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Improving Travel Time Reliability Using Ramp Metering: Field Assessment Results on the A6W Motorway in Paris

Bhouri Neila, Haj-Salem Habib

INRETS/GRETIA, Le Descartes 2, 2 rue de la Butte Verte
93166 Noisy Le Grand Cedex, France (Email : bhouri@inrets.fr, haj-salem@inrets.fr)

Abstract: The terms “unreliability” and “congestion” are often used synonymously. However, a congested network is not necessarily unreliable. It is recognized, however, that control actions that reduce congestion can improve reliability. Similarly, any control actions that improve reliability can reduce congestion. In this paper, the reliability criteria is applied for the field assessments of several ramp metering strategies implemented on the A6W motorway in Paris, and the travel time reliability is improved using the ramp metering techniques.

Keywords: Reliability, Travel Time, Congestion, Ramp Metering, Field Implementation, Feedback Control, ALINEA Strategy, Coordination.

1. INTRODUCTION

Congestion in the urban and freeway networks is a major traffic problem. Much research and development of Intelligent Transportation Systems (ITS) and other management policies are developed aiming at congestion reduction. However, despite improved road capacity, urban expansion and increased mobility means that users prefer private cars, leading to the same problems of congestion.

Drivers nowadays are used to this recurrent everyday congestion. They don't like it, but they allow for it: they leave home early enough to get to work on time. They allow an hour per journey every day for a trip which can take just half an hour if there is no congestion. But they may have more serious problems if this congestion varies every day and their travel time is not reliable, so they are not able to predict their travel time correctly in order to arrive on time. Travellers require consistency in their travel time. That's why there is an increasing awareness of the issue of travel time reliability. Among the various new activities around the reliability of transportation systems, there is an OECD working group preparing a report on “*Surface Transport Networks: Improving Reliability and Levels of Service*”. This report will be published in September, 2009 (JTRC 2009).

The transport reliability literature review produced by the OECD working group reveals a number of ways in which transport reliability can be defined. A useful definition recognizes that network users time their actions according to expected network performance. That's why they defined

reliability as “*The ability of the transport system to provide the expected level of service quality, on which users have organized their activities*”. According to this definition, reliability can be improved either by supplying better reliability or by changing expectations of the level of reliability.

As congestion has a negative impact on reliability, one can expect to see that actions that reduce congestion can thus improve the reliability of the system. In this paper we investigate the travel time reliability of several ramp metering strategies.

In the context of traffic management systems, ramp metering offers several operational features for improving motorway flow, traffic safety and air pollution by on-ramp traffic flow control. Ramp metering strategies are capable of:

- reducing the extent of recurrent and non-recurrent congestion on motorways,
- reducing total travel time including waiting times on the ramps,
- increasing the total travel distance and optimizing utilization of motorway capacity,
- reducing air pollution.

In this paper some travel time reliability indices are defined, discussed and then applied to assess three control strategies: No Control, ALINEA (isolated) and a coordinated strategy. The reference case is the no control case. These strategies are implemented on the A6W motorway toward Paris in France.

This paper is organized as follows: section 2 is dedicated to the definition and the description of the travel time reliability indices. Section 3 describes the test sites whereas the candidate strategies are reported in the section 4. Field trials description and available data used for the evaluation are explained in the section 5. In the section 6, evaluation results of the reliability indices are presented and discussed.

2. DEFINITION OF TRAVEL TIME RELIABILITY

Measuring transport reliability consists in defining indicators that provide appropriate measures of the inconsistency in travel time within the network. A distinction has to be drawn between the network provider or operator and the user points of view. For the network provider the reliability indicators must focus on the system robustness (or vulnerability) and on its operating performance. The indicators used are, for example, the connectivity of the network, its capacity to respond to unpredictable demand or the supply conditions offered by a degraded network, etc.

From the user point of view, the invariability of the travel time experienced corresponds to the main index. Indicators must focus on the quantification of this travel time variability. Several definitions for travel time reliability exist and many different relevant indicators have been proposed (Lomax *et al.* (2003); Van Lint (2004)). Some of them are statistical range indicators such as the "Standard Deviation" or the "Variation Coefficient" computed for a given time of day or day of a week. Other approaches are related to the Buffer Index, Tardy Trips or the Skewness and width of the travel time distribution. Depending on the travel time reliability study, it may be more appropriate to use one indicator than another. For example, the standard deviation (or spread) of travel times can be advised as a cost effective measure to monitor travel time variation and reliability, whereas the buffer index indicator can be more useful for user information.

In the literature, the Buffer Index appears to relate particularly well to the way in which travelers make their decisions (FHWA, 2006). The investigations are focused on these indicators to compare the impact of ramp metering on the travel time reliability.

- **Buffer Index (BI):** is defined as the extra time a user has to add to the average travel time so as to arrive on time 95% of the time. It is computed as the difference between the 95th Percentile Travel Time (TT95) and mean travel time (M), divided by mean travel time.

$$BI = \frac{TT_{95} - M}{M}$$

The 95th Percentile Travel Time (TT95) expresses how much delay there will be on the heaviest travel days.

The Buffer Index is useful in the user's assessment of how much extra time has to be allowed for uncertainty in travel conditions. It hence answers simple questions such as "How much time do I need to allow?" "When should I leave?". For example, if the average travel time $M = 20$ minutes, the Buffer index $BI = 40\%$, the Buffer time $= 20 \times 0.40 = 8$ minutes. Therefore, the traveler should allow 28 minutes for their trip in order to ensure on-time arrival 95 percent of the journey time.

- **Planning Time Index:** total time needed to plan for an on-time arrival 95% of the time as compared to free flow travel time. It is computed as the 95th percentile travel time (TT95) divided by free-flow travel time (TT_{free-flow}):

$$PTI = \frac{TT_{95}}{TT_{free-flow}}$$

For example, if $PTI = 1.60$ and $TT_{free-flow} = 15$ minutes, a traveller should plan 24 minutes in total to ensure on-time arrival at 95% of the time.

Because these indicators use the 95-percentile value of the travel time distribution as a reference of the definitions, they take into account more explicitly the extreme travel time delays.

- **Travel Time Index:** average time it takes to travel during peak hours compared to free flow conditions, computed as mean travel time divided by free flow travel time:

$$TTI = \frac{M}{TT_{free-flow}}$$

The TTI indicator is known as a congestion indicator and will be used to compare the reliability with the congestion states.

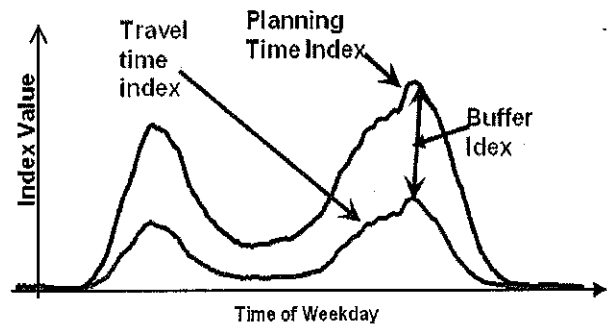


Fig. 1. Reliability indicators relation (Turner, 2006)

3. FIELD TRAILS CONTEXT

Within the framework of the European Project EURAMP work plan, field trials have been designed and carried out on the France test site aiming at the traffic impact assessment of coordinated and isolated ramp metering strategies.

The motorway section A6W (Fig. 1) of the French field test comprises 5 on-ramps (Chilly-Mazarin, Savigny, Viry, Grigny and Ris-Orangis) which are fully equipped with signal lights and loop measurement stations. The total motorway length is around 20km. This motorway section is fully equipped with traffic flow, occupancy rate and speed measurement stations roughly every 500 meters. The controlled ramps include 2 measurement stations each. The upstream one is used to detect surface intersection blocking, and the downstream one is used by the on-ramp metering strategy.

The main authority in charge of traffic management is the DIRIF (*Direction Interdépartementale de l'Ile de France*). The DIRIF motorway network covers 600km (A1 to A13). Traffic management and control is subdivided into four control centers (North, South, East and West). The level of congestion on the "Ile de France" network (including Paris ring road) represents 80% of the total congestion on the whole of the French motorway network. The test site considered is the most critical area of the A6W motorway toward Paris. Morning and evening peak congestions are observed over several hours and several kilometers.

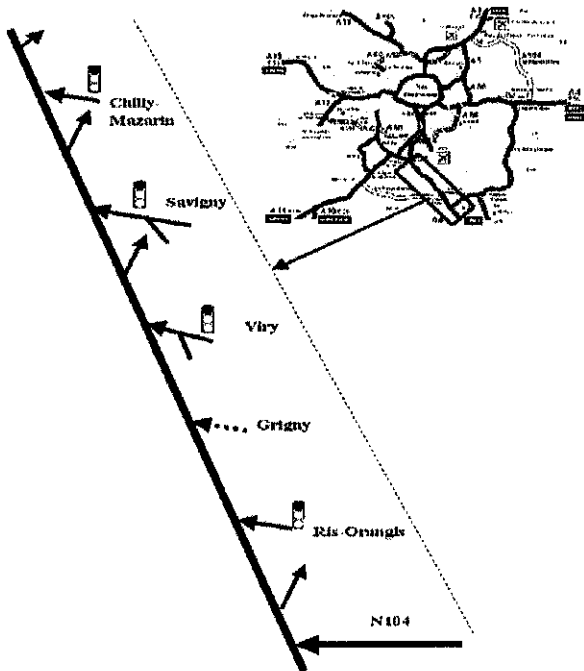


Fig. 4. A6W test site.

4. DESCRIPTIONS OF CANDIDATE STRATEGIES

The three main control strategies which were implemented and tested are: ALINEA, Variable Cycle ALINEA and the Coordination Strategy. The no-control case was considered as a reference. In the following, the presented results are limited to the Coordinated and ALINEA strategies. VC_ALINEA is excluded since it is very similar to ALINEA.

4.1 Isolated traffic responsive strategy: ALINEA

ALINEA is based on a rigorous feedback philosophy (Bhouri *et al.*, 1990; Haj-salem *et al.*, 1990, 1991, 1995, Papageorgiou *et al.*, 1989, 1991, Smulder *et al.*, 1991). Since the main aim of ramp metering is to maintain the capacity flow downstream of the merging area, the control strategy for each controllable on-ramp should be based on downstream measurements. Therefore, ALINEA, which was developed by the application of the well-known methods of the classical feedback theory, obtains the following form:

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

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. Obviously, the above feedback law is simpler than any other local metering strategy.

4.2 Coordinated control strategy

The coordinated strategy is based on the heuristic approach and the application of ALINEA at the first step. This strategy is based on the motorway axis logic and is implemented as follows:

1. Apply ALINEA to all controlled on-ramps giving the all control sets (U_{al}).
2. Find the location of the head of the congestion by testing if the first on-ramp (r_1) where ALINEA is active ($O_1 > 0.9 \bar{O}_{1,cr}$) and the queue constraint not active.
3. For every upstream on-ramp $r_{up} = r_1+1, \dots, Nb_Ramps$: if the queue constraint of the on-ramp (r_{up}) is NOT active then correct the ALINEA command according to $U_{cor} = \alpha_1 U_{al}$ if $r_{up} = r_1+1$ and $U_{cor} = \alpha_2 U_{al}$ for the other upstream ramps, where (α_1) and (α_2) are parameters to be calibrated; otherwise do nothing.
4. Apply the new coordinated control sets on the field.
5. Wait until the next cycle time
6. Wait until the next cycle time
7. Go to step 1.

In order to avoid interference with urban intersection, ramp metering is released if the occupancy measurement located in the middle of each on-ramp value, exceeds a certain calibrated threshold.

For each control strategy, the characteristic of the cycle time is the following:

Cycle duration: 40 Sec, Max_green= 30 sec, Min_green=10sec, Amber=5 sec

5. DESCRIPTION OF FIELD TRIALS

The different strategies ALINEA, the Coordination and no-control were applied over alternate weeks over the period from the middle of September 2006 until the end of January 2007, after which comparative assessments of the impact on traffic were performed.

5.1 Available Data

Data collected over 140 days was stored in the SIRIUS database. This data had to be screened in order to discard days when there were major detector failures. Secondly, all days with atypical traffic patterns (essentially weekends and holidays) were discarded. Thirdly, in order to preserve the results comparability, 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 11, 10 and 9 days of data using No control, ALINEA, and the coordination strategies respectively.

6. THE RELIABILITY ASSESSMENT

In the frame work of the European Project EURAMP, the evaluation was focalised on the traffic impact of the implemented strategies during the peak morning periods (6h-11h and 8h-9h30). In particular the following criteria were used:

- Total Travel Distance (TTD) in veh*km
- Total Time Spent (TTS) in veh*h
- Mean Speed (MS) in km/h defined as TTD/TTS.
- Congestion severities in h*km
- Fuel consumption and environmental emission (CO₂,HC)

The traffic impact assessment results can be found in the EURAMP Deliverable D6.3, 2007.

In this paper, investigations are focused on the reliability results based on the predicted travel time of the main motorway section only (20km) and during the large morning period: 5h-12h. The reliability results can be considered as an add value of the traffic impact evaluation.

6.1 Travel time definition

In order to point out in a comprehensive way the impact of the ramp metering for the decision makers and for the users, the travel time calculation is based on the application of the "floating car" algorithm. The travel time estimation is based on real data measurement and in particular the speed measurements.

6.2 Travel time variability

Our first investigation concerned the travel time variability and the comparison between the three tested strategies (Bhouri *et al.*, 2009).

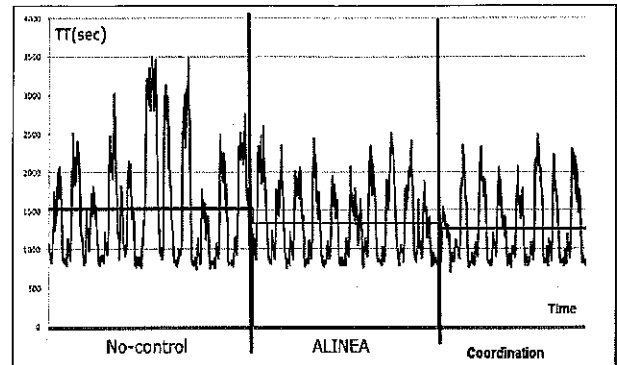


Fig. 3. Travel Time Variability

Screening Figure 3, the following remarks can be drawn:

- The travel time variability is reduced by using ramp metering control strategies.
- No significant differences on the travel time variability are observed between ALINEA and the coordinated strategy.

Table 1 depicts the Standard deviation and the Coefficient of variation.

	No-Control	ALINEA	Coordinated
Standard deviation	706	463	456
Coefficient of variation	46%	35%	36%

Table 1. Statistical indicators

6.3 Buffer Time and Planning Time Indexes

As explained before, the statistical indicator can be useful for the cost benefit analysis or other use, but for the users dissemination it is more helpful to use the buffer index or the planning time index.

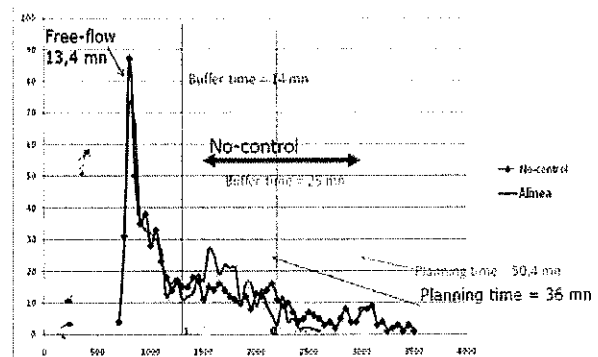


Fig. 4. Reliability indicators for ALINEA and the No control cases

Table 2 includes the means of the Buffer Time and the Planning Time computed for each strategy on the hole of the data. The reported results indicate that a user who plan to arrive on time to his destination with 95%, have to add to his mean travel time 25 minutes in case of no-control.. On the contrary, in case of ALINEA or the coordinated strategy, 14 minutes must be added. The comparison of the total travel time spent of the main path on the A6 motorway (20 Km) for the three strategies; we can observe that the improvement of the coordinated strategy is higher (17%) than ALINEA (12%). However, from a reliability point of view, the difference of gain between the ALINEA and the coordinated strategy is not very significant.

	TT (min)	Gain (%)	BT (min)	Gain (%)	PT (min)	Gain (%)
No-Control	25.4	***	25	***	50,4	***
ALINEA	22.3	12	13.8	44.5	36.2	28
COORD	21.2	17	14.1	43	35.3	30

Table 2: Travel Time and Buffer Time

Obviously, same results of the Buffer Index and the Planning Time index are observed as reported in Table 3.

	No-Control	Alinea	Coordination
Buffer Time Index	98%	62%	67%
Planning Time Index	3,8	2,7	2,7

Table 2 : Buffer Time Index and Planning Time Index

6.4 Reliability is not congestion

As indicated in table 2, the gain on Travel Time reflecting the congestion situation is different from the gain on the Buffer Time Indicators.

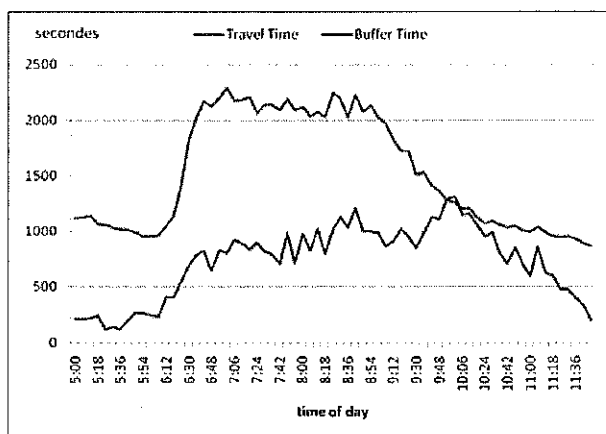


Fig 5. Congestion and Reliability

We can observe better this difference between congestion and reliability conditions if we observe the time of day variation of their indicators as reported in the figure 5. As a matter of fact, during the beginning of the congestion, travel time rise quicker than the buffer index. At about 9h: 30, the travel time become nearly normal around the low level. However the reliability of the travel time is the worst.

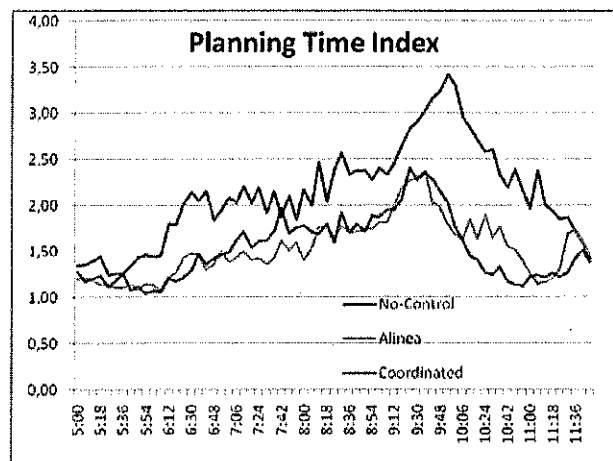


Fig. 6 comparison of the PPI for the three strategies

The comparison of the travel time reliability given by the three strategies (figure 6) shows a gain in the intensity and the duration of the perturbation when a ramp metering strategy is applied (ALINEA or the coordinated): it needs for a user to ensure to arrive in time in 95% of case nearly 2.6 times the free flow travel time at 10h: 30 in case of no control. However, it needs only 1.25 times of the free flow travel time in the same hour with the coordinate strategy. It needs 1.65 times with ALINEA at 10h: 30 which is not as good as the coordinated strategy. But the curves show that sometimes ALINEA gives better results than the coordinated. So we cannot conclude for a real superiority from the travel time reliability point of view for the coordinated strategy as compared to ALINEA.

7. CONCLUSION

In this paper the transportation reliability problem is presented and the travel time reliability indicators are used for the results assessment of three ramp metering strategies. The main conclusion of this field evaluation can be drawn as follows:

- The reliability of travel time depends on the congestion on the motorway but don't follow the same shape. Generally the travel time reliability is worst at the end of the congestion even when the travel time is normal again.
- Ramp metering strategies improve largely the travel time reliability. However, results of the application of an isolated or a coordinated strategy don't show a significant difference from the point of view of the

reliability. On the contrary, if we consider the mean travel time indicator, the coordinated strategy performances are better than ALINEA.

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