Assessing The Impact Of Speed Limit Changes On Urban Motorways: A Simulation Study In Lille, France
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Abstract

Recent directives in France on sustainable development have driven local Authorities to the reduction of speed limits on urban highways. Consequently, Local Authorities are interested in a thorough evaluation of this measure and in the estimation of the potential impact upon traffic and emissions.

In this paper, we undertake an a priori evaluation of speed limit reduction from 110km/h to 90km/h on the Lille motorway network, in France. We first provide an overview of key lessons learned from previous speed limit reduction experiences. Then, we present the methodology of the specific prior evaluation on the Lille network. In particular, we use a first order macroscopic traffic simulation tool for this a priori assessment. The model is first calibrated and then statistically validated using traffic data. This statistical validation is consistent with good practices in simulation. The evaluation output allows for a thorough understanding of the impacts on prevailing traffic conditions and air pollution. Additional scenarios are also considered in order to take into account driver behaviour on the non-compliance with speed limits.

Besides the various limitations of the study, especially those related to its predictive aspects, we can conclude that the intended measure will have a positive impact on traffic and emissions. Nevertheless, the magnitude of this impact is largely variable, in particular in regards to driver compliance.

1. Introduction and background

Speed limit operations are the object of a substantial part of the technical literature (Cohen et al, 1998). The main
effects of these measures can be classified in three large groups: (i) traffic conditions, (ii) safety-related, and (iii) environment-related. In this paragraph, we briefly discuss empirical evidence for each group for the case of motorway networks.

First, it is generally observed that lowering the legal speed limits results in lower average speeds, lower dispersion of speeds, reduced V85 percentiles and a capping of high speeds. A limit reduction of 20 km/h may reduce average speed by 5 to 10 km/h. This reduction is even higher in the case of non-saturated networks. The resulting increase in travel times is particularly sensitive at free flow traffic. Besides, this travel time increase is the basic input for economic evaluations on the effects of reduction of speed limits.

Second, previous experiences converge to the fact that lower legal speed limits have a straightforward positive effect on safety levels. In particular, accident rates are found to be reduced, especially those of severe/fatal crashes. Consistency in previous findings has allowed for empirical relationships to be established such as the Nilsson or Elvik laws (OECD, 2006). These laws enable us to model the effects of different policies on road safety levels.

Regarding emissions, the various formulations, such as the COPERT models (Ntziachristos, Samaras, 2000), show that the decrease in average running speeds (that follows a lowering speed limit policy implementation) induces significant reduction in local pollutants and greenhouse gas emissions (GHG) in situation of high fluidity. This decrease is not homogeneous but varies per pollutant type.

Lastly, previous lessons learned emphasize on the importance of an active policy support (awareness, recommendation, monitoring, enforcement policy) that is effective at the local level. Campaigns positively influence the attitudes and behaviors of drivers towards the new limitations and ensure obtaining tangible results.

2. Description of the network

The empirical setting of the present study includes the A1, A22, A25 Lille motorways as well as the RN356 French national road (see Figure 1).

These motorways accommodate a high traffic demand, especially during the peak hours. This demand has been increasing over the last years due to the growing economic attractiveness of the Lille region. Recurrent congestion is formed at the level of both the ramps and the link sections. The latter is exacerbated by the impact of frequent perturbations. Furthermore, the capacity reserves on the alternative network are very limited. As a result, saturation is quickly propagated to the rest of the network. The motorway segments considered have a configuration of 2x2, 2x3 or 2x4 lanes. In some rare cases, we find 2x5 lanes (A1-A25 junction). The speed limit reduction measure from
110 to 90 km/h concerns the following motorway segments:

- A25 highway: between the Englos and the Port Fluvial exits;
- A1 highway: upstream of the Lesquin ramp and up to the connection to the A25 highway;
- The common part of the A22, A27, A23 highways;
- The A22 highway: from the RN356 junction to the Wasquehal ramp (link to the North West Ring).

3. Ex ante assessment on the Lille network

The methodological assessment scheme used in this study is based on a standard corpus established for traffic management policy evaluation. It allows understanding the impacts of reduced speed limits on:

- traffic conditions, especially on average speed;
- emissions of pollutants and greenhouse gas emissions;
- and finally crashes.

Regarding traffic, the ex ante evaluation is carried out by simulation with a first order macroscopic model. The model uses the volume and speed data provided by the traffic management system of the Lille area. The model suffers from various limitations in terms of features. Nevertheless it offers the double advantage of implementation ease and limited input requirements if compared to microscopic simulation models with multiple features.

3.1. The simulation model

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 FREQ simulation tool used for this study was designed by the University of Berkeley [May, Leiman, 2005]. 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:

- modelling and coding the network;
- calibrating and validating the model for the case study and;
- 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. This sometimes reduces the temporal limits of the work undertaken. In order to capture the traffic conditions during a one-day period, we aggregated the data on one-hour slices. Thus, simulation results lay between 0 and 24h. 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.

3.2. Data qualification

Basic data for this study consist only of aggregated mean speeds V and flows Q collected during working days. They are extracted from the database of the traffic management system. They contain measurements provided by loop detector stations installed throughout the Lille motorway network. Inconsistencies and unusual traffic conditions are discarded at each station and for both the ‘before’ and ‘after’ period. Data clearance is made by application of a filtering process with the following criteria:
For any given loop station and at each time-step no incident or accident is recorded for as long as 5 km upstream or downstream and within a 5 hour-period.

This criteria is chosen to avoid possible influence upon the prevailing traffic conditions at the station’s location.

### 3.3. Local Level of Service (LOS)

The evolution of traffic conditions on the motorway sections can be described in terms of levels of service (LOS). These are arbitrarily set from certain thresholds related to speeds and traffic counts. In the US, the Highway Capacity Manual (HCM, 2000) defines six levels of service (LOS A to LOS F), four of which pertain to free flow conditions. In France, four levels of service are used. The determination of the thresholds for setting the four levels of service (LOS$_1$ to LOS$_4$) is based on the speed volume diagram which links up traffic flows to corresponding speeds. This diagram is calibrated from real data. The corresponding traffic states are illustrated in Fig.2 and given below:

- **LOS$_1$** free flow (LOS A and LOS B of HCM) with: $Q/C < 0.75$ to $V > V_c$
- **LOS$_2$** free flow to dense flow (LOS C and LOS D of HCM): $0.75 \leq Q/C < 0.90$ to $V \geq V_c$
- **LOS$_3$** dense flow (LOS E of HCM): $Q/C \geq 0.90$
- **LOS$_4$** congested flow (LOS F of HCM): $Q/C < 0.90$ to $V < V_c.$

![Fundamental Diagram](image)

Fig. 2. Representation of the levels of service on the fundamental diagram (French approach).

One should notice that unlike the LOS E of the HCM, LOS$_3$, also refers to traffic conditions with mean speeds slightly lower than the optimal speed at capacity.

### 3.4. Network modeling

For simulation purposes and in order to represent the spatial evolution of traffic conditions, any given network is divided into subsections. The following core rules were applied 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 2km.

In our case study, the 5km-long stretches were generally divided in 5 subsections according to their geometric configuration.
3.5. 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 in ensuring that the parameters’ set at the calibration stage are valid for any other set of traffic demand. The inputs required by FREQ12 are:

- Traffic counts at all entrances and exits of the network, including the mainline upstream and downstream ends. We used data collected in October 2010 for calibration and validation as loop detector stations were reliable (reliability rate ≥ 80%) for a maximum of subsections during several 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 bottlenecks, queue lengths, congestion occurrence, and clearance times. We used the Theil’s inequality coefficient (U) to evaluate the overall performance of the simulation related to the speed contour maps. 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:

\[
U = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (S_{n}^{sim} - S_{n}^{obs})^2 \over \left( \sqrt{\sum_{n=1}^{N} (S_{n}^{sim})^2} + \sqrt{\sum_{n=1}^{N} (S_{n}^{obs})^2} \right)^2}
\]

(1)

where \( S_{n}^{sim} \) and \( S_{n}^{obs} \) are the averages of simulated and real measurements at space-time point n.

Global traffic conditions on the motorway sections can be described by speed contour maps. These maps identify and quantify the traffic peaks on the motorway stretch with both the observed and simulated scenarios. Characteristics of the peaks - location, duration, congestion index and intensity - can be used to assess the impact of the dedicated lane on traffic congestion.

The speed contour maps (A) and (B) in Fig. 3 illustrate the comparison between measurements and simulation for the same day (10 October 2010). The level of service of traffic (LOS1 to LOS4) are correctly reproduced after calibration of the macroscopic model. For this specific period, the value of the Theil coefficient is \( U = 0.1013 \).
It is important to proceed with the validation of the model on a statistical basis in order to gain a better understanding of the impact of reduced speed limits on accuracy. This methodological approach is currently recommended by the manuals of good practices in traffic simulation [Park, Won 2006].

The basic principle of this method is to repeat the validation phase over a data sample of days. At the end of all the simulations performed over the sample, it becomes thus possible to associate a confidence interval to various indicators provided by the simulation. Therefore, we select other days of data available and we repeat all the steps of the validation phase. A five-day dataset is selected to constitute this small sample (October 20, 22, 25, 26 and 27). Using the theory of small samples, we determined the confidence intervals of the various indicators provided by the simulation.

We applied the same methodology on various sections of the highways A1, A25, RN356, and A22 (Figure 1). Results allow us to estimate the impact on traffic variables (especially speed) by comparing a baseline scenario (Business As Usual at 110 km/h) to the project scenario (S1 at 90 km/h). On the contrary, the assessment of speed limit reduction from 130 km/h to 110 km/h was not possible due to high data unavailability.

These simulations provide all the necessary elements for the global estimation of each scenario emissions depending on the total mileage and the conditions of average flow.

3.6. Expected impact on average speed

The simulation model is first calibrated and then validated on each motorway segment and per direction. The validation is made over a sample of days with available measurements. Table 1 shows an example of the results obtained for a A25-motorway segment and per simulated scenario 110 and 90 km/h. We observe that simulated average speeds in the BAU (110 km/h) and the S1 (90 km/h) cases may substantially vary with the day and the segment considered. In the case of the A25 going from the North-West ring to the Port Fluvial and for the 110 km/h scenario, we find a variation going between 61 and 83 km/h depending on the day. In the case of the 90 km/h scenario, the variation is limited between 57 and 77 km/h.

On the saturated sections, traffic is generally unstable. This is a general outcome of the fundamental diagram of the road. The scatterplot of the measurements of volume and speed exhibits a high dispersion at the level of service LOS_4, when the flow is congested. On the other hand, a small dispersion is observed at LOS_1 when traffic is free-flow. In the case of the A25 stretch which is regularly saturated at LOS_4, the daily average speed varies according the day, from 61 to 83 km/h. Therefore, at LOS_4, speed variations are large and hence this implies a high dispersion. Inversely, some other segments show a remarkable stability over the different days of the sample. On the
section of the A22 on the North-South direction for instance, traffic remains free-flow and speed varies little around the free speed at LOS_1.

Table 1. Impact on daily average speed (km/h) for BAU at 110km/h and S1 at 90km/h

<table>
<thead>
<tr>
<th>Simulation day</th>
<th>Average speed Speed limit 110km/h</th>
<th>Average speed Speed limit 90km/h</th>
<th>Difference (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 October 2010</td>
<td>82.7</td>
<td>76.6</td>
<td>6.1</td>
</tr>
<tr>
<td>22 October 2010</td>
<td>60.7</td>
<td>57.4</td>
<td>3.3</td>
</tr>
<tr>
<td>25 October 2010</td>
<td>67.4</td>
<td>63.4</td>
<td>4</td>
</tr>
<tr>
<td>26 October 2010</td>
<td>70.5</td>
<td>66.3</td>
<td>4.2</td>
</tr>
<tr>
<td>27 October 2010</td>
<td>64.2</td>
<td>60.7</td>
<td>3.5</td>
</tr>
</tbody>
</table>

In Table 2 below, the impact on average speed is defined as the difference between the average speed before minus the average speed after.

Table 2. Average impact on daily average speed (km/h) when passing from 110 (BAU) to 90km/h (S1) speed limit

<table>
<thead>
<tr>
<th>Motorway Stretch</th>
<th>Direction</th>
<th>Impact on average speed</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>A25</td>
<td>A25 to A1</td>
<td>4.2</td>
<td>[2.8 ; 5.6]</td>
</tr>
<tr>
<td>A25</td>
<td>A1 to A25</td>
<td>4.7</td>
<td>[4.0 ; 5.3]</td>
</tr>
<tr>
<td>A1</td>
<td>A1 to A25</td>
<td>7.3</td>
<td>[5.9 ; 8.8]</td>
</tr>
<tr>
<td>A1</td>
<td>A25 to A1</td>
<td>11.3</td>
<td>[6.5 ; 16.0]</td>
</tr>
<tr>
<td>RN356</td>
<td>A1 to A22</td>
<td>14.3</td>
<td>[11.2 ; 17.3]</td>
</tr>
<tr>
<td>RN356</td>
<td>A22 to A1</td>
<td>14.9</td>
<td>[8.9 ; 20.8]</td>
</tr>
<tr>
<td>A22</td>
<td>A1 to A22</td>
<td>13.2</td>
<td>[10.1 ; 16.3]</td>
</tr>
<tr>
<td>A22</td>
<td>A22 to A1</td>
<td>16.5</td>
<td>[16.0 ; 16.9]</td>
</tr>
</tbody>
</table>

Our methodology of statistical validation is consistent with good practices and accepted simulation techniques. It offers the benefit of enabling the estimation of the impacts’ precision Thus, Table 2 presents the average impact (standard deviation before-after) on daily average speed as well as its 95% confidence interval. As we use small sample replications, the determination of the confidence interval of the impact on average speed is based on the Student-Fisher distribution rather than the normal distribution.

The various simulations show that there is no significant change in delay on the exit ramps under the two scenarios (BAU and S1). Similarly, congestion observed on the links during the morning and evening peak hours seems not to be affected by a speed limit reduction from 110 to 90km/h (Cohen et al, 2014).

4. Taking into account the violation rate of the introduced speed limit

The macroscopic simulation performed takes into account the speed limit in full, regardless of the actual level of compliance by the users. It therefore amounted to a compliance rate of 100%. In fact, the reduction from 110km/h to 90km/h induces systematically an increase in the number of violations of the speed limit. This is a general rule observed on many road networks: the more the speed limit decreases, the more the violation rate increases. Measurements on the Lille network, recorded from the loop sensors, show that on the sections at 110km/h, there is on average 15% to 35% of offenses. On sections at 90km/h, the rate increased from 45% to 70%.

This phenomenon impacts the credibility of the simulation: when comparing scenarios at 110km/h and 90km/h, we should increase the violation rate in the scenario at 90km/h. One possible approach is to test a scenario with a speed limit higher than 90 km/h. We choose arbitrarily a speed limit of 100km/h. Therefore, we assume that a scenario at
100km/h would represent the scenario at 90km/h with a compliance rate of about 50%.

Using the model already calibrated and validated, we perform a new simulation run with a speed limit of 100km/h. The following table summarizes, for the example of the A1-A25 stretch, the main effects on the average speed.

Table 3. Impact on daily average speed (km/h) when passing from 110 to 100 and 90km/h speed limit

<table>
<thead>
<tr>
<th>Common trunk A1-A25</th>
<th>Reference</th>
<th>Scenario</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed limit 110km/h</td>
<td>82</td>
<td>80.8</td>
<td>75.5</td>
</tr>
</tbody>
</table>

It is interesting to notice that, for the analyzed case, the impact of the change from 110 to 100 km/h is low: the difference between the two average speeds is only 1.2 km/h. It reached 6.5km/h when passing from 110 to 90 km/h:it is multiplied by more than 5. Nevertheless, the magnitude of this result cannot be generalized, given the high variability observed previously, depending on the day and the motorway section considered.

Finally, it is worth noting that an eventually lower impact on average speeds implies a latent reduction of the measure’s effectiveness in terms of either emission or accident reduction.

5. Estimation of the impact on emissions

In this part, the computations are based on the formulas of the European standard COPERT III (COmputer Programme to calculate Emissions from Road Transport). These formulas are implemented in the IMPACT software developed in France (ADEME, 2003). Following COPERT III, the environmental indicators are expressed as a function of the average speeds estimated by the previous simulations described in section 3. In addition, we note that IMPACT allows taking into account both the fleet age and the percentage of heavy vehicles in the fleet. We thus obtain both the main local pollutants CO, CO$_2$, NO$_x$, the greenhouse gases, and the fuel consumption (petrol and diesel). The calculated values in Table 4 also include the total VOCs. In our case, only hot emissions are to be considered: cold start effect and evaporation losses are not to be considered. VOCs emissions depend mainly on the average speed.

The data extracted from the traffic management database allow for the estimation of the hourly rate of heavy vehicles on certain axes. As a result, this rate is considered to be constant over a given one-hour period of a given working day. The latter enables us to estimate emissions while accounting for this key-parameter.

Table 4. Potential daily savings (%) in main pollutants when passing from a 110 to a 90 km/h speed limit

<table>
<thead>
<tr>
<th>Stretch</th>
<th>Direction</th>
<th>CO2</th>
<th>SO2</th>
<th>CH4</th>
<th>N2O</th>
<th>CO</th>
<th>NOx</th>
<th>VOC</th>
<th>Particles</th>
<th>Petrol</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>A25</td>
<td>A25-A1</td>
<td>-1.24</td>
<td>-1.25</td>
<td>0.78</td>
<td>0.01</td>
<td>-7.85</td>
<td>-2.08</td>
<td>-6.59</td>
<td>-0.05</td>
<td>-3.34</td>
<td>-0.79</td>
</tr>
<tr>
<td>A1</td>
<td>A1-A25</td>
<td>2.26</td>
<td>2.28</td>
<td>4.78</td>
<td>0.02</td>
<td>9.6</td>
<td>-0.13</td>
<td>-7.58</td>
<td>8.79</td>
<td>0.39</td>
<td>2.68</td>
</tr>
<tr>
<td>A1</td>
<td>A25-A1</td>
<td>7.65</td>
<td>7.72</td>
<td>7.93</td>
<td>15.8</td>
<td>29.99</td>
<td>3.88</td>
<td>-1.16</td>
<td>18.01</td>
<td>7.61</td>
<td>7.74</td>
</tr>
<tr>
<td>RN356</td>
<td>A1-A22</td>
<td>7.93</td>
<td>8</td>
<td>9.41</td>
<td>12.59</td>
<td>30.89</td>
<td>3.45</td>
<td>-4.91</td>
<td>19.77</td>
<td>7.16</td>
<td>8.18</td>
</tr>
<tr>
<td>RN356</td>
<td>A22-A1</td>
<td>7.33</td>
<td>7.4</td>
<td>7.57</td>
<td>15.94</td>
<td>28.32</td>
<td>3.7</td>
<td>-1.29</td>
<td>17.18</td>
<td>7.23</td>
<td>7.44</td>
</tr>
<tr>
<td>A22</td>
<td>A1-A22</td>
<td>6.23</td>
<td>6.29</td>
<td>8.41</td>
<td>9.03</td>
<td>25.6</td>
<td>2.09</td>
<td>-7.26</td>
<td>17.3</td>
<td>4.73</td>
<td>6.61</td>
</tr>
</tbody>
</table>

Table 4 summarizes the main effects of the speed limit reduction from 110 to 90km/h. The effects are given in percentages. Positive values represent daily emissions’ savings. On the contrary, negative values represent an increase in emissions. These results depend mainly on the values of average speed at 110km/h or 90km/h on the curve representing the emission (in g/km) as a function of speed.

We observe that the environmental impact is positive in seven out of the eight cases studied. Results are
particularly interesting in the RN356 and the A22 section where we have a 6 to 10% reduction in CO₂ emissions. In fact, these are slightly saturated segments with rather high average daily speeds. It seems that on these segments there is a high average speed variation before and after the implementation of the speed limit reduction.

Inversely, saturation phenomena in the A25-A1 direction of the A25 segment keep average daily speeds rather low. The simulations made over the 5-day dataset give an average speed reduction from 69 to only 65 km/h when passing from the 110 to the 90 km/h speed limit. This speed level leads to a slight increase in emissions due to the specific form of the COPERT curves.

The last columns give the daily savings in energy consumption when passing from the BAU to the S1 case. The conclusions drawn are similar to those regarding main pollutants.

6. Concluding remarks

6.1. Study limitations

As it is the case in most a priori assessment, conclusions should be carefully interpreted and used. In fact, the quantitative results are to be taken as trends and not as absolute reference values.

Even the most rigorous simulation suffers from approximations that are related to the modeling procedure, the initial hypotheses made and their limitations. Furthermore, traffic data unavailability on motorway interchanges combined with the application of the conservation law can prove to be problematic under congestion. Turning to the environmental aspects, the computations were made based on the average speeds used in the aggregated and simplified COPERT formulas. The soundness of these formulas at the local level remains open to question. Finally, the real impacts of speed limit reductions are highly dependent upon driver behavior and related policy measures such as information and awareness campaigns.

6.2. Expected trends

Concluding, it appears that a speed limit reduction from 110 to 90km/h on the A1, A25, RN356, and A22 sections of the Lille motorway network would lead to a decrease in average daily speeds. The resulting reduction is expected to be low in the saturated sections (approximately 4km/h on the A25) and higher in the non-saturated sections (up to 15km/h on the A22).

Given the shape of the emission curves, the environmental impact is expected to be positive on those segments where initial average speeds are high (over 70-80 km/h).

In spite the inherent limitations of any prediction effort, our conclusions suggest that speed limit reductions would have a positive overall effect. Nevertheless, the magnitude of this effect is not constant across the motorway segments considered.

Acknowledgements

Financial support for the research presented in this paper was provided by the Direction Interdépartementale des Routes du Nord (DIRN), France. The authors would like to thank this agency and specifically Hugues Amiotte and Jean-Eric Péruchon for their valuable contribution.

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