reason of disturbance and traffic breakdown). With 3 lane configuration 73% still keep the right, lane 20% uses middle lane and only 7% use left lane with a better traffic condition.

**System Framework and next steps**

The new system called MARCO_plus has been designed, developed and implemented with the support of UE funded CORVETTE Project. Design and implementation of the overall system has been done by a consortium of company (GEMMO, MANTOVANI, FRACASSO, SIEMENS) while the telematic subsystems have been supplied by SIEMENS (Supervisor central software has been developed by CSST for SIEMENS).

Test and tuning of the system starts in February 2003 and operation has started in spring 2003. Results and final assessment of traffic control strategies is expected by summer 2003.

As already mentioned the Mestre-Venice Beltway is one of the “red spot” of the TERN (Trans European Network). As a consequence an improvement of the traffic fluidity and of safety level will improve the overall performance of the TERN itself. Moreover the experience gained in this context will help in increasing the level of understanding and the level of awareness on ITS impacts on motorway traffic management and operation.