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ALINEA: a local Traffic Responsive Strategy for Ramp Metering: Field Results on A6 Motorway in Paris

Habib Haj-Salem [(1)], Philippe Poirier[(2)], Jean-François Heylliard [(2)], Jean-Paul Peynaud [(2)]

(1) INRETS, 2 Av du Gle Malleret Joinville F 94114 Arcueil France,

email: hadj-salem@inrets.fr

(2) DREIF/SIER 79B, Av. Du Mal de Lattre de Tassigny BP-45 F-94002 Creteil France,

email ppo@sier.dreif.fr

Abstract -- **ALINEA, a local feedback ramp metering strategy, has experienced on A6 motorway around Paris on four consecutive on-ramps. This paper summarizes the field results achieved and presents the main features of ALINEA. The impact of ramp metering is studied by comparative evaluation of a number of performance indexes in the cases with and without control. The main finding of the field trial is that application of an efficient ramp metering strategy considerably improves traffic conditions on the motorway. The reported results indicate easy application, flexibility, and high efficiency of ALINEA. Planned future implementations are briefly outlined.**

Key Words: **Ramp Metering, Field Implementation, ALINEA Strategy.**

I. CONTEXT

IN the context of traffic management systems, the ramp metering offers several operational features for improving motorway flow, traffic safety and air pollution by on-ramp traffic flow control. The on-ramp metering techniques are not a new traffic management concept. It was applied in US since 1960. However, in France, these techniques have major difficulties, to be integrated in the traffic management centre, due the misunderstanding of the traffic impact of such control techniques. Since 1990, a large working group including operators, policy makers, technical study institute (CERTU) and national research institute (INRETS), was created, aiming at defining pilot test sites, installing equipment and control devices, planning the experimentation plan and full evaluation of the ramp metering control. In this paper, the results obtained on Ile de France pilot test site are presented. Two experimentations are under way: on Bordeaux and on Marseille pilot motorway test sites.

II. INTRODUCTION

From field trials conducted within European projects [6,7] it is well-known that ramp metering is 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.

Moreover, ramp metering has proved to be suitable as a tool for reducing or avoiding rat-running traffic in the adjacent road network [9].

The motorway part of the test site (see Fig. 1) comprises 5 on-ramps (Chilly-Mazarin, Savigny, Viry, Grigny and Ris-Orangis). Due to technical reasons, the on-ramp Grigny was not equipped with signal light devices.

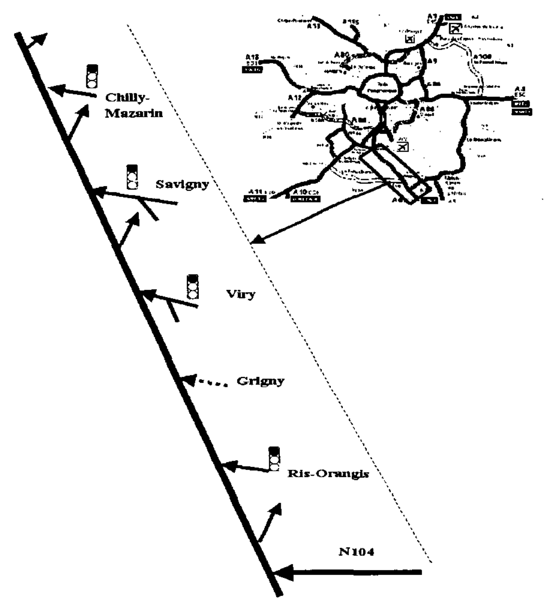

Fig 1. A6W test site. The considered test site is the most critical area of the A6W motorway toward Paris city. Morning and evening peak congestions are observed over several hours and several kilometers.

1) Operational Policy

The main authorities in charge of traffic management are the SIER (Service Interdépartemental d'Exploitation de la Route) operates the motorway network. The SIER motorway network covers 515 km (A1 to A13). The traffic management and control are subdivided into four control centres (North, South, East and West). The level of the congestion on the "Ile de France" network (including Paris ring road) represents 80 % of the total congestion on the overall France motorway network.

Since 1988, the "Direction Régionale de l'Equipement de l'Ile de France -DREIF-" has launched a project called "SIRIUS" (Service d'Information pour un Réseau Intelligible aux USagers) aiming at optimising the traffic conditions on the overall Ile de France motorway network in terms of traffic control including automatic incident detection, ramp metering, speed limits, lane assignment, traffic information and guidance of the users. Concerning the ramp metering control, only the South control centre (PC-A6 Arcueil) is partially equipped. The used strategy is the fixed time control.

In 1996, the SIER authorities decided on 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" and including several ramp metering strategies: fixed time, traffic responsive (ALINEA) and coordinated strategy. The presented field test is based on the application of this developed system.

III. FIELD TRIAL DESCRIPTION

A. General Description

To investigate the impact of ramp metering on motorway traffic conditions, it was decided to apply in weekly alternation ramp metering and no control respectively over the period from May, until June, 1999, and to perform subsequently a comparative evaluation of the corresponding traffic conditions.

1) Fixed time characteristics

TABLE 1. FIXED TIME CONTROL STRATEGY

On-ramps	Control intervals	Cycle Durations (sec)	Green Durations (sec)
Ris	6h30 - 6h50	50	30
	6h50 - 7h00	50	25
	7h00 - 7h05	50	50
	7h05 - 7h45	50	25
	7h45 - 9h05	50	50
Viry	6h30 - 9h10	60	28
Savigny	6h30 - 9h15	35	19
Chilly	6h30 - 9h15	60	40

2) Isolated Traffic Responsive Strategy: ALINEA

The ramp metering strategy applied for the field test is ALINEA [1,3,5]. ALINEA is based on a rigorous feedback philosophy. In fact, 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. 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 switchings are necessary).

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 [4, 8, 9] to be more efficient than other known local ramp metering strategies. Clearly, the efficiency of the applied control strategy (in our case ALINEA) is of highest importance for achieving a possible positive impact of ramp metering on motorway traffic.

3) Available Data

The considered motorway length is around 17 km. This motorway part is fully equipped with traffic flow and occupancy rate measurement stations at around each 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.

Full sixteen days 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 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 8 days of data using ALINEA control and 8 days without control and one day for the fixed time control. The corresponding data of the 7 other days using fixed time strategy were collected from SIRIUS database during 1998 in the same periods (May and June 1998).

Furthermore, during ALINEA trials, queue length surveys on each controlled on-ramp has been conducted by 25 investigators. Each 5 minutes, the travel time, the estimated queue length and the exceptional events (if any) are collected for each controlled on-ramp

IV. ASSESSMENT RESULTS

A. *Assessment Criteria*

In order to minimize the level of demand variations on the evaluation, the statistical analysis of the similarities of demand profiles between the selected days, has been made. Based on the statistical T-Test of the measured traffic volume (6h:00-11h:00) of one measurement station located at the far upstream of the test site, the results obtained indicate, at 95% confident interval, a similarities between all days except the Mondays. Attention has been paid to avoiding days when congestion spillback to this measurement station location.

This difference is due to the traffic composition on Monday. As a matter of fact, from Friday midnight to Monday 10h:00 p.m, the lorries can not use the motorway whereas for the other days they can use a motorway path at any hours of the days. On the other hand, the morning period of Monday corresponds to the end of the weekend, and a high levels of demand are generally observed.

These remarks led to split the collected data sets into both sets: Monday and the rest of days sets per strategy. This splitting ensures the comparability between sets.

For each set, the quantitative assessment criteria calculated from measured data are:

- Total Travel Distance (TTD) in veh*km
- Total Time Spent (TTS) in veh*h
- Mean Speed (MS) in km/h defined to be equal to TTD/TTS.
- Congestion severities in h*km
- The travel time

These assessment criteria are computed during the following time interval: 6h-7h, 6h-9h:30, 7h-9h:30, 9h:30-11h and 6h-11h.

TABLE 2: INDEX PERFORMANCE BY STRATEGY NORMAL DAYS

Periods	Criteria	Refer.	Fixed-Time	Gain (%)	ALINEA	Gain (%)
7h-9h:30	TTD	181122	182766	0.9	185820	2.6
	TTS	260149	243658	-6.3	218933	-15.8
	MS	41.8	45	7.7	54.1	21.9
	TT(min)	23.3	21.6	7.2	18	-18
6h-11h	TTD	364180	357974	-1.7	369926	1.6
	TTS	425355	383589	-9.8	366741	-13.8
	MS	51.4	56	9	60.5	17.8
	TT(min)	18.9	17.4	-8.3	16.1	-15.1

Table 2 presents the overall results in terms of four performance indexes during the rush hours period (7h - 9h:30) and the overall period (6h-11h), over all selected days including the gain. The gain is computed as:

100(Strategy Index - Reference Index / Reference Index)*

with ALINEA (6 days), without control (6 days), and fixed time control (6 days). All performance indexes include the motorway and the ramps.

These results will next be commented for each assessment criterion individually. The other periods results can be found in details in [11].

Table 3 summarizes the same index as reported on Table 2, for the Monday data sets. The assessment between Mondays and the other days, indicates a significant differences of the TTD and the TTS indexes. During the Mondays the motorway part support a high level of traffic.

Nevertheless, screening the gain in Table 2, the reported results of the benefit levels are similar as compared to Table 1.

TABLE 3. PERFORMANCE INDEX OF MONDAYS

Periods	Criteria	Reference	Fixed-Time	Gain (%)	ALINEA	Gain (%)
7h-9h:30	TTD	193046	196695	1.9	196208	1.6
	TTS	215049	194215	-9.7	179718	-16.4
	MS	53.9	60.8	12.8	65.5	21.6
	TT(min)	18	16	-11.4	14.8	-17.8
6h-11h	TTD	389193	393223	1	389477	0.1
	TTS	364666	341147	-6.4	326310	-10.5
	MS	64	69.2	8	71.6	11.8
	TT(min)	15.2	14.1	-7.4	13.6	-10.6

B. *Global Performance Indexes*

1) *Total Travel Distance (T.T.D.)*

The Total Travel Distance does not change significantly by application of ramp metering control as compared to the no control case.

This average result, however, does not necessarily imply that there is no change of route selection behaviour in the case of ramp metering. In fact, even if the value of the travel distance criterion changes only slightly during rush hours sub periods, this may have an important impact on traffic congestion. In other words, the diversion of only 500 vehicles at the beginning of the rush hours may be enough to preserve capacity flow on the motorway thus avoiding or delaying congestion. But, clearly, this small amount of diverted vehicles does not change significantly the average value of the T.T.D. criterion.

2) *Total Time Spent (T.T.S.)*

Under similar values of the T.T.D. criterion (as it is the case here), the value of T.T.S. is an index of the extension of congestion and of the amount of the corresponding delays. According to the average results of Table 1, the T.T.S. decreases by 6.3% and 15.8% in the case of fixed time and ALINEA respectively. This is a considerable reduction confirming the significance of ramp metering for reducing recurrent congestion on urban motorways, which was already reported from previous field trials [1,2,4,5]. This performance index includes the unavoidable delays caused by ramp metering on the controlled on-ramps.

3) *Mean Speed (M.S.)*

Interpretation and discussion of changes related to the mean speed index follow the lines of the previous statements on corresponding changes of T.T.S. We, therefore, just mention here the Mean Speed changes appearing on Table 2 in the case of ramp metering as compared to the no control situation: increase by 9,7% and 17,8% on the motorway with fixed time and ALINEA respectively.

4) travel time (TT)

In order to point out in a comprehensive terms the impact of the ramp metering for decision makers and for the users, the travel time calculation is done in two different ways. The first one is indicated in Table 2 and based on the computation of the ratio *L/v* where *v* is the mean speed and equal to *TTD/TTS* and *L* is the section length where the travel time estimation is addressed. The second approach consists to compute the travel time from each on-ramp to the main destination corresponding to the main output of the considered test site namely Wissous (see Fig. 2). This computation includes the waiting time of each ramp provided by the investigators and the travel time on the motorway.

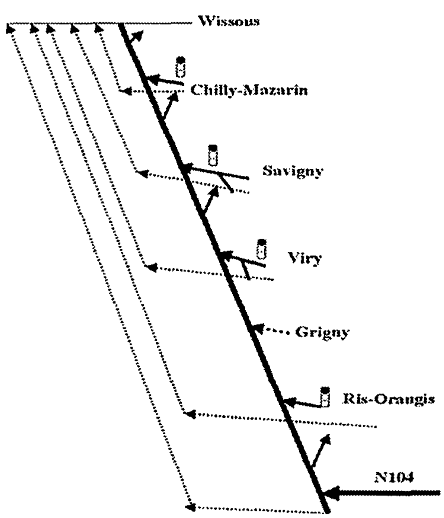

Fig. 2. Paths for mean TT estimation. Five paths are considered. The first one corresponds to the motorway path whereas the four others correspond to on-ramp origins toward the main destination Wissous.

For each path, the travel is estimated as the some of the motorway travel time and the waiting time on the corresponding on-ramp. Both periods are considered: 6h-7h and 7h-9h:30. The second period is more significant because the ramp metering control is active.

Table 4 depicted the obtained results of the second period. The first one resulted can be found in [11]. The following remarks can be drawn:

- Compared to no control case, the increase of the mean travel time on the ramps using ramp metering control is acceptable. The observed maximum value is less than one minute.
- The benefit decreases according to the total length of the path. This comprehensive phenomenon is due to the estimation of the travel time. As far as the motorway travel time is more higher than the on-ramp, the benefit increases accordingly.

TABLE 4. MEAN TRAVEL TIME ESTIMATION BY PATH

		REFERENCE: No Control			ALINEA			
Origine To Wissous Dest	Length (Km)	on-ramp TT	Motorway TT	Total TT	on-ramp TT	Motorway TT	Total TT	Gain Tot. TT(%)
N104	16.2	0	23.3	23.3	0	19.1	19.1	-18
RIS	13.8	0.3	19.8	20.1	0.2	17.1	17.3	-14.3
Viry	10.8	1.2	12.1	13.3	1.9	10.7	12.6	-5.4
Savigny	7.4	0.9	5.6	6.5	0.8	5	5.8	-10.8
Chilly	4.1	0.4	2.4	2.8	1.2	2.2	3.4	20.2

However, for on-ramp Chilly, compared to no control case, the travel times increase. This result is very surprising and needs more traffic analysis. In fact, this negative traffic impacts is not related to the on-ramp metering control but to the particular site topology. As a matter of fact, the motorway destination A10 is located at 800 meters far to the vicinity of on-ramp Chilly. This exit is overloaded during the peak morning period. Consequently, the congestion appear first on the A10 exit and spillback to the carriage way of A6 until Chilly on-ramp. The data analysis has demonstrated that the levels of congestion observed on A10 exit with ALINEA are higher as compared to the no control case and leading to the increase of the estimated travel time.

These results indicate with high probability that the benefits of ramp metering action are higher under non recurrent congestion with a low waiting time on the ramps.

V. OVERRIDE CONSTRAINT

As indicated in the ALINEA description (section III), the override constraint is activated when the queue length exceeds the on-ramp capacity measured by the detectors located at the upstream of each ramp.

In addition to this automatic functioning of the override constraint, a surveys of the time evolution of the on ramp queue have been organized. These surveys were done with ALINEA only. Thus, during 10 days, between 6h-9h30 and each 5 minute intervals the on ramp queues are estimated by the investigators on the field.

TABLE 5. MEAN OVERRIDE ACTIVATION WITH ALINEA

On-ramps	Override activation in %	Remarks
RIS	3.8	Observed during strike of public transport days
Viry	3.1	Observed only during one day
Savigny	1.4	65% are Observed during strike of public transport days
Chilly	0	
All on-ramps	1.4	

Table 5. summarizes the mean activation (in %) of the override constraint for each on ramp and over the 10 days. Exceptional event are mentioned. In particular, with ALINEA strategy, the override constraints are activated in case of public transport strike days. During the normal days no excessive activations of the override constraint are observed.

VI. Brief Cost benefit analysis

The cost benefit analysis consists in converting the calculated traffic indexes into economic costs. In general, the *TTS, TTD* and *MS* indexes are used. According to the national park composition of vehicles, the evaluation indices are converted in equivalent tutelary cost.

In our case, the *TTS* index is used. The tutelary quantity of 1 vh*h is equivalent to 94 FF/vh*h. Considering the overall periods (6h-11h), the *TTS* and the *TTD* indices are equal to 6112 vh*h, 369926 vh*km and 7089 vh*h, 364180 vh*km for ALINEA and no control case respectively. For the same *TTD* index, the *TTS* index of no control is equal to:

$7089*369926/364180 = 7201\ vh*h$

Under the same *TTD* index, the gain is equal to 1089 vh*h for ALINEA. Assume that the control is working during 250 days per year. The total cost benefit is equal to:

$1089*250*94 = 25591500\ FF \sim 25\ MFF\ /year$

The estimated cost of the equipments and the maintenance of 4 ramps is around 4 MFF. In consequence, the net cost benefit is equal to 21 MF per year.

These results are very similar than those indicated in reference [1].

VII. CONCLUSIONS

Field trials have been designed and executed over a period of several months at the A6 motorway located at the southern part of the Ile de France motorway network in the aim of investigating the impact of ramp metering measures on motorway traffic. A detailed evaluation of the available data leads to the following conclusions:

- Ramp metering reduces the recurrent congestion level and increases the mean speed on the motorway, probably along with a slight increase of the served demand. This observed impact of ramp metering meets perfectly the operational policy of the SIER
- Used data in this field trial include a certain amount of inaccuracies originating from different sources:
  - Unavoidable detector inaccuracies despite a careful off-line data screening.
  - Demands of ramp metering days and no control days are comparable but (unavoidably) not identical.
  - Link queues may only be observed if they are sufficiently long and, as a consequence, the calculation of the *TTS* are probably systematically biased (underestimation of congestion and delays).
  - Mean speed is calculated from the traffic volume and occupancy rate measurements rather than directly measured.
  - Although these data inaccuracies may have an impact on the quantitative figures of the field trial assessment but they do not affect the main qualitative conclusions of the assessment.

It must be particularly emphasized that the reported positive evaluation results of ramp metering action are closely related to the utilized control strategy ALINEA. Less efficient ramp metering strategies that may fail to significantly improve traffic conditions on the motorway, or that may be too restrictive (thus underloading the motorway), will probably fail to reach the level of improvement of the traffic conditions achieved within this field test.

VIII. Future Ramp metering on "Ile de France" motorway network

Related future investigations include a more specific, in-depth evaluation of the field trial results aiming at developing suitable real-time strategies for coordinated ramp metering. Since January 2001, extended off-line simulation studies have been undertaken by INRETS with the collaboration of the SIER. The considered test site covers around 150 km and includes 80 on-ramps and 17 motorway convergents where the MTMC will be tested.

Two main stages are considered:

1. the evaluation of the traffic impact of classical ramp metering (ALINEA) and the Motorway To Motorway Control (MTMC) on a large scale network.
2. the development of coordinated ramp metering control strategy based on the application of the automatic control concept.

The used simulation model is the well known macroscopic simulation model named METACOR [10]. The model will validate and calibrate on the considered network using real data measurements.

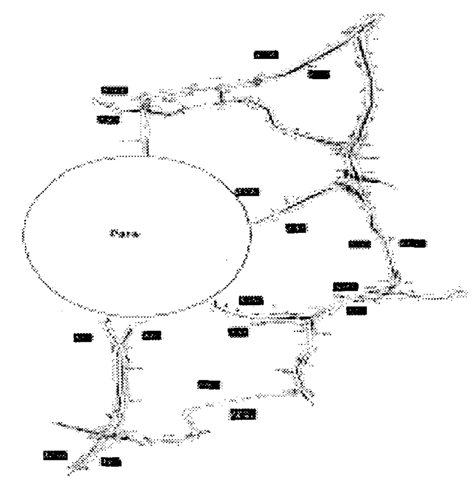

Fig.3 stretch of the off-line simulation network using METACOR model (output of the graphic display)

In the considered test site the A86 motorway is very congested during the morning and evening periods in both directions: from the North to the South and vice et versa. Off-line simulation study results will probably demonstrate the positive impact of the classical on ramp metering control combined with the MTMC control on isolated and coordinated levels. This study is just at the beginning and all results will be published in next future.

Moreover, these results will also serve to convince the policy makers in order to generalize the operational implementation of the on-ramp metering technique to the Ile de France motorway network and elsewhere in France.

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