TOPIC 18
ENVIRONMENT AND
SUSTAINABLE MOBILITY

A METHOD FOR ASSESSING ENERGETIC AND ENVIRONMENTAL IMPACT OF TRAFFIC CHANGES IN URBAN AREAS USING INSTRUMENTED VEHICLES

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Abstract

A method has been developed to assess the real impact of changes in the traffic control systems implemented in Amiens—1992—and in Niort on trip duration, vehicle speeds and accelerations, fuel consumption and pollutant emissions. This method is based on in-situ measurements using vehicles operated under real-world driving conditions, along preselected routes and at different times, over a 15-day period "before and after" the implementation of the new systems.

INTRODUCTION

Systems aimed at controlling traffic lights are often considered as a tools for reducing trip duration, fuel consumption and pollutant emissions from the vehicles. In order to assess the impact of such alternatives, a method using instrumented vehicles operated before and after the implementation of such systems has been developed and applied to two cases: in Amiens, where the traffic control system installed at 45 junctions had been extended to 68 traffic lights after optimization; in Niort, a new dynamic management system had been implemented at 47 junctions (Prodyn system including loops distant from the junctions with an interaction between close junctions). A calculation model for pollutant emissions was used to process an environmental assessment in Niort.

METHOD

In the selected areas, routes were determined according to the changes brought to the control systems, in co-operation with the city technical departments, on the basis of traffic-related statistical data recorded in Niort. These include main and secondary roads.

In Amiens, five routes (four of which in both directions) were selected in the controlled area. Route 1 (Georges Clémenceau—rue de Paris) is a north-south two-way arterial of 2.4 km long, including in its central section some narrow streets of the city centre. Route 2 (Faidherbe—Pont Noyelles, 2.9 km) is a west-east road including only narrow streets of the city centre and intersecting the main north-south arterials. Route 3 (Marechal Foch—Jacques Duclos, 4 km) follows the ring boulevards of the historical centre. Route 4 (Beauvillé—Port d'Aval, 1.7 km) is an east-west arterial, including main two-way avenues. Finally, route 5 (outer boulevards, 3.7 km) runs along south outer boulevards (André, Roumégoux et al. 1994).

In Niort, routes were selected in an area where 16 junctions were to be modified (south-west of the city): a route including south-west two-way boulevards (Boulevards Atlantique and Wellinborough—about 7.0 km) and two routes leading to and from the city centre in both directions (Routes Tour Chabot—La Rochelle, 3.3 km; and Wellinborough—La Rochelle: 5.3 km), along centre streets and through suburban residential and industrial areas (André, Vidon et al. 1994).

Trips were performed at four different times of the day (during peak hours in the morning and in the evening, and during off-peak hours), and by night in Niort. Two vehicles (a Renault Super 5 with a 1300 cm^3 engine, and a Renault 21 GTS or Peugeot 405, with a 1700 cm^3 engine, previously tuned), were equipped with systems aimed at recording the distance travelled and the vehicle speed, the engine rotation speed and fuel consumption at second time intervals. Trips were performed with a hot engine.

In Amiens, the vehicles have always been driven by the two same drivers simultaneously, but not in the same areas. In Niort, the vehicles have been driven by 2 sample groups including 8 Niort drivers (different samples for the two experiment stages: before and after the implementation of control systems), providing for a certain diversity in terms of age, sex and family and occupational status. This approach offered more realistic test conditions, but yielded a greater variability of results. In addition, two technicians in charge of experiment monitoring performed tests in the evening to extend the test scope to off-peak hour periods.

Two experiment stages were performed for two consecutive weeks at a 12-month time interval (18 months in the Niort case), before and after the changes or the implementation of traffic light control systems. Vehicle flows were simultaneously recorded by the technical departments of both towns at different route points. Preliminary tests were performed to identify the routes to be selected, to determine in-situ operating conditions of the vehicles, to measure fuel consumption on a test bench, and to calibrate the distance between junctions to be taken into account for the experiment.

AVERAGE TRAFFIC CHARACTERISTICS

Globally, 766 routes were followed and correctly recorded in Amiens, and 682 in Niort, ie 85 and 110 recorded measurements respectively for each route. Traffic conditions measured in Niort were far better than those observed in Amiens (Table 1).

Average traffic characteristics measured in Amiens

Average trip durations for the various routes range from 5 to 13 minutes, over distances ranging from to 1.7 to 4.9 km. Average speeds are very low: they vary from 16 to 30 km/h as a function of the route studied. Standard deviations correspond to 25 to 30% of the mean values. Maximum average speeds do not exceed 40 km/h (except for outer boulevards). Minimum speeds range from about 10 to 15 km/h. Average speed calculated over the whole test period is 22 km/h and running speed is 33 km/h.

A great number of stops is observed: 3 to 9 stops on average as a function of the route, ie 0.8 to 3.3 stops per kilometer (2.0 on average); the maximum recorded is 20 stops. Idling durations (intersections, congestions, etc.) are very significant. They amount to about 37% of total duration in the before implementation stage, from 24% for the outer boulevards up to 47% for boulevards located in the historical centre.

Average traffic characteristics measured in Niort

Average trip durations for the various routes range from about 8 to 14 minutes, over distances ranging from 3.2 to 7 kilometers. Average speed recorded over the whole test period is 28.5 km/h and ranges from 23 to 35 km/h as a function of the route selected. Average speed, not including stop periods, is 38 km/h. Minimum average speeds recorded range from about 15 to 16 km/h along the routes in the city centre Tour Chabot—La Rochelle. Average maximum speeds reach 65 km/h on the Atlantique—Wellinborough boulevards for outward trips, and 56 km/h for return trips.

For all the routes, the average stop number is 6.5 (ie 1.3 stop per kilometer, 0.8 to 1.9 as a function of the routes). Average stop duration corresponds to 25% of the total trip duration on average, and—as a function of the route—it ranges from 22% (Boulevards Atlantique—Wellinborough) to 28% (city centre).

Table 1 Average traffic characteristics measured in Amiens and in Niort

	Average speed (km/h)	Running speed (km/h)	Stop duration (in %)	Stop rate per km
Amiens	22	33	35	2.0
- variations for the different routes	16-30	26-39	20-41	0.8-3.3
Niort	29	38	25	1.3
- variations for the different routes	23-35	32-43	22-28	0.8-1.9

VARIABILITY OF RESULTS

Trip durations, idling durations and fuel consumption can significantly vary for a same route, since time is the most important factor of traffic condition variations. Thus, in Amiens, maximum trip durations can be twice higher than the mean value, and 4 times the minimum duration. Measurement standard deviations correspond to 30% of average values. The highest duration values are nearly always observed over the 5—6.30 pm period, the lowest ones over the 9—10.30 am period, the ratio between the two values ranging from 1.2 to 2 (Figure 1). Result variability is lower in Niort where maximum trip durations are higher than the mean value by only 50%, and are three times the minimum values (standard deviation of about 20% as compared to average values).

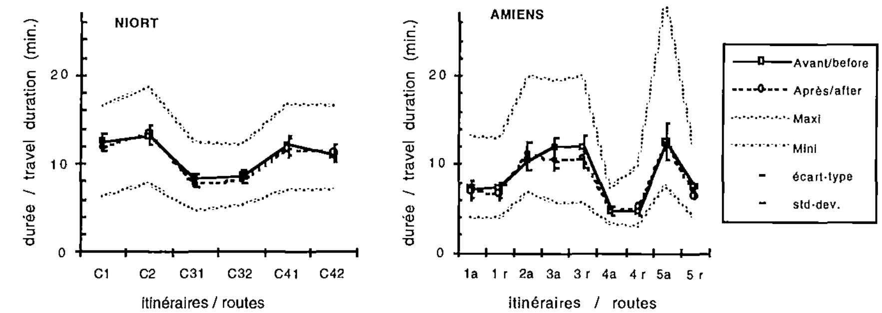

Figure 1 **Variations of trip durations for test routes in Amiens and Niort, before and after the improvement of the traffic control systems (standard-deviation and mini-maxi values)**

IMPACT OF CONTROL SYSTEM CHANGES IN AMIENS

Comparing average values in Amiens

A comparative analysis related to trip durations, idling durations, fuel consumption, etc..., was performed over values recorded before and after the extension and optimization of traffic control equipment, using variance analyses (Tables 2 to 5, and 7). All routes being considered, trip durations do not significantly differ between the two measurements stages, but significant reductions were measured on the centre boulevards (route 3, outward and return trips,—11% and—13%) and outer boulevards (route 5,—14%). These reductions correspond mainly to off-peak hours (up to 20% for a number of routes). Conversely, a significant increase in trip durations was observed on the east-west arterial (route 4, return trip, + 14%, up to 29% for off-peak hours) intersecting the north-south arterial (1) and the centre boulevards (3). During the morning peak, a decrease in trip duration is to be noted on the outer boulevards (-16%); in the evening, trip durations are reduced for the centre and outer boulevards (route 3, outward trip and route 5, return trip, -13 and -12%), but are increased for routes through the city centre (route 1, outward trip and route 2, + 15 and 13%).

The most significant gains are observed for idling durations, which are significantly reduced by 16% between the two experiment stages (dropping to 33% of the whole trip duration, against 37% in the before implementation stage). The most significant reductions are related to the centre boulevards (route 3, outward and return trips, -34 and -26%), the west-east road (route 4, outward trip, -24%) and outer boulevards (route 5, return trip, -44%). These reductions vary according to time periods: north-south arterial (route 1, outward trip), except the evening hour, centre boulevards (route 3, outward and return trips, from -20% during peak hours to -45% during off-peak hours) and outer boulevards (route 5, return trip, -30% to 60%). In the same way, a reduction in the stop number is to be noted (on average 6.4 stops per route in the before implementation stage, and 5.9 after).

Table 2 Average traffic characteristics in Amiens, before and after the implementation of the improved traffic control systems

Routes	Distance (km)	Average duration (min)		Relative stop duration (%)		Distance between stops (m)	
		before	after	before	after	before	after
Global	(3.06)	8.64	8.29	37.0	32.5	481	515
north-south arterial (1a)	2.43	7.1	6.9	35.7	34.7	457	510
north-south arterial (1r)	2.46	7.3	6.7	32.9	30.6	437	655
east-west secondary arter (2)	2.92	10.4	11.3	37.6	38.6	343	304
centre boulevards (3a)	4.01	11.9	10.4	47.2	35.4	456	520
centre boulevards (3r)	3.96	12.0	10.7	42.9	35.6	433	503
main east-west arterial (4a)	1.72	4.9	4.7	40.8	32.5	522	531
main east-west arterial (4r)	1.71	4.6	5.3	31.2	30.9	473	376
outer boulevards (5a)	4.85	12.6	12.6	33.4	31.0	540	539
outer boulevards (5r)	3.68	7.6	6.5	24.2	15.9	795	1193

Table 3 Variations of travel and stop durations in Amiens, before and after the implementation of traffic control systems, versus time (statistically significant in bold)

Routes	duration gains (%) versus time					stop duration variations (%) versus time				
	Global	7-8h30	9-10h30	15-16h	17-18h30	Global	7-8h30	9-10h30	15-16h	17-18h30
Global	-4	-6	-9	-11	2	**-16**	-15	**-29**	**-28**	-7
1a	-3	-9	-17	-4	15	-5	-17	**-37**	-16	**47**
1r	-8	-6	-12	-10	-7	-15	-13	-14	-13	-19
2	9	1	0	11	**13**	12	1	-6	16	16
3a	**-13**	-8	**-22**	**-14**	**-13**	**-34**	-22	**-59**	**-43**	**-28**
3r	**-11**	-9	**-20**	**-23**	-5	**-26**	**-23**	**-55**	**-45**	-13
4a	-5	**16**	-9	-12	-11	**-24**	39	**-40**	**-41**	**-34**
4r	**14**	8	**29**	15	4	13	-16	69	**23**	**1**
5a	0	-9	10	-14	-4	-7	-21	26	-31	-16
5r	**-14**	**-16**	**-18**	**-19**	**-12**	**-44**	**-45**	**-58**	**-60**	**-29**

Average speeds increase significantly on centre boulevards (route 3, +11 to +14%), and outer boulevards (route 5, return trip, +17%), ie gains range from 1 to 5 km/h, and decrease on the east-west arterials (route 4, return trip, -12%). These variations are mainly due to reductions in stop number and idling duration, as traffic speeds (exclusive of stops) do no increase (on the centre boulevards (3); average speed increases by 3 km/h as running speed decreases by 2.5 km/h). As a function of the route studied, average speeds range from 17 to 20 km/h during peak hours, and from 22 to 30 km/h during off-peak hours (Tables 4 and 5).

Table 4 Speeds versus experiment stages and routes in Amiens

Routes	Average speed (km/h))		Running speed (stops excluded) (km/h)	
	before	after	before	after
Global	21.3	22.1	33.8	32.7
north-south arterial (1a)	20.5	20.9	31.9	32.0
north-south arterial (1r)	20.3	22.0	30.2	31.6
east-west secondary arterial (2)	16.9	15.6	27.1	25.3
centre boulevards (3a)	20.1	23.1	38.2	35.7
centre boulevards (3r)	19.9	22.2	34.9	34.5
main east-west arterial (4a)	21.1	22.2	35.7	32.8
main east-west arterial (4r)	22.2	19.6	32.2	28.3
outer boulevards (5a)	23.1	23.1	34.7	33.4
outer boulevards (5r)	29.0	33.9	38.3	40.3

Table 5 Average speed and running speed versus time (all routes being considered)

Time	Average speed (km/h)		Running speed (km/h)	
	before	after	before	after
7-8.30 am	20.1	20.9	32.2	31.7
9-10.30 am	26.5	28.8	39.1	38.3
3-4 pm	22.4	24.6	35.1	34.9
5-6.30 pm	17.0	17.4	28.9	28.0

Fuel consumptions (Amiens)

Fuel consumptions were measured for each gear ratio, first on a test bench before each experiment stage, and then in-situ, during test performance. In-situ fuel consumptions are significantly higher than those recorded on the test bench, since they were measured essentially under unstationary operating conditions (Table 6).

Table 6 Fuel consumptions measured, during the tests performed on the road and on a chassis dynamometer, for each experiment stage (before and after)

	Renault 21				Renault 5			
Fuel consumption	In situ		On bench		In situ		On bench	
litres/100 km, l/h	phase 1	phase 2	phase 1	phase 2	phase 1	phase 2	phase 1	phase 2
1st gear	27.5	20.4	-	-	25.5	24.6	-	-
2nd	13.3	11.2	9.4	6.9	11.7	10.6	7.2	6.5
3rd	9.1	7.7	6.5	5.0	7.4	6.5	4.8	5.3
4th	7.1	5.6	5.4	4.1	5.4	5.1	3.9	4.9
5th	-	3.8	-	-	4.3	5.8	-	-
idle (l/h)	0.8	0.4	0.9	0.56	0.9	0.8	0.7	0.75

Table 7 Comparison of calculated fuel consumption versus vehicles and time (variations before-after in %, statistically significant variations in bold)

Variations of fuel consumptions (in %)	Variations according to vehicles			Variations according to time			
Routes	Global	R 21	R 5	7-8h30	9-10h30	15-16h	17-18h30
Global	-3.3	-4.6	-2.0	-4.3	-5.5	-7.6	0.9
north-south arterial (1a)	-2.1	-1.3	-3.0	-5.2	**-7.8**	-2.7	5.1
north-south arterial(1r)	**-7.4**	-7.4	-7.5	-5.1	-9.8	-10.6	-6.5
east-west secondary arter (2)	5.8	0.9	10.6	0.3	-0.7	7.2	**10.8**
centre boulevards (3a)	**-7.5**	-6.1	**-8.6**	-5.3	**-10.4**	**-7.2**	**-8.5**
centre boulevards (3r)	**-6.6**	-7.4	-4.7	-6.1	**-10.5**	**-12.2**	-3.7
main east-west arterial (4a)	-3.3	-1.6	-4.4	**9.6**	-6.0	-7.4	**-8.0**
main east-west arterial (4r)	**6.1**	4.9	6.7	1.8	**12.1**	6.1	1.7
outer boulevards(5a)	-0.5	0.5	-1.2	-4.7	4.0	-7.4	-4.1
outer boulevards (5r)	**-9.1**	**-5.1**	**-12.6**	**-9.7**	**-9.7**	**-11.9**	**-9.0**

Consumption variations measured between the two stages are very significant, even inconsistent: for the R21 vehicle, reductions of about 23 to 27% were recorded on the test bench, and 15 to 26% on the road; for the R5 vehicle, increases observed range from 9 to 25% on the test bench, and reductions from 4 and 12 % were recorded on the road. Nevertheless, global average values on the road are relatively consistent for the R5 vehicle (9.6 and 9.4 l/100 km), but significantly differ for the R21 vehicle between the two series of measurement (11.1 and 8.4 l/100 km, ie -24%). This demonstrates the weak point of such consumption measurements despite the precautions taken as related to equipment and vehicles, and leads to treat with caution the results of such a type of assessment, ie based on vehicle fuel consumption data.

To solve these problems, a fuel calculation model has been developed from recorded data. For each experiment stage and each vehicle, the best form for the calculation model has been investigated using the step-by-step multilinear regression method, including the most pertinent parameters successively. The parameters eventually selected are: idling and running durations, distance travelled and the number of stops along the route. The model has been constructed specifically for each route, including "before" and "after" implementation stage recordings, in order to take account of the traffic conditions of both experiment stages.

Assessing the energetic impact of changes brought to traffic light control equipment, from calculated fuel consumption data and applying this model to the kinematic data recorded in Amiens, led to a global reduction in consumptions between the two experiment stages, for both vehicles (3 to 4 %), and specifically for route 1, return trip (north-south arterial), route 3, outward and return trips (centre boulevards), and route 5, return trip (outer boulevards), with reductions ranging from 7 to 9%. Mean values are significantly different with a 5% probability. For routes 2 and 4, return trips (east-west arterial), fuel consumption is increased by 6%. A number of significant gains are observed during peak hours. Globally, the number of conditions involving energy savings is higher (11 cases) than the number of fuel consumption increases (3 cases, Table 7). Significant variations range from 7 to 12%.

Traffic condition changes affect consumptions significantly: maximum values observed are usually twice higher than the lowest consumption values and 1.7 times higher than mean values. Consumptions values ranging from 15 to 18 l/100 km are reached where consumptions ranging from 6 to 8 l/ 100 km could be observed (Figure 2).

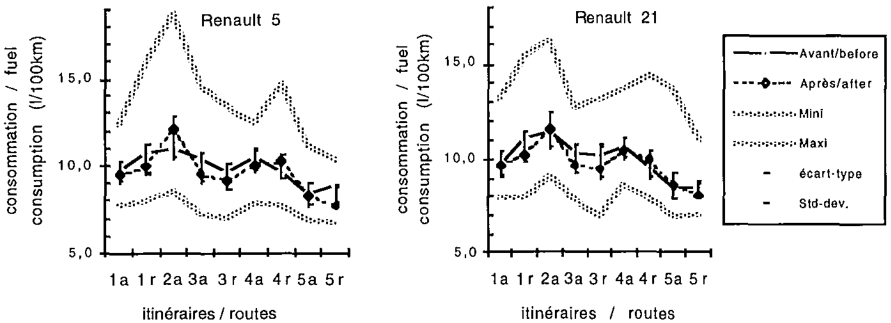

Figure 2 **Average fuel consumptions in Amiens versus routes before and after changes in traffic control systems, and variations (standard-deviation, minimum-maximum values)**

Assessment over all selected routes (Amiens case)

Variations measured between 2 successive intersections (duration, consumption, etc.) and corresponding traffic data were used to draw up conclusions before and after equipment implementation, and therefore to quantify actual gains. Various values (related to traffic, durations, consumptions, etc.) were calculated for each section between two successive intersections and for each time period. The values obtained were averaged over all the days of the week and for the two vehicles. Each quantity (distance travelled, duration, idling duration, fuel consumption, pollutant emissions) averaged as a function of the route section and time period considered, was multiplied by the traffic value of the corresponding time period, thus yielding global traffic quantities (of duration, consumption, etc.) over one hour. These quantities were cumulated over all road sections and were compared between the before and after implementation stages.

This assessment study was performed on a daily 4 one-hour period basis (7.30 am-8.30 am ; 9 am—10 am; 3 pm—4 pm; 5 pm- 6 pm), from Monday to Friday. Consumptions were calculated using the simulation model. Conditions resulting in a too significant traffic decrease (road works, etc.) and not significant variations were disregarded. Various assumptions related to traffic composition and considering the two vehicles were also studied, but the impact of traffic composition remains relatively low.

In the before implementation stage, daily traffic volume was assessed to about 89 395 km x vehicles, ie 4 220 driving hours, of which 1 607 hours spent at stop, with an overall fuel consumption amounting to 8 812 litres. Average speed was 21.2 km/h, (average speed not including stops: 34.2 km/h), and average consumption was 9.9 l/100 km.

Control system optimization yielded the following values: traffic volume increased to 91 835 km x vehicles (ie +2.9%), corresponding to 3 951 driving hours, of which 1 246 hours at stop, for an overall consumption of 8 524 litres.

Actual gains thus amount to 7% for trip durations, to 23.3% for idling duration and to 3.8% for fuel consumptions, with a 2.9% simultaneous traffic increase. Average speed is 23.2 km/h (ie + 9.7%), while average speed not including stops does not increase (33.9 km/h, ie -0.8 %), average consumption amounts to 9.3 l/100 km (ie -5.8%). Gains obtained are very significant and demonstrate the interest of such an operation, at least for a short term period of one year.

Most significant gains were recorded during off-peak hours: -14 to -15% for trip durations (-2 and -5% at peak hours), -38 to -45% for idling durations (-12 and -17% at peak hours), -6 to -7% for consumptions (-2 and -3% at peak hours). The 3-5 pm period contributes to the most significant gains recorded: it accounts for 39% of trip duration reductions, 31% of idling duration reductions, and 41% of energy gains (Table 8).

Table 8 Global assessment (4 daily hours) in Amiens, and contribution of the periods

Variations measured in %	7-8.30 am	9-10 am	3-4 pm	5-6.30 pm	total (4h)
Traffic quantity	+ 4.8 %	+ 2,4 %	- 0.8 %	+ 4.2 %	+ 2.9 %
Travel durations	-4.6 %	-14.6 %	- 13.5 %	-1.7 %	-7.0 %
relative contribution (%)	20.2 %	32.4 %	39.2 %	8.2 %	
Idle durations	-17.0 %	-45.3 %	-38.3 %	-12.2 %	-23.3 %
relative contribution (%)	22.7 %	27.3 %	31.1 %	18.9 %	
Fuel consumptions	-2.5 %	-5.8 %	-7.3 %	-1.5 %	-3.8 %
relative contribution (%)	19.3 %	26.8 %	41.3 %	12.5 %	

For the evening peak hour (5-6 pm) only low gains were recorded (1.5% for consumptions, 1.7% for travel duration), partly limited by traffic increases (+4.2%), which poorly contributes to the gains achieved. But this time period accounts for more than one third of trip durations and fuel consumptions (34% and 32% in the before implementation stage), lowest average speeds (18 km/h) and highest consumption values (10.6 and 10.3 l/100 km in the before and after implementation stages, on average by 1l/100 km higher than the average value over the 4 test hours). Major efforts in the search for additional gains should be made in this evening peak period.

IMPACT OF THE DYNAMIC CONTROL SYSTEMS IN NIORT

Comparing mean values before and after the implementation of traffic control systems

Similar comparative studies, related to implemented dynamic traffic control equipment, were performed in Niort (Tables 9 and 10). All routes being considered, no significant difference is observed in trip durations between the two experiment stages. But, significant reductions in idling durations (-7.6%) and stop number (-0.4 stops or -5.5%) are to be noted.

Table 9 Average traffic characteristics in Niort, before and after the implementation of traffic control systems

Routes	distance (km)	travel duration (min)		stop duration (%)		distance between stops (m)	
		before	after	before	after	before	after
global	5.2	11.01	10.92	25.7	24.0	788	832
Blvds Atlan.-Wellin.	6.9	12.59	11.89	24.0	19.5	984	1206
Blvds Wellin.-Atlan.	7.0	13.07	13.52	23.8	25.3	955	866
Tour Chabot—La Rochelle	3.2	8.30	7.70	29.0	24.8	587	702
La Rochelle—Tour Chabot	3.3	8.61	8.18	28.6	27.6	539	617
Wellinb.—La Roch	5.4	12.11	11.77	27.4	24.7	718	776
La Roch—Wellinb.	5.3	11.05	11.35	23.4	23.1	859	846

Table 10 Speeds recorded during the two experiment stages on Niort routes

Routes	Average speed (km/h))		Running speed (except stops) (km/h)	
	before	after	before	after
Global	28.4	28.6	38.3	37.6
Blvds Atlantique-Wellinborough	32.8	34.7	43.1	43.1
Blvds Wellinborough-Atlantique	32.3	31.3	42.4	41.8
Tour Chabot—La Rochelle	23.4	25.2	33.0	33.6
La Rochelle—Tour Chabot	22.9	24.0	32.1	33.1
Wellinborough—La Rochelle	26.6	27.4	36.7	36.4
La Rochelle—Wellinborough	28.5	27.8	37.2	36.1

A significant reduction of 7% for trip durations, of 21% for idling durations, and of 16% for stop number between measurement stages is observed for the centre route Tour Chabot-La Rochelle (31). Significant reductions in idling durations (-23%) and of stop number (-18%) were measured on the boulevards in the Atlantique-Wellinborough direction.

The comparative analysis of duration mean values before and after system implementation versus time period, yielded the following significant variations:

- trip duration increase by 7% for the boulevards Atlantique-Wellinborough route between 8.30 and 11 am, and 16% decrease at night;
- reductions in travel duration for the Atlantique-Wellinborough boulevard route during off-peak hours (-8 and -11%), for the city centre route Tour Chabot-La Rochelle in the morning (-17%) and for the centre Wellinborough-La Rochelle route (-8% for the 8.30—11 am period);
- reductions in trip duration are relatively well distributed between off-peak and peak hours;
- reductions in idling durations are relatively important, but only a few number of cases are significant.

Fuel consumptions and pollutant emissions

As for the Amiens case, significant variations were observed for consumptions measured on a test bench and during on-the-road tests. This prevented energetic assessment on the only basis of the values obtained by comparative study of measured consumptions. A calculation model for pollutant emissions and fuel consumption was finally used to make an energetic and environmental assessment.

This *modem* model (Joumard et al. 1992) was developed as part of the DRIVE European research programme, based on a wide database including values related to pollutant emissions and fuel consumptions recorded on a test bench (150 vehicles representative of in-operation vehicle fleets all over Europe). Instantaneous pollutant emissions and fuel consumption were recorded during a 1.30 h test programme including a number of test cycles representative of European urban driving conditions. Instantaneous pollutant emissions are recorded at second time intervals as a function of vehicle speeds and accelerations: carbon monoxide CO, total hydrocarbons HC, nitrogen oxides NOx, carbon dioxide CO2 and fuel consumption. These calculations are performed for each vehicle category considering vehicle technology (petrol engine, catalyst, or diesel engine), and engine capacity.

As regards this model, which provides high quality statistical data, the calculation step defined for kinematic data (step of 10 km/h) is liable to be insufficient for assessing low differences in recorded kinematics. Model accuracy has been therefore enhanced by preliminary interpolation of emission initial matrix as a function of speeds and instantaneous accelerations (10 x 7 size) into a matrix provided with an accuracy increased by a factor 5 (42 x 23 size). This model was applied to all the kinematics recorded during the tests performed in Niort, considering the specific technical characteristics of the two vehicles.

All routes being considered, no significant discrepancies were observed between pollutant emission values and fuel consumptions calculated, using the "modem" instantaneous emission model and the kinematic values recorded before and after the implementation of the dynamic control systems. Furthermore, variations are very low (less than 1%). The comparison of the test routes demonstrated that pollutant emissions and fuel consumptions significantly decreased only for route 1 Boulevard Atlantique-Wellinborough. Reductions in CO and HC emissions (less significant) were also observed on the city centre route Tour Chabot—La Rochelle for outward and return trips. These reductions amount to 2-5% as a function of the pollutant and routes studied (Table 11).

Table 11 Pollutant emissions and fuel consumption gains (in %)—CO : Carbon Monoxide, HC : Hydrocarbon, NOx : Nitrogen Oxides, CO2 : carbon dioxide (significant in bold)

Routes	CO	HC	NOx	CO2	Simulated fuel consumption
Global	-0.1	-0.6	-1.1	0.1	0.0
Blvds Atlantique-Wellinborough	**-3.5**	**-2.7**	**-2.2**	**-3.3**	**-3.3**
Blvds Wellinborough-Atlantique	1.5	2.1	-1.1	-0.2	0.2
Tour Chabot—La Rochelle	**-3.8**	**-4.5**	0.4	-1.2	-1.8
La Rochelle—Tour Chabot	-0.7	**-4.9**	2.1	2.5	1.6
Wellinborough—La Rochelle	-1.0	-2.1	0.1	0.3	0.0
La Rochelle—Wellinborough	1.8	1.3	-0.5	1.5	1.5

Assessment over all selected routes, including traffic data (Niort)

As previously noted, evaluation was performed by comparing data related to measured variations between successive junctions and corresponding traffic data. Compared to the Amiens case, traffic condition data were assigned in a more accurate manner: to each recorded route were assigned traffic data of the corresponding half hour time period. Global quantities (traffic, duration, distance travelled, idling duration, consumption, pollutant emissions) were calculated for each route section and time period, and then cumulated over all road sections and compared between the before and after implementation stages. The following conclusions were thus established on a 2.30 hour daily traffic basis (half an hour for each of the 5 times periods), from Monday to Friday.

The total volume of traffic, expressed by the cumulated number of vehicles on all road sections, increased significantly between the two experiment stages, by about 6.5%. The total trip number (obtained by multiplying the distances travelled on the selected route sections by the number of involved vehicles) also increased by about 6.8%. These increased values seem very high and they can be explained only by abnormally differing traffic conditions, either due to the time of the year studied or to other incidents. A very punctual assignment of traffic data (of the order of 1/2 hour) could have generated significant variations, but hourly traffic values would have been less correlated to vehicle measurements values, which are very punctual.

In any case, on the basis of a traffic increase of 6.5% between the two experiment stages, and over a 2.30 hour daily period, the study covered a traffic volume assessed to 17,660 kilometers x vehicles in the before implementation stage, ie 642 driving hours, of which 191 spent at stop (ie 29.7% of trip duration), for a total consumption of 1 542 litres. These figures correspond to an average speed of 27.5 km/h, an average running speed (not including stops) of 39.1 km/h, and an average consumption of 8.7 litres/100 km (-0.5%).

After the implementation of dynamic control systems, traffic volume amounted to 18,860 kilometres x vehicles (ie an increase of +6.8%), corresponding to 660 driving hours (ie +2.7%), of which 180 hours spent at stop,(ie 27.3% of the trip duration and a decrease of -5.5%), for a total consumption of 1 633 litres (+5.9%). The total stop number is decreased by -1.9%. Average speed is 28.6 km/h (+4%), average running speed (not including stops) is 39.4 km/h (+0.6%), and average consumption of 8.7 litres/100 km (-0.5%)

Assessment performed over absolute quantities of pollutants yielded the following increases:

Carbon monoxide CO:	+ 5.2 %,	Hydrocarbons HC:	+ 4.2 %,
Nitrogen oxides NOx:	+ 6.5 %,	Carbon dioxide CO2	+ 6.1 %.

These quantities did not increase as much as traffic did. The results obtained for trip durations, idling duration and the stop number are thus relatively positive. In relative values, ie corresponding to traffic quantities (distances travelled x corresponding traffic conditions), gains are as follows:

travel durations:	- 3.9 %,	idling durations:	- 11.5 %
stop number (per km):	- 8.2 %		
consumptions (per km):	- 0.9 %		
CO (en g/km):	- 1.5 %	HC (in g/km):	- 2.4 %
NOx (en g/km):	- 0.3 %	CO2 (in g/km):	- 0.6 %

Relative gains as related to stop duration and number are very significant. As regards energy consumption and pollutant emissions, compared to distance travelled, the gains obtained are not so significant.

Result distribution as a function of time periods demonstrates that there is no real peak hour: each time period (except the 8 pm-12 pm period accounts for 20 to 27% of the total volume (Table 12), ie traffic conditions are relatively steady all over the day for all the routes and time periods considered. It should be nevertheless noted that there is a relative similarity of traffic conditions between 7 am—8.30 am and 4.30 pm and 7 pm periods on the one hand, and off-peak hours (8.30 am—11 am and 1 pm-4.30 pm, Table 12).

Significant changes are to be observed between the two experiment stages as a function of time. Thus, during the 8.30 am-11 am and 1 pm-4.30 pm periods, traffic increased quite significantly, while traffic values recorded in the morning seemed to decrease. Furthermore, most significant gains were observed for trip durations and stop number of the one hand, and for pollutant emissions on the other hand, mainly related to 7 am-8.30 am and 8.30 am-11 am periods, and to a lesser extent at the beginning of the afternoon.

Owing to relatively comparable traffic volumes between the four daily periods, and to relatively low differences in traffic indicators (average or traffic speeds and stop rate), these different changes cannot a-priori be explained.

A decrease in carbon oxides CO and unburnt hydrocarbons HC (emitted in the idling phases) and an increase in nitrogen oxides (emitted at high speeds) can be simultaneously observed.

Table 12 Global assessment of traffic control changes in Niort (2.5 daily hours)

Variations measured in %	7-8.30 am	8.30-11 am	1-4.30 pm	4.30-7 pm	8-12 pm	Total (2h30)
Traffic quantity	-2.3	+8.6	+15.4	+5.8	+22.4	+6.8
Gains (%) :						
travel duration	- 6.4	- 5.7	- 2.1	- 0.3	- 1.6	- 3.9
stop duration	- 14.6	- 19.4	- 9.6	- 4.4	+ 12.0	- 11.5
stop number	- 10.6	- 11.8	- 5.0	- 3.0	- 20.0	- 8.2
Traffic conditions						
average Speed (km/h)						
before	26.1	28.5	28.8	25.9	43.4	27.5
after	27.9	30.2	29.4	26.0	44.1	28.6
running speed (km/h)						
before	37.6	39.7	39.9	38.3	52.1	39.1
after	38.6	39.8	39.6	37.7	54.4	39.4
stop rates / km						
before	1.43	1.27	1.25	1.47	0.82	1.34
after	1.28	1.12	1.19	1.42	0.66	1.23
Gains (%) :						
fuel consumption	- 1.5	- 0.7	- 0.7	+ 0.1	+ 0.1	- 0.9
CO emissions	- 2.8	- 2.8	+ 0.1	+ 0.3	- 1.4	- 1.5
HC emissions	- 4.1	- 3.8	- 1.0	+ 0.1	- 3.4	- 2.4
NOx emissions	+ 1.0	+ 0.2	- 1.7	- 1.1	+ 1.6	- 0.3
CO2 emissions	- 1.1	- 0.2	- 0.9	- 0.0	- 0.5	- 0.6

COMPARING THE TWO CASES

The extension and optimization of an existing centralized management system of traffic lights in Amiens yielded relatively positive results: significant reductions in trip durations, in stop number and duration for a number of routes, systematically generating reduced consumption values. Average traffic speed does not increase. A study performed on the basis of traffic data recorded showed gains assessed to about 7% for trip durations, 23% for idling durations and 4% for consumptions, with a simultaneous traffic increase of 3%. This analysis clearly demonstrates the interest of such an operation, at least in the short range. Most significant gains are achieved during off-peak hours and over a limited number of road sections. Only low gains (2%) are observed for the evening peak hour which accounts for 1/3 of trip durations and fuel consumption (exceeding by 1 l/100km the standard value). Most significant improvements are observed on main arterials (Boulevards and east-west roads).

In Niort, the implementation of a new dynamic control system for traffic lights yielded a significant decrease of stop duration and number, some reductions in trip durations on a number of routes. Significant reductions in pollutant emissions and fuel consumption can be noted for a number of routes (-3% to -5%). A deterioration of traffic conditions is observed on a number of road sections. These are mainly city incoming and outgoing routes intersecting the boulevards. A global assessment shows a traffic increase of 6.8% between the two experiment stages and allows determining significant relative gains amounting to 4% for trip durations, to 12% for idling durations and to 8% for stop number. Gains obtained for emissions and consumptions (ranging from 0 to 2.5%) are low and even insignificant.

In both cases, the major improvement relates to the optimization of stop conditions (reduction in stop number and duration). Privileged conditions are sometimes provided for a number of main roads (boulevards) to the detriment of secondary roads. Nevertheless, this study yielded positive conclusions. The more relative results obtained in Niort can be explained by the fact that traffic conditions were already relatively good before the implementation of new control systems. They can be related to the difficulty in optimizing a management system whose design is completely new. This can also explain that the environmental and energetic impact in Niort did not confirm expectations.

CONCLUSIONS

This study allowed the definition of an accurate assessment method, based on on-board recorded kinematics which is relatively easy to implement. It demonstrates that direct measurement of fuel consumption on the vehicle must be performed with a great care. Significant reductions in trip durations, consumptions and mainly in idling durations are observed on a number of routes, mainly during off-peak hours, against a number of increases on some other routes. Significant variations were located, providing for an accurate identification of sensible spots and positive effects. A wide spread of measured values can be observed, time period being the main factor of variation. Traffic conditions have a real impact on fuel consumption (by a factor 1 or 2). The existing model for calculating pollutant emissions and fuel consumption was used to assess the energetic and environmental impact from recorded kinematic data.

This method was applied to quantify the advantage of extending and optimizing the management systems existing in Amiens and the implementation of new dynamic control systems in Niort. Gains are essentially observed for trip duration, stop number and duration. In Amiens, a reduction of -4% in consumption was measured, while traffic volume was increased by 3%. In Niort, energetic and environmental gains are more limited.

ACKNOWLEDGMENTS

This study was conducted with the technical or financial support of

- GTME (Nanterre, France), ADEME, and the technical departments of the Niort city for the experiments conducted in Niort, as part of the THERMIE European Research Programme (General Directorate XVII)
- technical departments of the Amiens city and ADEME—Picardie for the experiments performed in Amiens
- and the technical teams of INRETS, TRL in Great Britain, TÜV-Rheinland in Germany, for experiments aimed at constructing a model of pollutant emissions, as part of the European DRIVE project (General Directorate XIII).

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