SIMULATION, IMPLEMENTATION AND EVALUATION OF A DEDICATED LANE ON AN URBAN MOTORWAY

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ABSTRACT

The A1 motorway connects the Charles-de-Gaulle Airport to Paris and is one of the busiest roads in France. In order to cope with the reduction of taxi supply in the centre of Paris during the morning peak period, the Regional Highways Authority has decided to allocate the inner-left lane to taxis and buses from 7 to 10 am. Prior to the implementation a macroscopic simulation had been performed for an a priori evaluation of the operation. Input data were collected and consisted only of macroscopic traffic variables: flows, speeds and density. The study compares the simulation results with data measured after implementation. It shows how macroscopic simulation may be used efficiently in a priori assessment of managed lanes operations. Real traffic conditions were analyzed in two stages to take into account the short-term effect of the strategy and mid-term changes in driver behaviour with enforcement control being applied.

The key findings of the study indicate the occurrence of a new bottleneck at the upstream end of the dedicated lane shown by both simulation and on-site measurements with the same congestion pattern. However, simulated travel times are lower than real ones due to drivers' poor compliance with the operation despite penalties. A comparison between data before and after the enforcement control took effect shows a 3-10 minute travel time saving for a 200 vph switch from the dedicated to the general purpose lanes. Since taxis do not have a priority access to the slip road toward the city, they still get stuck in the pre-existing congestion at the downstream end of the dedicated lane. So the actual goal of the operation is not achieved. Nevertheless, the simulation results fit well with the measured data, which highlights the relevance of properly calibrated macroscopic models in a priori evaluation of managed lanes operations.

Keywords: bottleneck, calibration, congestion, dedicated lane, evaluation, macroscopic simulation, validation, traffic management, travel times.

INTRODUCTION

Managed lane operations are implemented in several European countries to cope with growing congestion on urban motorways. Those traffic management strategies consist of redefining the configuration of the road's transverse profile according to traffic conditions. For large infrastructures it is possible for instance to create a new lane, by reducing the widths of the existing ones. This is known as a *plus lane*. Where the lanes are not wide enough, the hard shoulder may be opened to create a so-called *peak hour lane*. With the aid of Intelligent Transportation Systems tools, lanes management is more and more automated and dynamic. Results from several operations show increases in the total capacity of the road sections where the strategies are applied. In Germany, capacity grew by 25% with hard shoulder running on the A4 motorway [Sparmann, 2007]. However the findings are lower in France where lane widths are generally narrower. Capacity increased only by 7.5 to 10% on the A4-A86 site near Paris [Desnouailles and Cohen, 2007]. It is precisely in this context of physical restrictions that, for the past few years, many local communities have requested authorizations to open their hard shoulders to traffic during peak periods. In Grenoble, hard shoulder running on the A48 motorway is used to promote public transport and represents the first dedicated lane in France.

Dedicated lanes are commonly deployed in North America, especially in the form of High Occupancy Vehicle lanes. Their use is restricted to vehicles with a predetermined number of occupants. Several studies have been done to investigate the real impacts of HOV lanes on traffic congestion. [Menendez and Daganzo, 2007] showed that «HOV lanes may smooth flow through some bottlenecks by dampening lane changing activity». On the other hand, [Kwon and Varaiya, 2007] found that single-HOV lanes suffer a 20% capacity drop and provide little time saving compared to the adjacent general purpose lanes. The authors attributed these results, obtained from peak hour traffic data from 700+ loop detector stations installed on California's HOV system, to overtaking restrictions on such facilities. While the primary objective of dedicated lanes is to increase the number of persons transported, especially during peak periods, they have also been used for safety purposes during the past few years.

The objective of this paper is to compare the results obtained from the macroscopic simulation that had been carried out prior to the implementation of a dedicated lane on the A1 motorway near Paris, with the data collected during the first six (6) months of the operation. The use of macroscopic simulation for an a priori evaluation of this kind of strategies will be highlighted as well as the potential and real impacts of dedicated lanes on traffic congestion.

The paper is organized as follows: a first section describes the case study. The second section highlights the methodology for the data qualification and the simulation process. The results are presented in the third section, followed by a discussion section aiming at analyzing the gaps between simulation results and the measurements. The conclusion retrieves the main impacts of the dedicated lane on traffic conditions, identifies the weaknesses of the macroscopic simulation and ways for further investigations.

SITE DESCRIPTION

The scheme implemented, since the spring of 2009, on the A1 motorway in France is an example of a dedicated lane with an economic purpose. This motorway is one of the busiest in France, with daily traffic averaging 130,000 vehicles in each direction. Congestion on the section between Charles de Gaulle Airport and Paris (southbound) lasts more than 5 hours during the AM peak period. Queue lengths usually exceed 5 kms, from Paris backwards. Lane's widths vary from 2.8 and 3.75 m and shoulders do not exist at some locations. This restrictive configuration of the transverse profile makes it impossible to increase the capacity through lane addition. During the morning, taxi drivers preferred to stay at the Airport waiting for passengers rather than attempting to go to Paris and get stuck in the congestion. As a consequence the taxi supply in the centre of Paris was drastically low, putting the city in an unfavourable situation compared with other major European cities like London or Madrid which attract tourists and businessmen. As part of the Government's program to enhance Paris's competitiveness, the Regional Highways Authority is implementing an innovative lanes management strategy on the A1 motorway. It aims at favouring taxis and buses by allocating to them the inner-left lane of the infrastructure from 7 to 10 on weekdays.

METHODOLOGY

The assessment of the strategy is carried out within a sustainable mobility framework, which emphasizes the impacts on the overall level of service, vehicle consumptions and emissions and travel time changes. The collected data consist of the macroscopic traffic variables: time-mean speeds, flows, and densities. Before the implementation, these data were used to set traffic conditions during the reference period, and simulate the potential effects of the dedicated lane. The different steps of both data processing and operation' simulation are presented hereafter. After implementation data are collected during two stages to take into account the short-term effect of the strategy and mid-term changes in driver behaviour with enforcement control being applied. Simulation results and mid-term traffic measures are eventually compared.

Data Qualification

Basic data for this study consist only of aggregated mean speeds V, flows Q and occupancy occ. They were collected from the SIRIUS database which contains measurements provided by loop detector stations installed throughout the motorway network of the Paris Region. The dedicated lane being applied during the morning peak period between 7 and 10 am. In order to catch the whole morning peak period, we used 6min-data from 6 am to 1.30 pm. For each station and both before and after periods, inconsistencies and unusual traffic conditions were discarded through proper filtering process with the following criteria applied successively:

- The maximum height of water is 3 mm during rainy days. According to previous studies made by the Innovation and Research Program in Road Transport (PREDIT), this threshold corresponds to the case of extreme precipitation [Delanne and Gothié, 2005].

- For any given loop station and at each time-step no incident or accident is recorded at less than 5 kms upstream or downstream and within 5 hours, since this could affect traffic conditions at the station's location.

This filtering process was applied on a per-station basis. Therefore a specific day would not necessarily be selected for all the stations together.

Operation Simulation

The main benefit of macroscopic simulation pertains to the model's inputs. The process is deterministic; so that no unobservable parameters are needed. Furthermore, once calibrated a single run is sufficient to characterize a specific traffic configuration. The simulation tool used for this study was designed at the University of Berkeley. FREQ12 is a macroscopic model based on the relationship between the state variables of traffic, the equation of conservation and the fundamental diagram. The model is tuned by direct manipulations of the subsection capacities. The simulation process comprises three steps which consist of modelling and coding the network, calibrating and validating the model for the case study and finally simulating the reference situation for further operation scenarios. As all simulation packages, FREQ has its own restrictions that the user needs to take into account during simulation. For instance, the model only allows a maximum of 24 time steps for simulation which greatly reduces the temporal limits of the study. In order to capture the traffic conditions during the whole activation period without significant loss of information, we aggregated the data on 12 minute time slices. Thus, simulation results lay between 0648 and 1124, although congestion may last beyond this period. Another restriction of FREQ pertains to the subsections' fundamental diagrams. The model provides a set of curves among which the user may choose the one that best fits the real data. Finally, the minimum value of free-flow speed is set at 50 mph (~80km/h) and the lower-limb speed-flow curve is unique for the whole network, which is not always the case on urban motorways where the configuration of the subsections is not homogeneous.

Network Modelling

For simulation purposes and in order to represent the spatial evolution of traffic conditions, a given network is generally divided into subsections. The following core rules apply for this discretization:

- There is no on- or off-ramp at the mainline entrance;
- There is no on- or off-ramp at the mainline exit;
- Each on-ramp or geometric configuration change marks the upstream end of a new subsection;
- Each off-ramp or geometric change marks the downstream end of a current subsection;
- Subsection length does not exceed 2kms.

The 17-km long stretch of our case study was divided in 21 subsections according to its geometric configuration.

Model calibration and validation

Traffic simulation tools are built on robust algorithms and models. However, in order to reproduce prevailing conditions for a particular road and traffic configuration, they need to be calibrated with site-specific data. Validation consists of ensuring that the parameters set at the calibration stage are valid for any other set of traffic demand. The inputs required by FREQ12 consist of:

- Traffic counts at all entrances and exits of the network, including the mainline upstream and downstream ends. We used data of 04/14/08 and 04/16/08 for calibration and validation respectively, for loop detector stations were reliable (RR≥80%) for a maximum of subsections during both days.
- Free-flow speeds and capacities of all subsections. These values were obtained from the fundamental diagrams pre-calibrated with measured traffic data for the before-period. They were eventually adjusted during the calibration process.

The aim of any calibration process is to minimize the gap between simulation results and measurements of predetermined measures of performance. For this case study, we sought to capture the temporal and spatial distribution of speeds and used visual and statistical tests. Visual tests helped to verify whether or not the model identified the exact location of bottleneck, queue lengths, congestion occurrence and clearance times. To evaluate the overall performance of the simulation relating to the speed contour maps, we used the Theil's inequality coefficient (U). This statistic provides information on the relative error and is bounded between 0 and 1. A value of 0 implies perfect fitting between simulation and measurements. [Toledo and Koutsopoulos, 2004]. Theil's coefficient is given by the following equation:

$$U = \frac{\sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(S_n^{sim} - S_n^{obs}\right)^2}}{\sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(S_n^{sim}\right)^2} + \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(S_n^{obs}\right)^2}} \qquad \text{[Eq. 2]}$$

Where S_n^{sim} and S_n^{obs} are the averages of simulated and real measurements at space-time point n.
We found a U_{min} of 0.1 and 0.09 for calibration and validation respectively. Once calibrated, the model had been used to simulate traffic conditions during the reference period.

RESULTS

This study presents only the results related to the speeds contour maps and the travel times on both types of lanes. In order to carry out the Before/After analysis we present two sets of results in the following sections. They are related to traffic conditions during the base period and during the scheme implementation. Furthermore, we consider the short and mid-term effects of the operation on traffic conditions for the after period.

Reference Traffic Conditions

Whether in simulation or in reality, a before/after analysis always compares a reference situation to potential or implemented scenarios. In this section, we present both the simulated and observed reference situation. The main results obtained from both simulation and observations are given below:

- The bottleneck is located at the slip road going toward the ring road (westbound).
- Congestion occurs at about 7am and clears after 11h24 am (end time of simulation).
- Queue length slightly exceeds 5 kms.

Speed contour maps

Tables 1 and 2 show the respective simulated and real contour maps. Theil's inequality coefficient is equal to 0.14. In general, simulation results show a gap of less than 10% in the queue length and an error corresponding to one time step (12 min) in congestion occurrence time.

Table 1- Real contour map at the reference period (speed in km/h)

TS/S	S1	S2	S5	S6	S7	S8	S9	S10	S11	S12	S13	S15	S18	S19	S21
Station	16+0900	16+0000	12+0800	11+0600	10+0700	08+0800	08+0355	07+0800	07+0400	06+0000	05+0170	04+0000	01+0800	00+0700	00-0252
06 :48	113	95	113	108	73	89	89	76	93	79	68	21	49	40	60
07 :00	121	103	114	99	41	79	66	54	84	76	29	18	33	25	60
07 :12	120	101	118	105	41	68	62	80	89	64	27	14	20	19	59
07 :24	126	102	117	107	42	67	54	64	80	43	19	11	18	17	60
07 :36	123	105	116	111	42	48	41	31	56	15	20	11	15	16	60
07 :48	124	105	115	110	50	49	30	28	50	13	20	12	15	15	59
08 :00	122	104	115	109	78	45	29	34	53	17	22	12	14	14	61
08 :12	124	106	116	110	83	72	64	34	69	16	22	12	13	14	60
08 :24	125	102	114	109	85	92	98	40	88	26	23	12	13	13	61
08 :36	124	102	114	109	86	95	99	30	102	53	22	13	13	13	59
08 :48	126	108	114	111	86	96	98	30	100	80	25	13	13	13	60
09 :00	124	102	114	109	59	92	97	45	99	80	28	13	14	13	60
09 :12	120	102	113	111	66	91	97	37	102	76	24	13	13	13	59
09 :24	117	96	111	111	87	93	95	39	101	51	26	12	13	14	57
09 :36	112	94	110	111	90	92	96	39	102	30	26	13	13	13	58
09 :48	110	92	110	111	92	93	96	30	103	59	29	13	14	13	56
10 :00	110	91	110	113	93	92	96	34	103	77	25	12	14	14	56
10 :12	108	91	109	111	93	93	95	68	102	74	26	13	15	15	57
10 :24	108	89	112	113	93	93	96	94	103	78	28	15	16	15	57
10 :36	105	88	109	112	93	92	95	92	103	80	33	15	16	16	55
10 :48	109	91	107	112	94	91	96	83	103	79	85	15	16	17	58
11 :00	111	91	111	113	94	92	95	93	104	78	94	16	17	18	59
11 :12	114	96	111	113	94	94	96	93	105	81	93	19	18	19	57
11 :24	108	92	111	114	94	93	96	92	104	80	95	27	19	20	57

V > 60 km/h   V = 30-60 km/h   V = 15-30 km/h   V ≤ 15 km/h

Table 2- Simulated contour map at the reference period (speed in km/h)

TS/S	S1	S2	S5	S6	S7	S8	S9	S10	S11	S12	S13	S15	S18	S19	S21
Station	16+0900	16+0000	12+0800	11+0600	10+0700	08+0800	08+0355	07+0800	07+0400	06+0000	05+0170	04+0000	01+0800	00+0700	00-0252
06:48	117	100	113	113	95	95	97	90	98	101	88	80	69	47	80
07:00	117	100	113	113	90	90	79	82	84	88	88	43	35	37	80
07:12	117	100	113	113	88	88	53	82	84	101	39	11	29	34	80
07:24	117	100	113	113	88	88	39	82	84	53	18	14	27	31	80
07:36	117	100	113	113	93	93	42	82	84	27	19	13	23	26	80
07:48	117	100	113	113	95	95	66	85	80	21	21	13	21	24	80
08:00	117	100	113	113	97	97	97	93	43	16	18	13	19	21	80
08:12	117	100	113	113	97	97	97	93	37	18	18	13	18	19	80
08:24	117	100	113	113	97	97	97	93	42	18	18	13	18	19	80
08:36	117	100	113	113	97	97	97	93	60	21	21	14	18	19	80
08:48	117	100	113	113	95	95	97	90	68	24	24	16	18	21	80
09:00	117	100	113	113	97	97	97	92	64	23	23	16	18	21	80
09:12	117	100	113	113	95	95	97	92	69	23	23	18	18	21	80
09:24	117	100	113	113	97	97	97	93	71	19	21	16	19	21	80
09:36	117	100	113	113	97	97	97	93	77	21	21	18	19	21	80
09:48	117	100	113	113	97	97	97	93	95	19	19	16	18	19	80
10:00	117	100	113	113	97	97	97	93	103	19	19	14	18	21	80
10:12	117	100	113	113	97	97	97	93	87	18	18	14	19	23	80
10:24	117	100	113	113	97	97	97	93	63	16	18	14	21	24	80
10:36	117	100	113	113	97	97	97	93	55	19	21	18	24	29	80
10:48	117	100	113	113	97	97	97	93	51	19	21	18	26	29	80
11:00	117	100	113	113	97	97	97	93	42	18	18	16	26	31	80
11:12	117	100	113	113	97	97	97	93	29	16	16	16	26	31	80
11:24	117	100	113	113	97	97	97	93	18	13	13	13	26	29	80

V > 60 km/h   V = 30-60 km/h   V = 15-30 km/h   V ≤ 15 km/h

Travel times

Reference travel times are computed by an algorithm embedded in the SIRIUS system. The calculated values range from 27 to 35 minutes during the morning while simulated travel times vary between 27 and 36 minutes. The maximum error between the two sets of results, as shown in Figure 1, is of 6%.

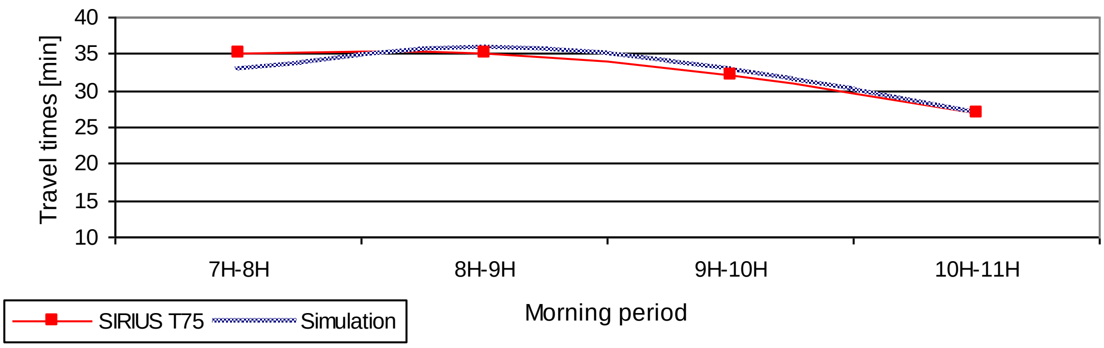


Figure 1- Real and simulated travel times during the reference period

The impacts of the dedicated lane had been evaluated by macroscopic simulation before the implementation according to the simulated results presented above.

Impacts of the Dedicated Lane on Traffic Conditions

Cameras are installed along the dedicated lane to track unauthorized drivers. Although the operation started in April, fines were not levied until August. Hence, during the first three months (from April to July), there was no incentive to prevent users from driving on the dedicated lane. For this reason we will divide the after period into two stages. Changes in traffic conditions after those three months are referred to as “mid-term effects” and are most likely to be compared with the simulation results. This will allow us to see whether or not enforcement may contribute to the effectiveness of the operation.

Simulation Results

The dedicated lane was simulated with the following hypotheses:

- The hourly traffic demand is 600 vehicles (taxis and buses) during the activation period;
- The violation rate of the operation is set at 0% for both types of users;
- Authorized vehicles enter the lane at the upstream end and leave at the downstream end.
- The activation implies a capacity drop on the remaining infrastructure corresponding to the per-lane capacity obtained from calibration.

Table 3 gives the simulated speed contour map on the general purpose lanes from 6 h 48 to 11 h 24 am. The special lane is located in subsections S12b to S17a. These results indicate that the pre-existing bottleneck (B1) remains at the slip road towards the ring road in Paris, while a new one (B2) occurs at the upstream end of the dedicated lane.

Table 3- Simulated contour map on the general purpose lanes during activation period (speed in km/h)

TS/SS	1	2	3	4	5	6	7	8	9	10	11	12a	12b	13	15	17a	17b	18	19	21
06 :48	117	100	113	113	113	113	92	92	97	90	98	101	101	88	80	47	35	69	47	80
07 :00	117	100	113	113	113	82	82	82	88	60	40	23	70	70	29	70	32	37	37	80
07 :12	117	100	113	113	113	39	82	82	42	35	35	21	70	39	18	32	16	29	34	80
07 :24	117	100	113	113	113	23	82	71	32	40	39	19	34	24	16	24	16	26	31	80
07 :36	117	100	113	113	113	23	72	37	27	35	35	18	32	31	14	21	13	21	24	80
07 :48	117	100	113	113	113	43	40	34	26	34	34	19	35	34	14	21	13	21	23	80
08 :00	117	100	113	113	113	45	26	26	21	24	24	18	31	29	14	18	13	19	21	80
08 :12	117	100	113	113	113	34	24	24	19	23	23	18	31	31	14	18	13	18	19	80
08 :24	117	100	113	113	113	42	26	26	21	23	23	18	34	32	16	18	13	18	19	80
08 :36	117	100	113	113	113	82	31	31	23	26	26	21	42	40	18	19	13	18	19	80
08 :48	117	100	113	113	113	60	32	32	24	27	27	21	70	47	19	23	14	18	19	80
09 :00	117	100	113	113	113	39	29	29	23	27	27	21	70	51	21	24	14	18	19	80
09 :12	117	100	113	113	113	31	31	31	23	27	27	21	70	58	24	24	16	18	21	80
09 :24	117	100	113	113	113	31	27	27	23	26	26	21	70	68	23	29	16	19	23	80
09 :36	117	100	113	113	113	39	27	27	21	24	24	21	70	70	26	27	16	19	21	80
09 :48	117	100	113	113	113	61	26	26	21	23	23	21	70	70	23	23	14	18	21	80
10 :00	117	100	113	113	113	111	26	26	21	23	23	21	70	70	21	23	14	18	21	80
10 :12	117	100	113	113	113	113	66	43	31	32	32	47	70	42	21	18	18	23	24	80
10 :24	117	100	113	113	113	113	97	97	69	45	32	40	39	31	23	21	21	24	29	80
10 :36	117	100	113	113	113	113	97	97	97	93	37	21	21	19	18	21	21	24	29	80
10 :48	117	100	113	113	113	113	97	97	97	93	35	21	21	19	18	21	21	26	29	80
11 :00	117	100	113	113	113	113	97	97	97	93	31	18	18	18	16	23	23	26	31	80
11 :12	117	100	113	113	113	113	97	97	97	93	23	16	16	16	16	23	23	26	31	80
11 :24	117	100	113	113	113	113	97	97	97	90	14	13	13	13	13	21	21	26	29	80

V > 60 km/h V = 30-60 km/h V = 15-30 km/h V ≤ 15 km/h

Queue length resulting from bottleneck B1 slightly exceeds 5 kms and lasts from about 7 to after 11 h 24 am, with noticeable increases in mean speeds near the beginning of the dedicated lane at subsections SS12b and SS13. The congestion due to bottleneck B2 starts at 7 and clears at 10 am. It covers another 5 km long stretch. The total simulated travel times are between 27 and 33 minutes for vehicles on the GPL and are shown in Figure 2 along with results for short and mid-term period.

Real short-term effects

Speed contour map for the first three months is shown in Table 4. Data collected for this period also indicated that the slip road to Paris still remains a bottleneck after the activation of the dedicated lane. A new bottleneck occurs at about 1 km upstream of the beginning of the lane at 7 am. Due to station unreliability during those first three months, it was not possible to measure accurately the length of the resulting queue. Nevertheless, the congestion's general pattern suggests a spillback of roughly 5 kms.

Table 4 - Actual contour map on the general purpose lanes during activation period from April to July 2009 (speed in km/h)

TS/SS	1	2	3	4	5	6	7	8	9	10	11	12a	12b	13	15	17a	17b	18	19	21
06 :48		85				87	44	66	54	64	80	95	61	34	20	34	35	65	53	64
07 :00		81				39	39	44	30	57	65	44	26	27	18	27	27	38	29	64
07 :12		79				43	36	38	28	56	69	38	21	22	15	17	15	25	23	63
07 :24		77				47	34	32	26	41	52	15	13	19	12	14	14	23	22	66
07 :36		62				85	29	23	21	27	33	11	12	13	12	13	12	21	22	68
07 :48		52				26	25	23	20	25	30	8	10	16	12	13	11	19	21	68
08 :00		51				15	24	21	20	27	32	9	11	14	13	12	11	18	20	66
08 :12		50				11	23	22	21	27	32	11	12	18	13	14	11	18	20	64
08 :24		53				15	23	21	19	24	29	10	11	16	13	13	9	17	22	64
08 :36		69				16	22	23	22	31	33	9	13	17	14	12	11	17	22	67
08 :48		66				17	23	22	22	32	33	11	13	17	16	12	12	16	21	67
09 :00		65				17	26	25	23	33	34	14	14	18	15	12	11	16	21	66
09 :12		72				15	26	29	24	35	39	16	13	17	13	12	10	17	20	65
09 :24		66				20	28	28	21	29	34	15	15	18	14	14	11	17	21	65
09 :36		70				24	23	24	23	35	37	17	16	20	15	15	11	18	22	61
09 :48		75				18	24	26	23	32	32	16	15	21	15	12	12	18	23	63
10 :00		74				14	25	26	21	33	35	16	14	19	14	16	12	19	22	62
10 :12		73				15	29	29	23	31	36	17	16	23	15	16	13	20	25	61
10 :24		73				19	29	39	31	37	37	25	18	27	15	16	13	18	23	59
10 :36		73				20	32	35	23	35	42	23	20	27	15	17	14	19	24	58
10 :48		72				17	33	39	23	44	47	28	20	28	15	19	15	20	24	59
11 :00		70				18	35	43	28	41	44	29	21	27	15	17	16	20	23	59
11 :12		55				22	40	42	26	38	45	25	19	27	14	17	13	19	23	59
11 :24		72					39	46	37	44	56	30	22	27	18	17	16	23	25	58

V > 60 km/h V = 30-60 km/h V = 15-30 km/h V ≤ 15 km/h Missing data

Real mid-term effects

The mid-term effects were evaluated from September to November. It is assumed that any modification observed in comparison to the short-term period must be due to changes in driver behaviour. Speeds' contour map for the GPL is given below.

Table 5- Real contour map on the general purpose lanes during activation period from September to November 2009 (speed in km/h)

TS/SS	1	2	3	4	5	6	7	8	9	10	11	12a	12b	13	15	17a	17b	18	19	21
06:48	102	100	115	96	104	83	44	59	49	60	76	102	79	42	22	31	31	56	36	62
07:00	104	99	114	96	83	38	36	49	37	54	71	53	39	27	18	24	20	33	26	62
07:12	101	100	116	97	76	36	34	39	29	46	67	45	28	23	15	18	15	25	21	63
07:24	103	101	115	97	91	34	31	34	25	40	59	20	22	21	12	15	13	21	18	63
07:36	109	101	115	97	103	26	29	29	22	34	48	20	19	21	13	14	12	19	16	62
07:48	114	104	115	95	101	27	27	26	18	28	35	18	16	20	12	13	11	18	15	63
08:00	105	103	117	95	97	23	27	25	16	23	29	13	16	19	13	12	12	17	15	62
08:12	109	104	114	95	78	16	24	22	16	23	27	22	16	22	13	13	12	18	14	64
08:24	118	105	116	96	61	20	24	23	16	24	29	17	16	23	13	12	12	16	15	63
08:36	116	105	117	95	26	20	24	25	18	24	31	17	19	23	13	12	13	17	14	64
08:48	109	104	114	95	27	17	26	26	19	26	32	23	19	22	13	13	13	18	14	64
09:00	111	106	115	96	24	16	26	26	18	26	32	20	18	22	13	13	13	17	14	63
09:12	108	102	114	97	29	21	27	30	23	32	43	27	21	23	14	13	13	17	14	63
09:24	102	99	112	94	31	22	29	33	25	32	44	27	21	24	13	12	12	16	15	60
09:36	105	98	114	95	74	26	31	30	23	32	41	20	20	22	14	12	11	18	15	61
09:48	97	94	113	94	107	30	32	33	23	30	35	31	19	21	13	13	11	19	16	60
10:00	102	93	113	94	107	70	35	34	21	29	36	25	19	23	15	13	13	19	17	59
10:12	94	94	114	95	111	80	38	45	25	34	45	24	24	26	17	14	14	20	18	58
10:24	100	93	113	93	108	101	77	73	53	44	67	26	27	27	17	15	16	21	19	57
10:36	98	92	112	93	107	110	92	88	90	85	90	46	31	31	19	17	15	21	18	59
10:48	97	93	113	93	109	109	93	91	94	89	97	48	39	34	22	17	16	21	20	60
11:00	88	93	113	94	109	110	93	93	94	91	97	42	91	65	31	18	19	25	24	59
11:12	96	92	112	93	109	112	92	92	95	91	98	93	92	80	71	21	23	27	23	57
11:24	97	93	114	93	110	110	92	92	95	91	98	94	93	80	81	23	24	29	26	57

V > 60 km/h V = 30-60 km/h V = 15-30 km/h V ≤ 15 km/h

The above table 5 tends to be closer the simulation results, which suggests changes in users' behaviour. The corresponding travel times are presented in the following graph for the whole trip from Roissy to Paris.

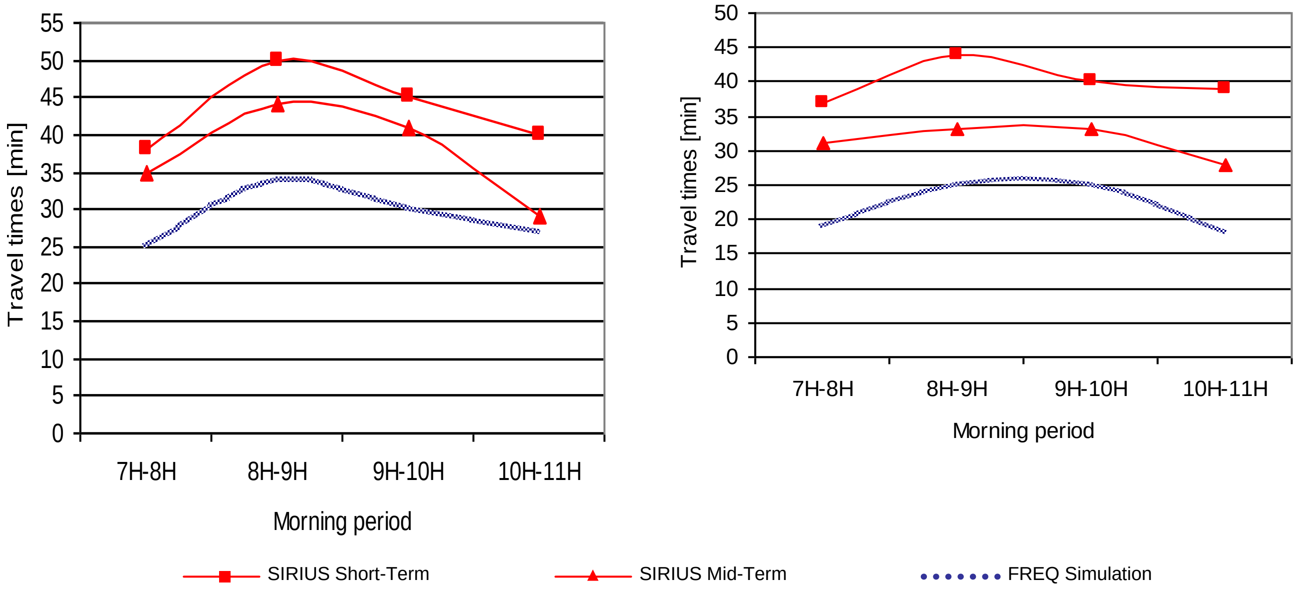


Figure 2- Real and simulated travel times during the after period (GPL: left; DL: right)

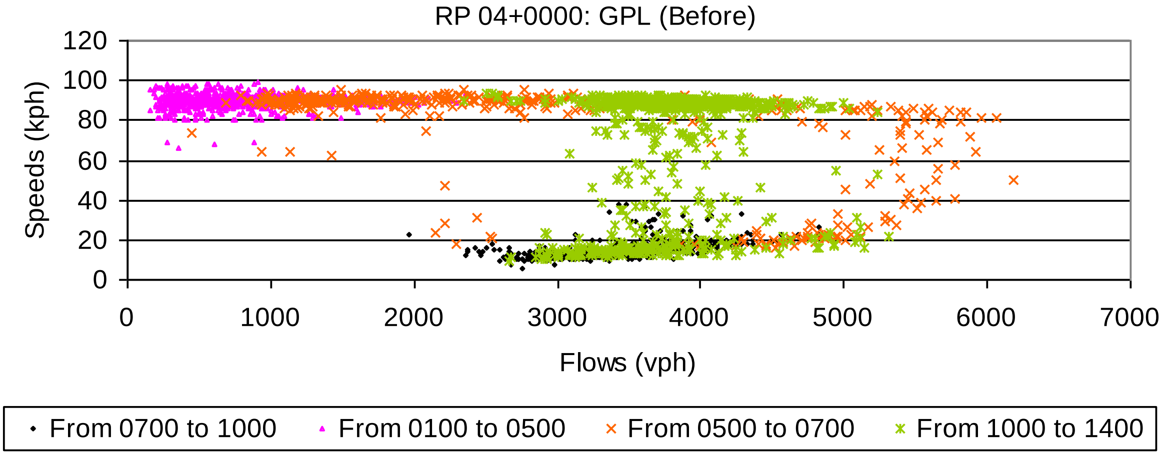
Simulated travel times on both general purpose lanes (GPL) and the dedicated lane are lower than the measured ones after implementation. But the above figure shows travel times savings with drivers' behaviour changes.

DISCUSSION

Results obtained during the Mid-term period are closer to the simulation forecasts than those of the short-term period. In fact, Theil's inequality coefficient computed for the speed contour maps is 0.04 versus 0.08. So far, observed travel times are still higher than simulated ones. For assessment purposes of lane management operations, the level of details provided by the macroscopic simulation proves to be accurate. Nevertheless, it is interesting to test the validity of the assumptions made for the simulation. They are related to the demands of traffic and the infrastructure supply along the dedicated lane.

Subsection capacity along the dedicated lane

Initially, the total capacity of a given subsection is estimated from the calibrated fundamental diagram. It has been assumed that this capacity is evenly distributed across all the lanes. Since the dedicated lane is likely to operate under its capacity, we compare the scattered plots for general purpose lanes along the dedicated lane in order to assess the drop incurred due to the operation. Only data from 0500 to 1400 are used to avoid the effect of the evening peak period since the dedicated lane is deactivated then. The two figures below depict the changes in subsection capacity on the general purpose lanes:



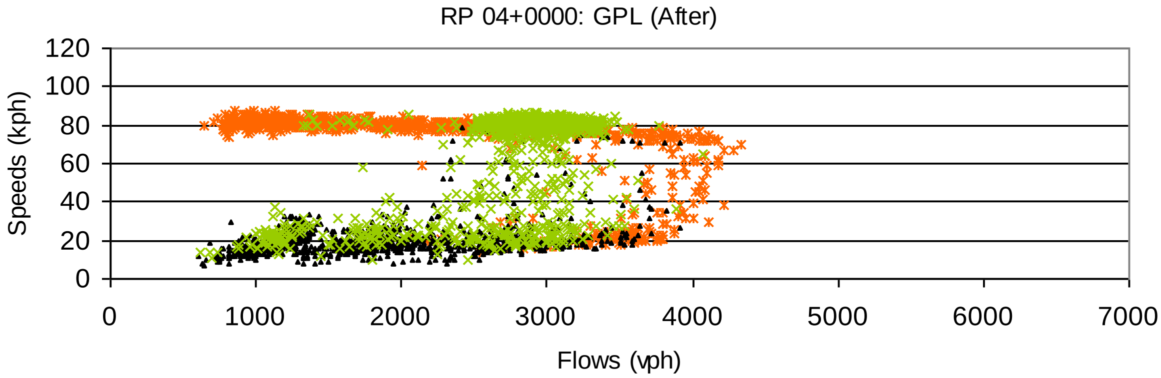


Figure 3- Flow-Speed plot changes on GPL along the dedicated lane

As shown above, capacity drops approximately from 5400 to 4000 vph, which corresponds to a 25% reduction for this 4-lane subsection. The same result is obtained at other locations along the dedicated lane, as assumed.

Traffic volumes on the dedicated lane

Another key assumption of the simulation was related to the demand level on the dedicated lane, as well as drivers' behaviour. In fact, traffic volume was set at 600 vph on the special lane with total obedience from both user categories. As shown in the following graphs, during the mid-term period traffic counts on the dedicated lane reached 800 vph for only the first 1.5 hour of activation. They are higher until deactivation.

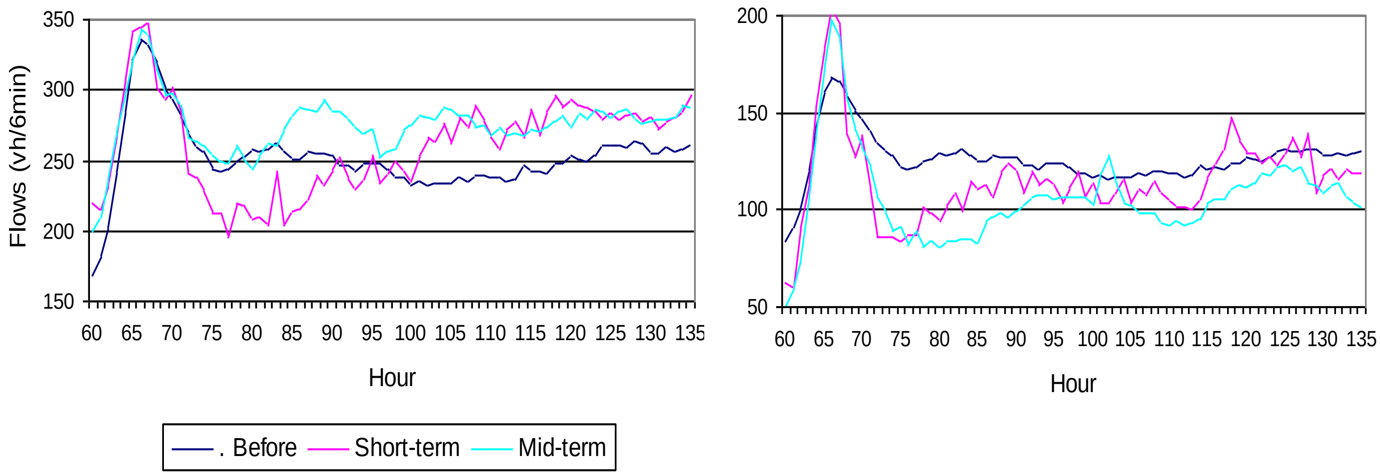


Figure 4- Traffic counts changes on GPL (left) and DL (right)

The short-term period is characterized by a drastic reduction in traffic flows on both lane types during the activation. This is due to the bottleneck B2 which is located at about 500 m upstream of the dedicated lane. Two factors may explain the occurrence of B2. First, more lane changing manoeuvres take place when approaching the facility. The second reason is that most of the traffic is restricted only to a subset of lanes. When capacity is exceeded a queue is formed, which traps even the vehicles moving toward the dedicated lane. We notice that immediately after deactivation (at 1000) flows grow rapidly on the general purpose lanes.

On the other hand for the mid-term period, from 8 am until 1 h 30 pm traffic counts on the GPL are higher than in the reference period. In the meantime fewer vehicles are observed on the dedicated lane. Since no significant changes have been measured on the total traffic volumes in the three (3) periods studied, this can be considered a consequence of the enforcement control. Nevertheless hourly traffic rate on the dedicated lane is still higher (800+) than that used in simulation (600). According to the results, a 200 vph reduction in the traffic volume on the dedicated lane allows a 3-10 minute saving on the general purpose lanes for the entire trip between Roissy and Paris. In the mid-term period, travel times range from 29 to 44 minutes, whilst FREQ simulation predicted 25-34 minutes. These latter values could be thus reached with a better compliance from the motorway users.

CONCLUSION

Most simulation studies aiming at evaluating traffic management operations are microscopic, and thus resource consuming, but they more detailed information for specific traffic movements. Our objective in this study was to show how a macroscopic simulator could be employed to assess lane management operations, using a case study on an urban motorway. The main advantage of macroscopic simulators is that they require a modest amount of data while applying a deterministic approach, with no need for several replications.

In this study, traffic conditions measured shortly after the implementation and after enforcement control took effect were compared with the simulation results. The analysis confirms the assumptions made and the methodology employed for the simulation study. The key findings are presented below:

1. Dedicating an existing lane to special users' categories may create a bottleneck upstream. Two main reasons were identified. First, lane changing manoeuvres are multiplied when approaching the dedicated lane with taxis switching to the left lane at the same time as non authorized vehicles are leaving it. This is confirmed by the on-site measurements which show a transition zone between the new congested area and the upstream end of the dedicated lane. The second reason that can explain the occurrence of the new bottleneck is related to initial traffic conditions and composition on the facility. When the demand level for the remaining general purpose lanes exceeds their capacity, queue spillback may even trap vehicles wishing to reach the special lane.

2. Enforcement controls do have an effect on drivers' compliance as fewer vehicles were recorded on the dedicated lane after violators received their first fines. Comparison between traffic conditions before and after enforcement controls indicates an improvement in traffic conditions on both sets of lanes when 200 vph switched from the dedicated to general purpose lanes. The travel time saving is more than 5-minutes. However, drivers' compliance is not total. There still remain a large number of non-authorized vehicles on the dedicated lane, whose behaviour may disturb the traffic stream since this lane is not physically separated.

3. As for the macroscopic simulation, we notice some gaps at the successive weaving sections. This has been mentioned in the literature as one of the weaknesses of the FREQ model, which uses the HCM1965 method to estimate the capacity of weaving sections. Unlike other studies which address this issue by utilizing microscopic tools for capacity analysis, our next step will be the use of second order macroscopic models.

As a whole, the operation is not likely to achieve its goal, which is to reduce travel times for taxis and buses. The main reason is that those vehicles still enter the pre-existing congestion at the downstream end of the dedicated lane. This result, shown by the simulation model, is confirmed by the on-site measurements. The study shows that macroscopic simulation can be efficiently employed in a priori assessments of the multiple lane management operations that are being planned for the urban motorway network in France.

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