Combining Ramp Metering and Hard Shoulder Strategies: Field Evaluation Results on the Ile the France Motorway Network

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Abstract

The paper is focused on the field trial description and the evaluation results of the implementation of the ramp metering and hard shoulder simultaneously on the Ile de France motorway network. The overall site includes 24 controlled on-ramps where the ramp metering strategy is applied in operational way. With respect to hard shoulder, the common part of the A4 and A86 motorway are equipped with variable message signs indicating the state of lane: Open or Closed. The hard shoulder is used as an additional live traffic lane during congestion periods. When traffic builds up road users will be instructed to use the hard shoulder as an extra traffic lane, increasing the motorway’s capacity, reducing congestion and keeping traffic moving. In this paper, the evaluation will focused on both axis of the motorway where ramp metering and lane shoulder are applied simultaneously. These field trials were conducted during two years (2008-2009).

1. Introduction

Congestion is always a common problem in many transportation commuting corridors. Continued growth in travel along congested urban freeway corridors exceeds the ability of transportation authorities to provide sufficient solutions and alternatives based on traditional roadway expansion and improvement projects. High construction...
costs, constrained right-of-way, statutory restrictions, and environmental factors are pushing transportation authorities to explore solutions such as active traffic management and managed lanes, which improve safety by reducing collisions and nonrecurring congestion and maximize throughput under congested conditions. Finding cost-effective options to mitigate recurrent and non-recurrent congestion on freeway facilities is one of the most significant challenges national and regional transportation organizations face. Several countries are implementing managed motorway concepts to improve motorway capacity without acquiring more land and building large-scale infrastructure projects. The examination of the use of innovative geometric design practices and techniques to improve the operational performance of congested freeway facilities without compromising safety are the innovative way of the traffic management policies. Managed motorway concepts introduce new and revised operational activities that place greater reliance on technology than traditional roadway projects. Managed motorways combine actively or dynamically managed operational regimes, specific infrastructure designs, and technology solutions. They use a range of traffic management measures to actively monitor the motorway based on real-time conditions:

- Dynamically control speeds
- Add capacity
- Collective road user information and guidance via Variable Message signs (VMS)
- Real time automatic Incident Detection (AID)

The objective of implementing this range of measures is to optimize traffic and safety performance. Examples of these measures include ramp metering, motorway to motorway control, Hard Shoulder Lane running (HSL), variable speed limits, lane control signals, dynamic rerouting, and the provision of driver information using variable message signs. Managed motorway concepts applied in Europe have been proven to reduce collisions, improve journey time reliability, and increase vehicular throughput. In 2006 a scan team observed that transportation agencies in Denmark, England, Germany, and the Netherlands, through the deployment of congestion management strategies, were able to optimize the investment in infrastructure to meet drivers’ needs. Strategies included speed harmonization, temporary shoulder use, and dynamic signing and rerouting.

However, we can observe that traffic corridor constitutes an entity in terms of operational objectives (Haj-Salem, 1995; Papageorgiou & al., 1998), user requirements, and impact of individual control devices. This means that the traffic control systems within corridors or motorway networks should be designed in an integrated way and not independently for each individual control measure attempting to optimize traffic flow on the motorway or the urban road network. Due to the lack of a general theoretical background, the non-linear nature of the traffic process, and the constraints imposed by the control measures, the extraction of the decision rules is a highly complicated and time consuming task. Nevertheless, during the last decade, this approach is well developed and field tests were performed using coordination approach and more or less integrated approach (Haj Salem & al., 1998, Kotsialos & al., 2002; Gomez & al., 2006, Zhan, 2004).

In this paper, the simultaneously using of hard shoulder lane running and isolated ramp metering is implemented on the field aiming at improving the traffic condition and the level of the congestion on the considered field motorway in France.

This paper is organized as follows: section 2 is dedicated to the description of the field implementation context along with summary of previous results are given; section 3 describes in details the two implemented control strategies (ramp metering and Hard Shoulder Running lane); section 4 is focalized on the description of the selected day and the used evaluation index for the evaluation process and section 5 details the obtained results.

2. Field implementation context

In frame of the French national project PDU (Plan de Déplacement Urbain) founded by the transport ministry, the main authorities in charge of traffic management namely DIRIF (Direction Interdépartementale de l’Ile de France) decided current 2008 to implement the ramp metering strategy on the East part of the motorway network in order to improve the level of congestion. The DIRIF motorway network (see fig. 1) covers around 750 km (A1 to A15). Four control centres (North, South, East and West) are implemented for the traffic management. Namely SIRIUS (Service d'Information pour un Réseau Intelligible aux USagers), the traffic management centres aiming at optimising the
traffic conditions on the overall Ile de France motorway network in terms of traffic control strategies including automatic incident detection, ramp metering, speed limits, lane assignment, collective users traffic information and guidance, lane shoulder. The level of the congestion on the "Ile de France" network (including Paris ringway) represents 80 % of the total congestion on the overall France motorway network. In 2003, the DIRIF authorities decided to the renewal of the existing ramp metering control system based essentially on a fixed time control and to implement a new flexible operational one named "ACCES-2" and including several ramp metering strategies: fixed time, traffic responsive (ALINEA) and coordinated strategy.

Fig. 1 depicts the overall IDF motorway network and the field implementation site. The considered field site includes the East part of the Ile de France motorway network: A86, A4 and A6 motorways axis in both directions (I: internal E: external directions) covering around 150 Km length. The total number of candidate on-ramps is equal to 22 (Red segment on the figure 1) and controlled by ACCES_2 system.

In 2003, the hard shoulder running lane (HSL) was implemented in SIRIUS on two sites: A4/A86 (Fig. 2) and A3/A86. The first field evaluation was performed (Aron & al., 2010, S. Cohen, 2006; S. Cohen & al., 2010). The positive impact of such strategy (on weekdays, the duration of the saturation on the weaving section decreased from 7% to 2% of the time and no major changes of the congestion downstream of the A4-A86 section) are lead the DIRIF to apply in operational way the hard shoulder lane running strategy.

In the following traffic impact evaluation, among the several part of the motorway network, the main focus is made on A4W/A86I (see fig. 2) where hard shoulder running and ramp metering are applied simultaneously. The main objective is to evaluate the traffic impacts of the ramp metering with and without hard lane shoulder.
3. Control strategy descriptions

3.1. Isolated Traffic Responsive Strategy: ALINEA

ALINEA (Haj Salem and al., 1990, 1995; Papageorgiou & al., 1990) is based on a feedback philosophy and the control law is the following:

\[ r_k = r_{k-1} + K(O^* - O_k) \]

Where \( r_k \) and \( r_{k-1} \) are on-ramp volumes at discrete time periods \( k \) and \( k-1 \) respectively, \( O_k \) is the measured downstream occupancy at discrete time \( k \), \( O^* \) is a pre-set desired occupancy value (typically \( O^* \) is set equal to the critical occupancy) and \( K \) is a regulation parameter. The feedback law suggests a fairly plausible control behaviour: If the measured occupancy \( O_k \) at cycle \( k \) is found to be lower (higher) than the desired occupancy \( O^* \), the second term of the right hand side of the equation becomes positive (negative) and the ordered on-ramp volume \( r_k \) is increased (decreased) as compared to its last value \( r_{k-1} \). Clearly, the feedback law acts in the same way both for congested and for light traffic (no necessary switching’s).

![Fig. 2. Stretch of the evaluation site](image)

The implementation of the ALINEA strategy is easy: only two measurement stations are required; one on the mainstream, immediately downstream of the ramp, and the other one on the ramp. For the present study, ALINEA was implemented independently at each of the four controlled on-ramps. A further detector is located at the upstream end of each ramp to detect excessive queue lengths. In order to avoid interference with surface traffic, ramp metering is released if this occupancy value exceeds a certain threshold. ALINEA has been found in a number of previous field investigations (Haj Salem, 2001; Papageorgiou & al., 1991; Haj Salem 2009), to be more efficient than other known local ramp metering strategies.

3.2. Hard Shoulder lane running strategy

The hard shoulder is used as an additional live traffic lane during congestion periods. When traffic builds up road users will be instructed to use the hard shoulder as an extra traffic lane, increasing the motorway’s capacity, reducing congestion and keeping traffic moving.

The A4W/A86I section corresponds to the merge of A4 and A86 motorway in both directions. The length of this section is around 3 km and conveys a daily traffic per day (280,000 vehicles). During the peak period, morning and
evening, this section is very congested (the biggest traffic congestion in Europe): more than 10 hours of congestion per day).

Since 2005 summer, the hard shoulder was opened during the peak hour periods (morning and evening) in order to alleviate the level of the congestion for both traffic directions. Moveable barriers were installed at the beginning of the common section on the right side of the additional lane. VMS are installed also in order to inform the road users on the state of the lane: closed or opened. The installed VMS consists to dynamic vertical signing of Lane Assignment Signals (LAS). The closure devices were installed at several key locations on the section where the drivers can see clearly whatever their position. In addition, to indicate the difference in use between the additional lanes has specific road markings and a light-colored surface. Safety has been improved by the installation of automatic incident detection cameras. In the event of an incident or accident when the lane is open, stationary vehicles on the hard-shoulder lane can be detected and the lane closed. The moveable barrier is operates by the operator. Based on the existing monitoring system (cameras), the operator decide to open (or closed) the additional lane according to the observed congestion.

**Fig 3. Hard Shoulder implementation devices**

### 4. Available Data

The field trials were started current February 2008 and completed by the end of October 2008. During this period ALINEA strategy is applied. For the no control case, the selected period is the same than ALINEA but during 2007. The collected data is based on the SIRIUS real data collection system which includes the measurements of traffic volume, occupancy rate and speed of all stations on 6 minute time intervals. For the 18 months in total, measurements data, accidents and incidents, weather conditions, active strategies (ALINEA and Hard Shoulder lane running) are collected. The weather conditions are provided by “Weather France Institute (Météo France)”. In order to constitute the data base of the evaluation, the selection of cleaned days of ALINEA and no control respectively were performed according to the following criteria:

- Weekly days (no holiday and week-end periods)
- No incidents/accidents or works
- No winter days

Full 18 months of collected data were stored in the SIRIUS database. Screening of the collected data was firstly necessary in order to discard data of days including major detector failures. Secondly, all days with atypical traffic patterns (essentially weekends, Mondays and holidays) were discarded. Thirdly, in order to preserve the comparability of results, all days including significant incidents or accidents (according to the incident files provided by the Police) were also left out.
This screening procedure eventually delivered 37 days of data using ALINEA and hard Shoulder and 55 days without control and hard shoulder. For each selected day and time periods, the activation of the hard shoulder is added as control variable for the statistical analysis. The activation of the hard shoulder is automatically detected by the measurements on the additional lane. As a matter of fact, if the measurements of traffic volume occupancy rates and speeds are different from zero this means that the lane is opened and the control variable is set to 1 otherwise it is set to zero (‘closed’). On the other hand, if the shoulder lane is opened, the duration of the opened period is tested and can’t be less than 2 hours. The two constituted data base of the No control (55 days) and ALINEA (37 days) include the state of the lane shoulder.

The first step of the evaluation procedure is the constitution of two sets by strategy: lane closed and lane opened. Based on the both data sets, calculation of the traffic indices is performed.

In this paper, the evaluation will focus on A4W/A86I motorway axis (toward Paris center) where 4 on-ramps are controlled and the hard lane shoulder is applied (opened) simultaneously.

5. Assessment Criteria

The evaluation procedure was based on a computation of several criteria for assessing and comparing the efficiency of the ramp metering installation and hard shoulder running lane. These criteria were calculated for each day. The horizon is fixed to the overall period (5h:00–22h:00), the morning peak period (6h:00-12h:00) and the evening period (17:00-21:00).

The following quantitative criteria were considered for the evaluation of the control strategy:

- The total time spent on the network (TTS) expressed in vh*h
- The total number of run kilometres (TTD) expressed in vh*km
- The mean speed (MS) expressed in Km/h
- Congestion mapping
- Other environment criteria also were computed:
  - Fuel consumption (liters) (Jurvillier, 1982)
  - Pollutant emission of CO & Hydrocarbon (HC) expressed in kg (European project TR 1030, INRESPONSE, D91, 1998 ; ADEME, 1998)

In this paper, only the peak morning period results are presented. The main reasons are due to that A4W conveys a daily traffic during the peak morning periods where ALINEA is active and the hard shoulder running lane is open. On the other hand, the total travel distance of A4 (TTD) represents 30% of the overall TTD of the considered network. Consequently, any improvements of the traffic condition of A4W will lead to the improvement of the traffic condition of all connected motorways (A86I/A86E). The overall results can be found in (Haj-Salem & al, 2009).

5.1. Evaluated Scenarios

In order to exhibit the traffic impact of the ramp metering and the hard Shoulder the following scenarios are considered:

- No control with Hard Shoulder open and closed
- ALINEA with Hard Shoulder open and closed

The evaluation of the impact of only the lane shoulder can be found in (S. cohen & al. 2008).

6. Assessment Results

The obtained results are included in table 1. The reported indices are computed during the morning period (6h:00-10h00) where ALINEA is active. Screening table 1, whatever the state of the hard shoulder lane, compared
to the no control, ALINEA improves the traffic indices. In particular, the TTD improvements are very important. This index increases by 6.2% and 5.2% when the hard shoulder lane is closed and opened respectively. With respect to absolute value, comparing “close” and “open” hard Shoulder lane results, the TTD is increased by 4% and 3% for no control and ALINEA respectively.

### Table 1. Overall results

<table>
<thead>
<tr>
<th>Indices</th>
<th>Shoulder Lane “Closed”</th>
<th>Shoulder Lane “Opened”</th>
<th>Benefit</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTS (vh*h)</td>
<td>6821</td>
<td>7101</td>
<td>-4.4%</td>
<td>-6.1%</td>
</tr>
<tr>
<td>TTD(vh*km)</td>
<td>264944</td>
<td>275516</td>
<td>6.3%</td>
<td>5.2%</td>
</tr>
<tr>
<td>MS (km/h)</td>
<td>38.84</td>
<td>38.80</td>
<td>11.3%</td>
<td>12.1%</td>
</tr>
<tr>
<td>ECO (Kg)</td>
<td>19417</td>
<td>20453</td>
<td>6.8%</td>
<td>-0.5%</td>
</tr>
<tr>
<td>EHC (Kg)</td>
<td>74411</td>
<td>75593</td>
<td>6.6%</td>
<td>-2.5%</td>
</tr>
<tr>
<td>Consum(lit)</td>
<td>89.2</td>
<td>114.9</td>
<td>-4.5%</td>
<td>-3.2%</td>
</tr>
</tbody>
</table>

*Fig 4. Depicts the time evolution of the TTS and TTD indices in case of “Opened” HLS. This time evolution confirms the computed indices reported in table 1.*

### 6.1. Congestion Mapping

The congestion mapping consist to draw the iso-occupancy rates measurements along the considered axis (A4W) in the plan (X,t). X corresponds to the position (Km) of the station and the mean measurements of the occupancy rates at each time slice (6 minutes).
Qualitatively, when the HSL is active, compared to the no control case, the surface of the congestion is reduced when ALINEA is applied.

7. Conclusion

The reported results indicate that the use of the HSL and the ramp metering simultaneously improves the traffic condition in a significant way. In particular, when the HSL is “closed” using the ramp metering technics (ALINEA), the TTS, TTD and the mean speed (MS) indices are increased by -4.4%, 6.3% and 11% respectively.

When the HLS is opened, according the increase of the TTD, we can assume that the capacity of the motorway is improved compared to the no control case. On the other hand the improvement of the mean speed (increases by around 5 km/h (12%)) is an additive benefit of the ramp metering strategy ALINEA. These results confirmed that the performance of the integrated control by combining several control strategies simultaneously, improves dramatically the traffic condition on the considered network.

References

ADEME, (1998), « Émission de Polluants et consommation liée à la circulation routière- Paramètres déterminant et méthodes de quantification, "connaître pour agir, guide et cahiers techniques".