ASSESSMENT OF A DYNAMIC MANAGED LANES OPERATION

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ABSTRACT

This paper presents the assessment of a managed lanes operation tested on the motorway network of the Paris region. The trial consists of opening the hard shoulder dynamically to traffic so as to increase the capacity of the section during high demand periods The prime objective of the operation is to reduce traffic congestion created by a serious recurrent bottleneck. The evaluation is based on a before-after study. It describes the impact on traffic efficiency, environment and safety.

Keywords: managed lanes, traffic efficiency, congestion, environmental impact, safety.

INTRODUCTION

Increasing congestion on most of the motorway networks has led decision-makers to test innovative practices of road use. Strict current budgetary constraints and environmental requirements for a sustainable mobility limit both the building of new infrastructures and the extension of existing networks. Therefore, various methods are being experimented to control traffic congestion and to increase the capacity of the existing infrastructures. The first one is to reserve the use of some lanes for specific categories of vehicles or users. Other techniques can, under certain conditions, increase the number of lanes by redesigning lanes or through the use of the hard shoulder as an additional lane (Kellermann, 2000). Lane management is a concern shared by many operators. Already in use for several decades in the United States in various forms, experiments with managed lanes have increased in recent years in Europe. In several European countries, the best use of the infrastructure is a priority and a privileged theme of investigation (Schrijnen, 2001).

Evaluation of managed lanes operations includes several steps: setting goals and objectives, identifying performance measures and required data, define a methodological framework and report results. Goals and objectives typically focus on mobility and traffic efficiency, environmental impacts and safety.

This paper provides elements to illustrate the above. It is based on the real case of a dynamic managed lanes operation on a weaving section (A4-A86) of an urban motorway of the Paris region. The objective of this operation is to increase, at a lower cost, the capacity of the road section by a dynamic reassignment of the road space. First, the different components of this innovative trial are described. The operating strategy of the dynamic opening and closing of the hard shoulder is then presented. Assessment is then performed based on cost benefit analysis. Various impacts are determined by a comparison with real data. Three domains are considered including traffic efficiency, pollution and greenhouse effect, and road safety. The results of the comparisons show that combining tried and tested technology, infrastructure and management procedures can lead to the best use of the available road space.

THE HARD SHOULDER RUNNING LANE ON A4-A86

The aim of this project, which has been operating on an experimental basis since September 2005, is to implement a solution to optimise the capacity of the existing infrastructure on the common trunk section of the A4 and A86 motorways in the east of Paris.

The context

In the Val-de-Marne department, the common section of the A4 and A86 motorways passes through the city of Joinville-le-Pont on a viaduct and runs parallel to the river Marne for almost 2200m. Until the summer of 2005, the 280,000 vehicles that used this section of the road every day caused some of the largest traffic jams in France: more than 10 hours of congestion per day with tailbacks regularly exceeding 10km. The reason for this is that the two-lane sections of the A86 and the three-lane sections of the A4 come together on this common trunk section, which has only four lanes. As a result, there is insufficient capacity, which leads to recurrent congestion.

The components of the system

The solution that has been implemented since the summer of 2005 allows traffic to use an additional lane (or auxiliary lane) to the right of the carriageway during periods of high demand. This lane uses the hard shoulder and therefore remains closed to traffic outside peak periods. After several months of road works in 2004 and 2005, the widths of the traffic lanes were modified without altering the total width of the motorway and without any major structural works. The width of the lanes was reduced from the standard 3.5m to 3m or 3.20m. Drivers are informed of the opening or the closure of the lane by Variable Message Signs (VMS) in accordance with the layout.

Photo 1. The hard shoulder running lane on the A4-A86 section

In addition, to emphasize the difference between a traffic lane and a hard shoulder when used as a traffic lane, and to show drivers the specific nature of the zone, the additional lane has specific road markings and a light-coloured surface. Moreover, it has been entirely resurfaced with low noise asphalt in order to reduce traffic noise.

Photo 2. Moveable barrier on the hard shoulder running lane of A4-A86

Moveable safety barriers are installed on the right side of the additional lane. When this lane is closed, the device pivots around its upstream end until it forms a lane reduction taper which takes up almost the entirety of the hard shoulder. These closure devices are installed at several key locations on the section so that drivers can see them whatever their position and are thus dissuaded from using the lane. In each traffic direction, the first device encountered by drivers is 69m long and the following ones are 25m long. The barriers were tested between June and October 2004 on a non-traffic experimental site.

Photo 3. Monitoring of A4-A86 with video AID systems

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, leading to the closure. Additional safety is provided by speed control radars on the A4 motorway in both traffic directions.

The dynamic management strategy

In normal mode, the additional lane is opened before the appearance of a recurrent congestion and prevents congestion forming upstream. The opening and closure of this lane are activated from the traffic control center according to the value of the occupancy rate (OCC) measured upstream of the common trunk section (opening if OCC ≥ 20% and closure if OCC ≤ 15%).

In degraded mode, the hard shoulder running lane is opened exceptionally in order to cope with the consequences of a particularly disruptive event (the closure of at least one traffic lane as the result of an incident) that has occurred on the common trunk or downstream. The objective is to speed up the return to normal traffic conditions. This opening must remain compatible with the need of emergency services to be able to reach road users, and with the main occupancy configuration adjacent to the incident. The additional lane is also opened to improve traffic flow in the event of disruptive works (closure of left-hand lanes). An occupancy rate that remains below 15% for some time on the two upstream branches of the common trunk section causes the closure. This closure criterion is still empirical: the operator must ascertain that there is no congestion on the common trunk section and the two upstream branches.

Opening duration

The interest of the hard shoulder running lane is to treat both recurring and non recurring congestion. Table 1 below gives the principal statistics relating to the daily duration of the opening of the additional lane.

Table 1. Duration of daily opening of the hard shoulder running lane

Duration	Working day		Saturday		Sunday	
(minutes)	Towards Paris	Towards province	Towards Paris	Towards province	Towards Paris	Towards province
Minimum	*90*	*54*	*48*	*102*	*72*	*36*
Maximum	*558*	*396*	*534*	*330*	*312*	*384*
Mean	*298*	*236*	*236*	*224*	*196*	*196*
Std deviation	*102*	*92*	*126*	*86*	*64*	*133*

In 2006, the additional lane was opened on average roughly 5 hours per day in the Paris-bound direction on working days, and 4 hours in the opposite direction. On Saturdays, it was opened on average 4 hours towards Paris and 3 hours 45 minutes in the opposite direction. On Sundays, the lane was opened 3 hours 20 minutes in both directions.

IMPACT ON TRAFFIC EFFICIENCY

The operation has been evaluated taking into account its innovative characteristics, in order to identify and measure the impact and usefulness of this new type of road design on traffic efficiency. Observations were conducted on the motorway for six months during April, May and June 2003 before the works and April, May and June 2006 after the works. This resulted in a large body of data covering two situations: as a reference, the existing layout during the year 2003 and the modified layout during the year 2006.

Capacity analysis

The traffic lanes are equipped with double loop sensors which give the basic traffic parameters: flow, speed and occupancy rate aggregated on variable time sequences. This basic data can be used to determine capacity. The recorded data is used to take representative measurement samples of the situations before and after the modification of the layout, and is selected on the following criteria: working day, rate of availability above 70%, homogeneous meteorological conditions, lack of incidents. The weather conditions and the nature of the traffic were similar for equivalent months: dry road surface, high traffic demand, similar percentage of lorries, namely a daily average of almost 8%.

The speed-concentration relationship was calibrated on the basis of measurements over 6min sequences. This calibration can then be used to estimate the main operating thresholds: capacity, free-flow speed, optimal speed at capacity, critical density. Several models were tested including the following forms: Greenshields' linear model, Greenberg's logarithmic model, Underwood's exponential model, May's exponential model and the generalised exponential model. Finally, the formulation chosen and described by Equation (1) is the generalised exponential model of the form:

$$u = a \exp(-b\, k^{\alpha}) \qquad (1)$$

where u denotes the mean speed (in km/h), k the concentration (in veh/km), and a, b and α are three real parameters which have to be adjusted. In all the cases tested, this model produced the best fitting (Cohen, 2004). Note that the parameter a is the free-flow speed, i.e. the maximum speed in very low traffic density. The form of the model means that nonlinear regression techniques must be used to estimate the parameters. From this calibration phase, various parameters are derived, in particular capacity. Numerical values of the models are listed below.

Table 2. Calibrated values of the fundamental diagram

Configuration		a	b	α
Before (2003)	towards Paris	85	2.6×10^{-6}	2.38
	away from Paris	104.5	1×10^{-5}	2.19
After (2006)	towards Paris	90.25	2.9×10^{-6}	2.36
	away from Paris	93.67	8.1×10^{-7}	2.6

Figure 2 illustrates the variations in the flow and speed measurements made on the common trunk section in the direction away from Paris. With the additional lane open there is a very marked increase in flows, particularly at full capacity.

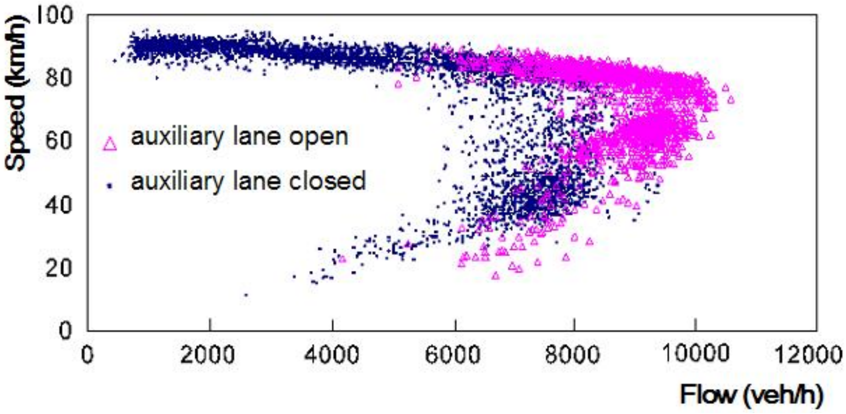

Figure 2. Speed/flow measurements, hard shoulder running lane open or closed

The capacity in the different configurations is estimated from the generalized exponential model. The main results are set out in Table 3. The effects of using the additional lane are apparent in both traffic directions, although they differ in degree.

Table 3. Capacity of the common trunk section, before and after

Capacity (veh/h)	Before (2003) *4 lanes + hard shoulder*	After (2006) *4 lanes + auxiliary lane closed*	After (2006) *4 lanes + auxiliary lane open*	Deviation (veh/h)
A4 towards Paris	*8670*	*7610*	*9310*	*640*
A4 away from Paris	*8820*	*8185*	*9725*	*905*

In the Paris-bound direction, the gain in capacity observed on the common trunk section is approximately 7.5%, i.e. 650veh/h. In 2003, the section with 4 lanes and a hard shoulder had a capacity of approximately 8700veh/h. In 2006, the capacity obtained with the additional lane open exceeded 9300veh/h. When this auxiliary lane was closed, the maximum flow was only 7600veh/h. The drop in the capacity is mainly due to the effect of narrowing lanes as described previously. In the direction moving away from Paris, the gain is even greater. The increase in capacity is about 10%, i.e. 900veh/h. In 2003, the section with 4 lanes and a hard shoulder had a capacity above 8800veh/h. In 2006, capacity with the additional lane open was around 9700veh/h. With the lane closed, the maximum flow was approximately 8200veh/h.

Level of service analysis

The concept of level of service refers to the traffic conditions observed locally on the common trunk section. Research on this area in France has led to the adoption of the following classification with 4 levels: free flow, free flow to dense traffic, flow at capacity, saturation. Using the additional lane on the common trunk section leads to a marked improvement in the level of service on weekdays, as shown in the charts below. Today, in comparison with the previous situation in 2003, there is an increase in operating time in free flow and fluid to dense traffic conditions and a correlative reduction in congested traffic conditions.

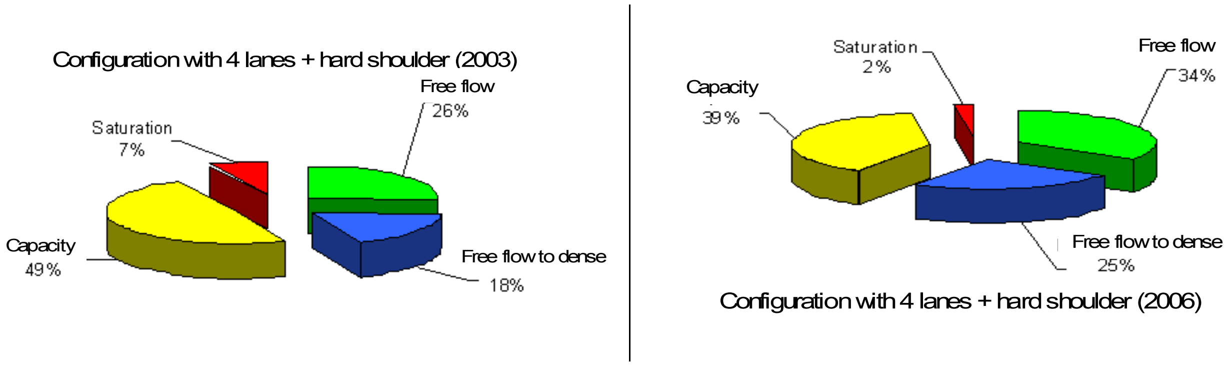

Figure 3. Time distribution of the levels of service on weekdays
(before (2003) and after (2006) modification)

The impact on free speed

Free speed (or maximum speed) is observed at very low flow rate. It is estimated on the basis of the calibration of the speed-flow relationship. At low traffic, the before-after comparison provides the following elements. In the Paris-bound direction, free speed increases up to the maximum speed limit of 90km/h. In the opposite direction, free speed falls by 10km/h so as to approach the speed limit. It seems that the automatic speed enforcement cameras influence free speed rather than the opening or the closing of the additional lane. These cameras were installed in 2005, in the context of the new speed enforcement policy in France.

Table 4. Evolution of free speed

Site	Period	Managed lanes	Free speed (km/h)
A4 towards Paris	before	4 lanes + hard shoulder	85
	after	4 lanes + peak lane closed	90
	after	4 lanes + peak lane open	90
A4 away from Paris	before	4 lanes + hard shoulder	104.5
	after	4 lanes + peak lane closed	94
	after	4 lanes + peak lane open	94

The impact on local speed

The data sets correspond to the speed measurements taken every 6 minutes from the two measuring stations located on the common trunk section. The average situation was computed over the observation period, between 6am and 10pm and gave the following results.

Table 5. Characteristics of the local speed

Local speed (km/h)	towards Paris		towards Province	
	before	after	before	after
Minimum	40	59	53	55
Maximum	86	92	104	92
Average	58	72	72	71
Standard deviation	11	8	15	10

The following time series illustrates the evolution over 6-minute intervals. For the period between 6am and 10pm, the average speed improves in the Paris-bound direction, rising from 58km/h to 72km/h. In the opposite direction, the variation goes down slightly from 72km/h to 71km/h.

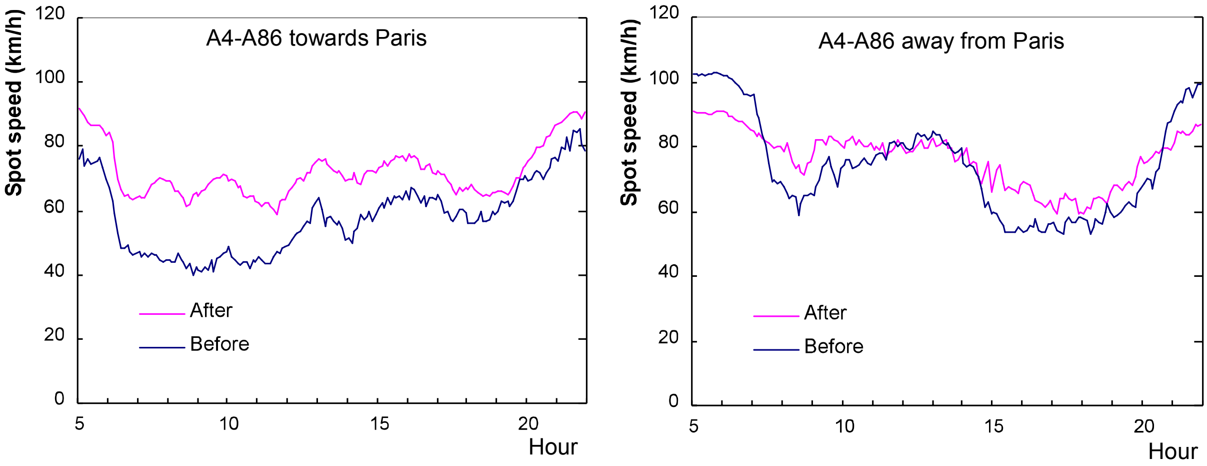

Figure 4. Impact of the modifications on the local speed

In both directions the net effect of the official 90km/h speed limit, monitored by the automatic speed cameras, is obvious. Average speed, measured over 6-minute intervals, does not exceed 90km/h in the new current configuration. Towards Paris, there is an improvement in local speed for the whole period between 6am and 10pm, with a significant variation of about 20km/h during the morning peak when the additional lane is generally open. In the opposite direction and during the morning peak as well as the evening peak with the lane usually open, the local mean speed is about 10km/h higher than before the modification.

The impact on average travel speed

Average travel speed is measured on the road network influenced by the A4-A86 common trunk section. This network is defined as all the roads which are directly affected by any major change in the traffic conditions on the defined section. This network includes, on the

A4 motorway, the part between Noisy-le-Grand and Bercy, and, on the A86 motorway, the part between Rosny and the Pompadour intersection.

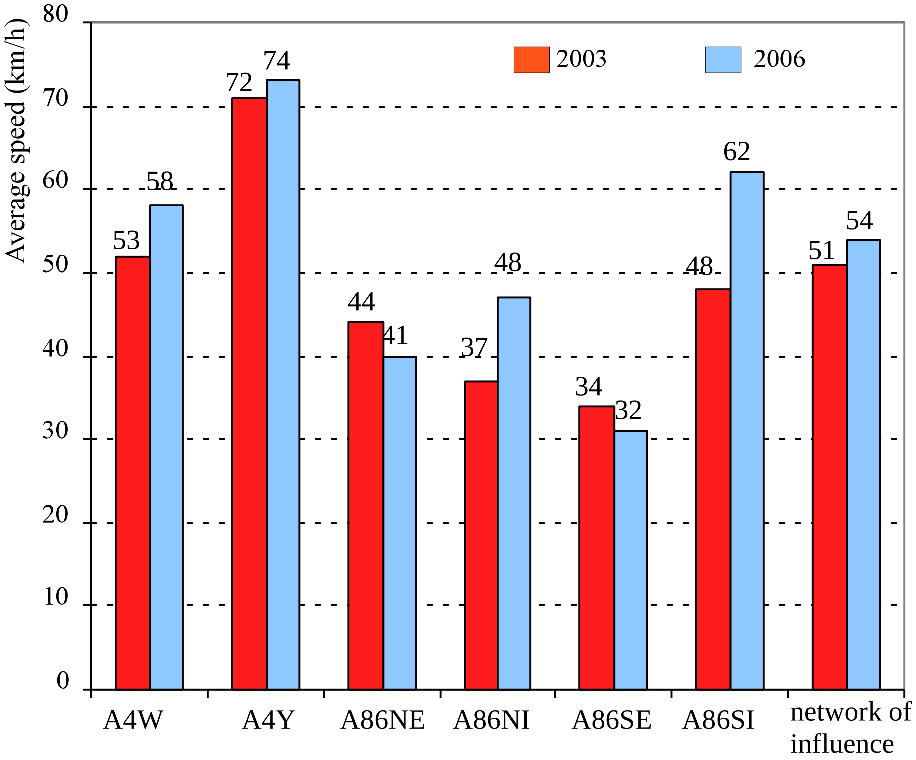

Figure 5. Changes in travel speed before/after the modification

The effects on average travel speed on the roads influenced by the A4-A86 section are generally positive, as shown in figure 5: there has been an improvement, in some cases a spectacular one, on four of the six routes analysed and a limited deterioration on the other two.

The impact on congestion

Traffic mapping makes it possible to draw automatic maps of the traffic conditions. The various recurrent traffic peaks are identified with their characteristics in terms of duration, length and intensity, on the layout and its zone of influence. Four contour levels are defined according to the average speed thresholds: 60, 45, 30 and 15km/h. Figure 6 illustrates, for one axis and one direction, the speed contours of the traffic peaks between 12pm and 00am, in the two situations before (2003) and after (2006) the modification.

On the part of the A4 motorway between Bercy and Noisy-le-Grand, there is a clear improvement in traffic conditions upstream of the common trunk section in the evening, during which time the additional lane remains open. This improvement is marked by a significant reduction of approximately 1.5km in the length of the congestion zone on the A4 upstream of A4-A86. It is also characterised by a big reduction in the recurrent bottleneck upstream of A86-A4.

Only one weak congestion point remains on this section. The duration of congestion is reduced by approximately one and a half hours. The improvement in traffic speed in the congestion area can be seen by the disappearance of the slowing zone which is usually observed, with a mean speed less than 30km/h.

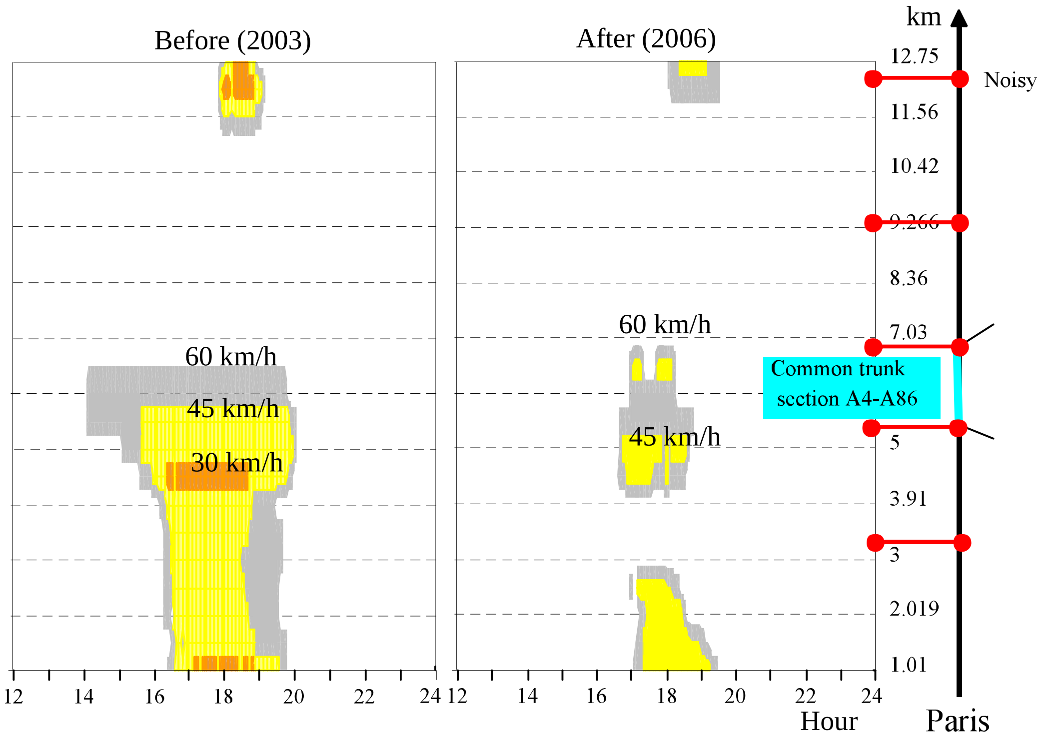

Figure 6. Speed contours during recurrent traffic peaks on A4

Lastly, it is important to note that there is no major change to the extent of the congestion downstream of the A4-A86 section. This shows that the local improvement of the capacity of A4-A86 does not create any downstream bottleneck.

Global quantitative indicators

Other global quantitative indicators give more precise details of the changes. They concern the total distance travelled by vehicles, the total time spent in traffic and the congestion index. This indicator describes the extent of the congestion and corresponds to the product of network length – relative to one lane and with a congested traffic condition (speed ≤ 30km/h) – and congestion duration. These indicators are compared per axis and per direction on a daily basis, before and after the modifications were introduced.

For any one working day, the relative variations of the indicators are characterised by a small reduction in the total distance travelled (-1.1%) associated a substantial drop (approximately 7%) of the total time spent in traffic. There is also a reduction (-6%) in congestion index. If these indicators are taken only at peak periods, during which the additional lane is open, the performance of the dynamic system put in place becomes apparent: the total time spent in traffic decreases (-5%), as does the congestion index (-19%), despite the heavy increase in traffic (+7.5%).

IMPACT ON POLLUTION

The environmental assessment is based on real traffic data associated with suitable models for the various pollutants and the fuel consumption. Models are extracted from the COPERT library [5]. The formulations take into account the mean speed of vehicles as main parameter to calculate fuel consumption and emissions of pollutants. The COPERT models also integrate the main technological developments as well as the European regulations. The before/after study makes it possible to quantify the variations of the emissions of pollutants and fuel consumption. The calculation is carried out for the whole network of influence of the A4-A86 section. Two categories of vehicles, passenger cars and lorries, are taken into account.

Daily emissions

The daily emissions, indicated in Table 6, relate to the main pollutants: carbon monoxide (CO), oxides of nitrogen (NOx) and other pollutants like the dioxide of sulphur (SO_2), fine particles (PM10 of which PM25) and many organic compounds (COV).

Table 6. Relative variation of emission of pollutants

	Working days		
Gramme (g)	Before (2003)	After (2006)	Variation
CO	4 006 416	2 446 907	-38.93%
NO_x	3 843 176	3075604	-19.97%
SO_2	139 653	21 082	-84.90%
Particles	237 589	163 832	-31.04%
COV	670 957	400 771	-40.27%

The results underline the performance and the effectiveness of the dynamic use of the peak lane. Between the configurations before (2003) and after (2006), all the categories of pollutant emissions decrease, as illustrated in figures 4-1 and 4-2. The reduction goes from 20% for oxides of nitrogen to more than 85% for the dioxide of sulphur. For gases for purpose of greenhouse, the before/after assessment leads to a reduction of 4.25% of the emissions.

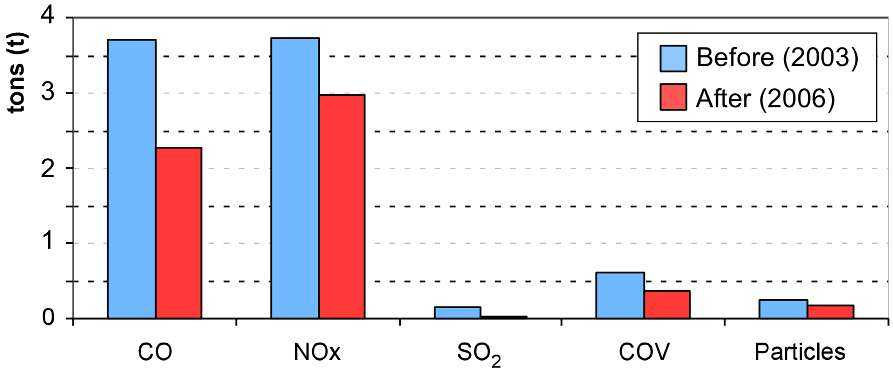

Figure 4.1. Daily evolution of the emissions of pollutants

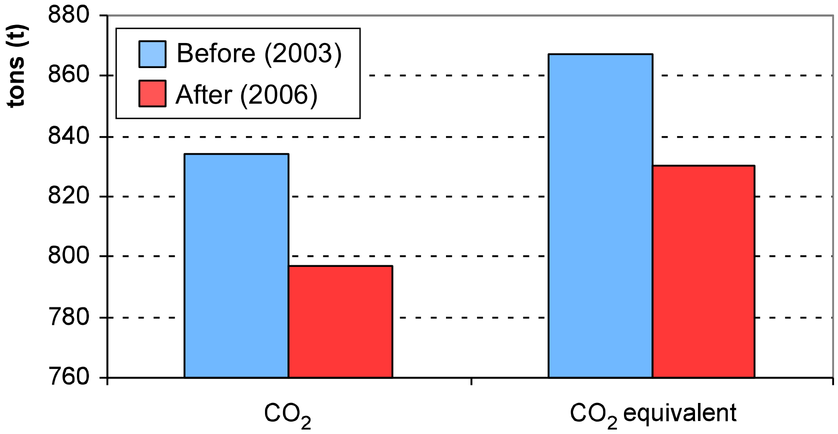

Figure 4.2. Daily evolution of CO_2 and equivalent CO_2

The following figure illustrates the reduction in the fuel consumption resulting from the dynamic use of the peak lane. The diminution reaches 15% approximately for the vehicles with gasoline and 1% approximately for the diesel.

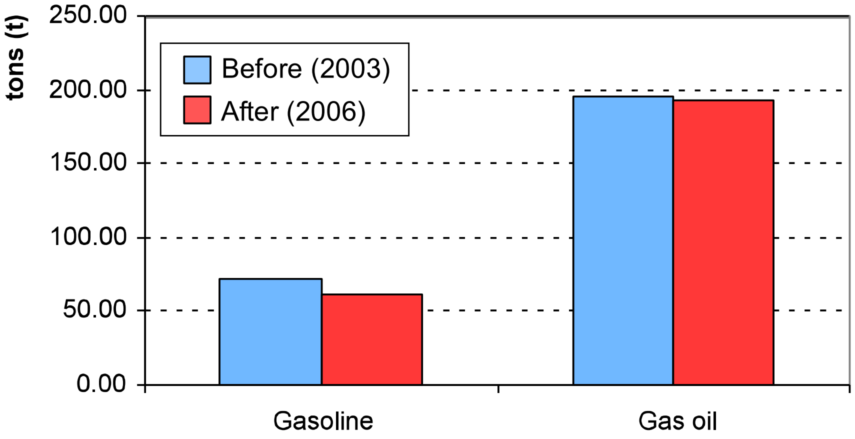

Figure 4.3 - Daily evolution of fuel consumption

The various results presented here underline the positive evolution on the environment from the comparison 2003/2006. The principal emissions of pollutants and gas for purpose of greenhouse just like the consumption of energy decrease. This reduction comes mainly from the improvement resulting from the use of the peak lane but also, to a lesser extent, as an effect of the regulation, and of the evolution of the fleet of vehicles and between years 2003 and 2006.

IMPACT ON SAFETY

Assessment method

The method for assessing the safety impact of a managed lane strategy is based on the work of Hauer (1997). It requires accident and traffic data for a period *before* the installation of the assessed system and a period *after* this installation. Injury accidents are taken from a French data base. Police reports are also analysed. As concerns traffic data, a variation in the total volume of traffic leads to a variation in the number of accidents. In addition, the levels of flow, speed and occupancy are linked to the accident rate, which leads to define traffic scenarios, and to analyze and extrapolate the number of accidents by traffic scenario. Here traffic flow, average speed and occupancy are available every six minutes. Furthermore, as the accident rate is multiplied by two during rainfall, it is necessary to check if there is a difference in rainfall during the *before* and *after* periods (Golob, 2003).

A first step of the method consists in defining the assessed site. Some authors such as Bauer (2004) think a downstream migration of congestion and accidents is possible. Therefore the impact on safety must be assessed on the weaving section, supplemented by downstream sections. We also added upstream sections, which were similarly concerned by congestion moving backwards. We note as “whole site” the set of the weaving, downstream and upstream sections.

A second step consists in defining a period *before* (period I) and a period *after* (period II). A third step consists in defining a reference site. A last step consists in predicting, on the basis of the data of the period I, the number of accidents which would have occurred during the period II on the assessed site, had no change been made. This prediction is described in detail in Aron et al (2009). It is then compared with the accidents which actually occurred.

Application of the method

The safety impact is computed on the weaving section itself and also on upstream and downstream sections, which can be influenced indirectly. In order to make the comparisons, some periods of fictitious opening for 2000-2002 (Period I) were reconstituted from the actual opening periods in 2006 (Period II) based on time and date.

As this weaving section was the most congested site in France, it was difficult to select a reference site, the evolution of which would have been a basis for predicting the evolution of the weaving section, had no change been made. We decided to use the whole site itself (the weaving section complemented by the upstream and downstream sections) during the time when the additional lane is closed. However, since the traffic is lighter during this period, the scenario approach is needed.

If we do not consider the scenario approach (i.e. if we ignore the difference between the traffic scenarios distributions during closing hours (the reference) and during opening hours), the assessment of the managed lane system on the weaving urban motorway section A4-A86 shows a non significant 8% reduction in the number of accidents when the additional lane is opened on the managed lane section and a non significant 5% increase in the number of accidents on the whole site (weaving section, upstream, downstream). This is in accordance with Urbanik and Bonilla (1987), who showed that increasing the number of lanes by decreasing the width of each lane leads to an increase in the accident rate near the downstream end of the section. Robert in 't Veld (2009) found that traffic safety (specified by the number of accidents with injuries) in the Netherlands on the routes with existing rush hour lanes and with those that still need to be constructed has decreased a little bit more than on the whole network of main roads (13% instead of 12%).

If we take the difference between the traffic scenarios distributions into account, assessment shows a non significant 3% reduction in the number of accidents when the additional lane is opened on the whole site (weaving, upstream, downstream sections).

A FINAL BALANCE

The socio-economic assessment of the operation is based on the cost benefit approach. The impacts taken into account include the time savings and the effects on the environment (excluding noise). Each scenario before and after is then characterized by the total of its monetized effects.

On the motorway network of influence, the reduction in the total time spent leads to a saving of 4 549 veh.hr during the working days, 3 094 veh.hr on Saturdays and 3 958 veh.hr on Sundays. On the basis of the value of time used in public economic calculation, the annual profit of time realized in 2006 compared to 2003, amounts to 1 226 906 veh.hr, that is to say a valorization of 16,4 M€.

On the same network of influence, the reduction in the principal emissions of pollutants, gases for purpose of greenhouse and fuel consumption leads in 2006 to an effective annual saving of 3,145 M€ in comparison to the situation of reference in 2003.

In light of the total annual gains (excluding noise) estimated at 19,5 M€, the initial investment of 19 M€ is thus recovered in one year.

CONCLUSION

In order to control congestion in the context of a sustainable mobility, motorway traffic managers and decision-makers are testing innovative use of the road as dynamic managed lanes. The operation launched on the common A4-A86 trunk motorway section near Paris has already become a reference in France. The devices set up on this site as well as the dynamic strategy tested have been the subject of an in-depth assessment. The results reveal significant gains in terms of improved traffic efficiency, environmental effects and socio-economic profitability.

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