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Ex-ante assessment of a speed limit reducing operation – A data-driven approach.

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Abstract

Reducing speed limits often leads to a decrease in the injury and fatality accident counts. This depends on the type of accident, on speed limits, on compliance and on traffic conditions, before and after implementation of the speed limit. In France, the speed limit is 130 km/h and 110 km/h on interurban and urban motorways respectively. The safety assessment of a speed limit reducing operation before its implementation is the subject of this paper. Such an assessment was required before the decision to reduce speed limits in an urban motorway network in the north of France. The safety assessment process consists of four steps: first, accident analysis for the prior period, in order to count the speed-related or density-related accidents; second, analysis of the empirical six-minute average speed and density before and after the introduction of the speed limit reduction; third, predicting new traffic conditions; fourth, using relationships linking the accident count to changes in speed and density. Results predict a decrease in the accident count, which is sensitive to various possible assumptions.

Keywords: Injury accidents; prediction; ex-ante assessment; speed limit; traffic conditions, power model.

Résumé

Les décisions de réduction de la limite de vitesse ont souvent conduit à une baisse du nombre des accidents corporels, le niveau de la baisse dépendant des vitesses, limites et pratiquées, avant et après l'introduction de la nouvelle mesure, des conditions de trafic, des types des accidents.

Cette contribution vise à présenter l'évaluation a priori de l'impact sur le nombre des accidents corporels, d'une réduction de la limite de vitesse de 20 km/h sur huit autoroutes autour de Lille au nord de la France.

Quatre étapes sont nécessaires pour établir une prévision du nombre des accidents : l'analyse des accidents survenus avant l'application de la mesure, l'analyse des conditions de trafic (vitesse, concentration) avant, la prévision des conditions de trafic futures, la spécification et l'utilisation des liens accidents-vitesse et accidents-concentration. Les résultats prédisent une réduction du nombre des accidents, réduction qui est sensible aux différentes hypothèses que l'on peut formuler.

Mots-clé: Accidents corporels ; prévision ; évaluation a priori ; limites de vitesse ; conditions de circulation.

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1. Introduction.

Driving at an inappropriate speed contributes to the occurrence of road accidents. A number of authors have used traffic conditions and accident databases to analyse the relationship between accidents and speed (Golob, 2004), (Abdel-Aty, 2005); accidents and Volume/Capacity ratio (Lord 2005); and accidents and traffic states (Yeo, 2013). The relationship between speed limits and accidents has been analysed from national accident databases before and after the setting of new speed limits (Nilsson, 2004), (Elvik, 2009, 2013), (Pauw, 2013), who suggested and used the power model, relating the after/before ratio of accident counts to the speed limit ratio.

The safety impact of a speed limit reduction (prior to its implementation) is assessed in this paper. The safety assessment process consists of four steps that are introduced in Section 2. Such an assessment was required before making the decision to reduce the speed limits in part of the ALLEGRO urban motorway network in the North of France – the site, traffic and accidents data are presented in Section 3. The method requires some relationships between accidents and traffic conditions: their calibration is given in Section 4, based on data coming from another motorway set, the Marius network in the South of France. Section 5 gives the results of the four steps for the ALLEGRO network, and Section 6 outlines the validation of this approach and the links with a future ex-post assessment, which has not yet been carried out. Concluding remarks are given at the end.

2. Method for predicting the injury or fatality accident count.

Making a prediction is a twofold process:

- Identifying what things should not change. There is no point in extrapolating them since either they remain constant or, they are excluded (subtracted) from the analysis and then added to the predictions.
- Identifying things that will change, formulating a model for them, calibrating this model and then using it.

In both cases hypotheses are made, which should be either validated or commonly accepted in the community. The prediction process consists of four steps:

2.1. Accident analysis

(Golob 2004) have shown strong links between accident counts (by type of accident) and traffic conditions. The first step of our method consists in simplifying his approach by classifying the accidents into just three types and reducing their links to traffic conditions to two dimensions (speed and density):

- Type 1. Some accidents are mainly due to the driver suffering from fatigue or falling asleep, to alcohol, or to a vehicle failure. Let us consider here that the number of such accidents is independent of any speed limit.
- Type 2. Other accidents are linked to a high speed (run off the road, rollovers); they occur in a low traffic flow and concern a single vehicle. Let us consider that changes in speed affect only those single-vehicle accidents.
- Type 3. The remaining accidents concern several vehicles (side collisions, rear-end collisions, multi-vehicle collisions) and are linked to a high relative speed, a high traffic density or a lane change. Let us consider that these accidents, concerning two or more vehicles, are affected only by the changes in traffic density.

2.2. Empirical speed analysis

Empirical speeds are analysed in two components:

- Fundamental Diagrams (FD), which link speed to traffic flow; FDs vary according to the speed limits.
- A deviation round the FD, because the FD is valid only on average and not at every single moment. These deviations are different at each six-minute period. Let us consider that they do not depend on the speed limit.

2.3. Traffic conditions prediction

It is the traffic authorities which decide speed limits (from safety, environmental or traffic efficiency points of view), but compliance is not perfect. Our task is thus twofold: to predict what will be and what ideally should be.

2.3.1. Predicting what will be

Let $V^{FD}(q)$ be the FD giving the speed corresponding to the traffic flow q . The empirical speed is split here into two components, the first given by the FD, the second being the deviation from the FD.

For every six-minute period i , let q_i, v_i, k_i be the empirical traffic flow, speed and density:

$$v_i = v_{speed_limit}^{FD}(q_i) + (v_i - v_{speed_limit}^{FD}(q_i)) \quad (1)$$

The relationship $q_i = k_i v_i$ implies that an average six-minute speed decrease leads to an increase in density k_i . For the non-congested branch of the FD, provided the new density (after the speed limit implementation) remains



lower than the critical density, the traffic demand q_i will go through. If it is not the case, the period passes into congestion, with a queue that needs to be managed. However, in the simulation study carried out on the same subject (Cohen, 2014) has shown that the increase in congestion was negligible. In addition, capacity was virtually maintained (see the FDs Fig. 4), except for the slow lane, when the new speed limit is 90 km/h. In congestion, when the demand is greater than the supply the FD congested branch is not impacted by the reduction of the speed limit (Fig.4). Let us therefore assume that after the implementation of the new speed limit the traffic flow and the traffic state remain constant by six-minute period. The new speed is obtained by adding to the empirical one the change in FD:

$$v_{new_speed_limit}^{FD}(q_i) - v_{old_speed_limit}^{FD}(q_i) \quad (2)$$

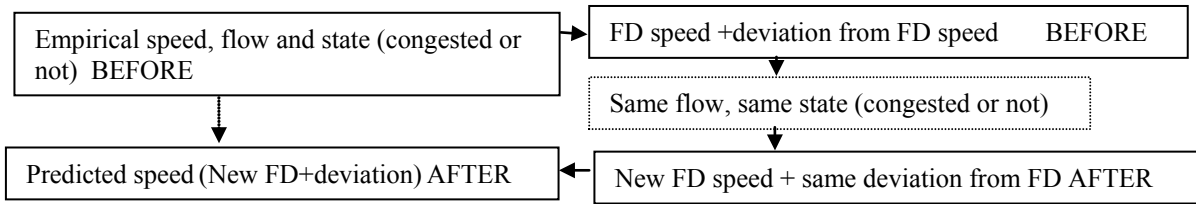


Fig. 1. Traffic conditions analysis and prediction

Thus the traffic density is deduced from the equation $Traffic\ flow = Speed \cdot Density$. The variability of the speed and density is conserved, since empirical six-minute deviations from the FD are taken up again.

2.3.2. Predicting what should be

In 2.3.1, the new empirical FD takes into account actual compliance with the new speed limit where already implemented. Computing the ideal result of the speed limit reduction (with full compliance) requires another model, where the empirical speed (when higher than the new speed limit) is replaced by the limit (or by a function of the limit, in the case of partial compliance). Individual speeds should be used, but due to unavailability on that site they have been replaced by six-minute average speeds. Compliance is said to be partial either where the rate τ of compliant drivers or periods is $<100\%$, or where the speed decrease is only $\rho \cdot (V_{old_lim} - V_{new_lim})$, ($0 < \rho < 1$). The empirical speed v , when greater than the new speed limit, is changed to v' or v'' :

$$v' = (1 - \tau) v + \tau \cdot V_{new_lim} \quad 0\% \leq \tau \leq 100\% - \text{see results in Tables 3-6 for } \tau = 100\% \text{ or } 50\% \quad (3)$$

$$v'' = \text{Max}\{V_{new_lim}, v - \rho (V_{old_lim} - V_{new_lim})\} \quad \text{see results in Tables 3-6 for } \rho = 50\% \quad (4)$$

2.4. Predicted accidents related to speed and traffic density

Two models are considered here, for modelling the impacts of speed and density on accident count.

2.4.1. Relationships between accident risk per vehicle-kilometre and empirical speed

Since national traffic and accident data before-after a decision to reduce speed limit was not available, the speed power model is calibrated from type-2 accidents and speed data from a motorway network; this model therefore has a different meaning and final use from (Nilsson, 2004). The accident count is based on the predicted speeds compared with the empirical speeds *before*, which differ from the speed limits.

Let $nb_acc(v)$ be the injury accident count at speed v and v_b ; the “before” speed the power model is:

$$nb_acc(v)/nb_acc(v_b) = (v/v_b)^\alpha \text{ or } nb_acc(v) = \beta v^\alpha \text{ with } \beta = nb_acc(v_b)/(v_b)^\alpha \quad (5)$$

The risk per vehicle-kilometre appears when dividing $nb_acc(v)$ by the number of vehicle-kilometres:

$$Risk(v) = nb_a \alpha(v) / nb_veh_km(v) = \beta \cdot v^\alpha / nb_veh_km(v) = \beta' \cdot v^\alpha \quad (6)$$

$$\text{with } \beta' = nb_a \alpha(v_b) / (v_b^\alpha \cdot nb_veh_km(v_b)) \quad (7)$$

The (theoretical) number of accidents Nb_acc is the sum, over the speed classes, of the risks per vehicle-kilometre, multiplied by the number of vehicle-kilometres of the class $nb_veh_km(v)$; so β' is solution of:

$$Nb_a \alpha = \sum_v nb_a \alpha(v) = \sum_v nb_veh_km(v) \cdot \beta' \cdot v^\alpha = \beta' \cdot \sum_v nb_veh_km(v) \cdot v^\alpha \quad (8)$$



R. Elvik (2009) gave the following values for α : for all injury accidents (1.6), for slight injury accidents (1.1), for serious injury accidents (2.6), for fatality accidents (4.1). Note that (Elvik, 2013), following (Hauer, 2009), found an even better fit with an exponential model, the number of accidents being proportional to $e^{0.034v}$.

2.4.2. Relationships between accident risk per vehicle-kilometre and traffic density or sensor occupancy

Occupancy and traffic density are related: assuming a constant vehicle length of 5 metres, the maximum density per lane is 200 vehicles/km, whereas the maximum occupancy is 100%, so the density is twice the occupancy (in percentage terms). (Ait-Belkacem, 2012) calibrated a power model linking the third-type accident count to occupancy (Table 1) from a French motorway network. However, when predicting the new traffic conditions on the ALLEGRO network, we remarked that while the speed limit reduction affects the proportion of high-density vehicle-kilometres (we say that a density is “high” when greater than the threshold $K_h = 24$ vehicles per lane), it does not much affect the traffic density distribution (conditionally to be in the low/high class), which simplifies the calculation. Indeed, let us note:

- $nb_veh_km(k)$ the number of vehicle-kilometres for density class k ,
- $Nb_Veh_Km(K_h)$ (with a capital N) the cumulated number of vehicle-kilometres for $k > K_h$,
- $Risk(k)$ the risk per vehicle-kilometre for density k ,
- f_k the conditional density (conditionally to $k > K_h$): $f_k = nb_veh_km(k) / Nb_Veh_Km(K_h)$.

$$Nb_Acc(K_h) = \sum_{k|k > K_h} nb_acc(k) = \sum_{k|k > K_h} nb_veh_km(k) \cdot Risk(k) = Nb_Veh_Km(K_h) \cdot \sum_{k|k > K_h} f_k \cdot Risk(k) \quad (9)$$

$\sum_{k|k > K_h} f_k \cdot Risk(k)$ remains constant (equal to $Nb_acc / Nb_Veh_Km(K_h)$), provided the conditional density f_k does not change. Thus, whatever the risk $Risk(k)$, the number of high-density accidents is proportional to the number of high-density vehicle-kilometres. Two auxiliary problems remain: for the determination of K_h and, when traffic data corresponding to accidents is missing, for the assignment of each accident into one of the two cases.

The predicted accident count Nb_acc is obtained through the following scheme:

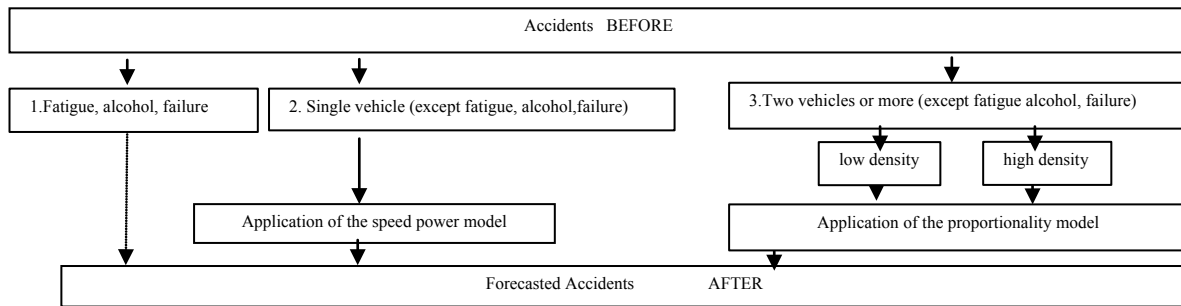


Fig. 2. Predicting accidents by type

3. The part of the ALLEGRO motorway network concerned by speed limit reduction.

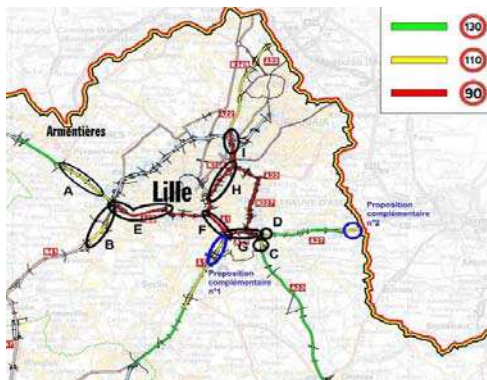


Fig.3. Speed limit reduction scheme near Lille

The speed limit will decrease from 130 km/h to 110 km/h in three motorway areas: A (A25 motorway), C (A23), and D (A27); it will decrease from 110 km/h to 90 km/h in areas E (A25), F (A1), G (weaving section A22-A27-A23), I (A22); additional sections PC1 and PC2 (A1), B (national road 41) and H (national road 356) are not considered here. 345 injury accidents, described in the French accident database BAAC (*Bulletins d'Analyse des Accidents Corporels*) occurred in 2003-2010 on this 23 km-long part of the Allegro Network. Traffic data from 15 stations was available only for 2009-2010, covering lane flow, speed and occupancy every six minutes. However it was not possible to link an accident to the traffic conditions before, because there were too few traffic stations available for this research.



4. Calibration of speed-accident or density-accident relationships from the “Marius” motorway network.

4.1. The Marius motorway network and data used for calibration

The calibration of speed-accident or density-accident relationships is based on one-year data (June 2009-May 2010) of the Marius motorway network which is made up of parts of the A7, A50, A51 and A55 motorways around Marseille (two or three lanes and 75 kilometres in each direction). Three sources of data have been used:

- Traffic data (time of passage of each vehicle in 100^{ths} of a second, individual speed and length, lane) was collected by Cete-Méditerranée on 104 traffic stations in each direction. Multiplying the number of vehicles recorded on different sensors by the distance between sensors gives a total of 1.5 billion vehicle-kilometres.
- Accident data (time of accident, type, location, etc.) was taken from the French accident database (BAAC). In one year, 292 injury or fatality accidents occurred on the Marius network. Traffic data was available for 256 of them.
- Weather data was taken from “Météo-France”, which recorded six-minute rain gauge information and hourly human information at a meteorological station located at the Marseille-Marignane airport.

4.2. Calibration of the average speed-accident and density-accident relationships

Since accidents often result from just one person driving at an inappropriate speed, the link between the *average* speed of a set of drivers and accidents is more tenuous, which might jeopardize the approach. As the initial lane of the accident is not available in the BAAC, the speed-accident or density-accident relationships have been calibrated independently by lane, as if each accident were independently related to the traffic conditions on each lane. The distributions of the 6-minute average speed and occupancy have been established for the full year; in addition, for every accident the 6-minute average speed and occupancy recorded 18 minutes *before* the accident, at the nearest upstream or downstream traffic station, have been considered, in order to ensure that this data has not been impacted by the accidents (AIT-BELKACEM, 2012). The following results have been obtained:

Table 1. Calibration of the exponents of the power model – Marius network.

Exponent α and (5% confidence interval) of the power model	Slow lane	Central lane	Fast lane
Speed (Daylight, no rain, based on 45 single-vehicle accidents)	0.2(-1.7;2.7)	0.7 (-1.5;2.9)	6.0(2.4;9.7)
(Night, no rain, based on 17 single-vehicle accidents)	4.1(0.6; 8.8)	6.1 (-5.1;17.3)	6.1(2.1;10.0)
Density power model (Daylight, no rain, 144 multi-vehicle accidents)*	1.4 (1.0;1.9)	1.4 (0.9; 1.8)	0.9(0.4; 1.3)
% of multi-vehicle accidents by density ≥ 24 vehicles/km/lane	70% of accidents concerning at least 2 vehicles		

(*) Unused, due to the assumption that the density distribution (restricted to the class of low densities) is constant; it is the same for high densities.

The arithmetic average over the 3 lanes of the speed exponents α is $\alpha=2.3$, greater than the values 2 in (Nilsson 2004) or 1.6 in (Elvik, 2009). This increase is not unexpected because we discarded from the calibration set accidents involving several vehicles, which tends to sharpen the speed-accident relationship.

5. Ex-ante assessment results of the speed decrease in the ALLEGRO motorway network.

5.1. Fundamental Diagrams on the ALLEGRO network

One way to obtain the relationship between speed and density is to classify the traffic flow, then to divide each class into two sub-classes (one congested, the other not) and to assign a sub-class to each six-minute period according to its traffic flow. The FD speed is the average of speeds by sub-class. Congestion is selected when the speed is lower (or density greater) than the critical speed (or density). These critical speeds and density can be:

- derived from the calibration of an analytic curve which globally models the FD;
- or estimated from the data subset corresponding to the maximum observed flow;
- or the values which correspond to the minimum of the sum of square deviations between the empirical data and the FD resulting from these critical values. Here this method has been employed, while forcing the same critical value on the three lanes (35 vehicles/lane/kilometre).

Unlike usual traffic simulation, no global form of a speed-density relationship is required. The main constraint – a decrease in speed when density increases – is not always satisfied with empirical data, and it is necessary to process monotonically the obtained average speeds by class. We have developed a heuristic which does so.



On some parts of the ALLEGRO network, the 90 km/h, 110 km/h and 130 km/h speed limits are already used, which makes it possible to build the three FDs (see Fig. 4).

Overestimation of the critical speed induces overestimation of the number of congested periods and the speed levels of both branches of the FD. This is because the average speed for a given flow class corresponds to the weighted average of the mean non-congested and congested speeds, the weights being the proportions of vehicles travelling during non-congested and congested periods. Overestimation of the critical speed implies that some non-congested periods, with a rather low speed, are wrongly classed in congestion; thus the non-congested average speed increases, because the lowest speed values are not integrated in this average; the congested average speed increases too, because of the addition of these wrongly classified speeds, which are rather high for the congested case. Of course, these two overestimations do not lead to any overestimation of the “average of the two averages”, which does not vary, because of the increase in the weight of the lowest average.

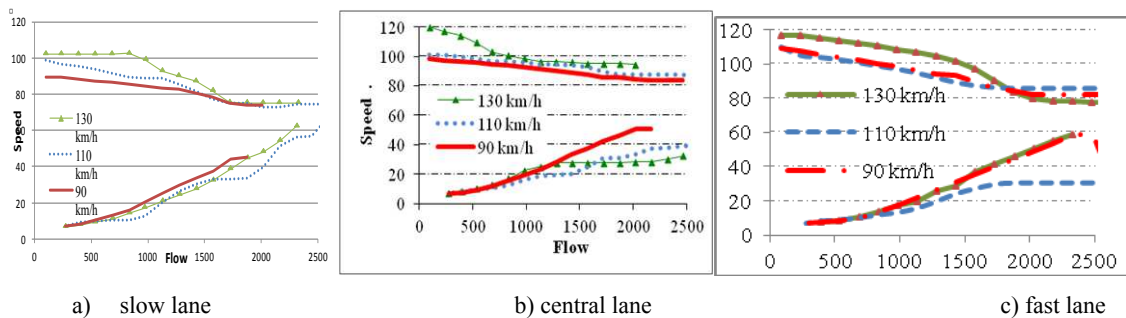


Fig.4. Fundamental Diagram in the ALLEGRO motorway network according to the speed limit for daylight, no rain periods.

In the central and fast lanes, capacity is the same whatever the speed limit; in the slow lane, capacity is the same at 110 km/h and 130 km/h, but decreases at 90 km/h. Since the sections used for determining the FDs were different, the FD modification cannot be completely attributed to the change in speed limits, and part of it is probably due to local geometric or traffic characteristics which, in turn, are not independent of the speed limit decisions.

5.2. Splitting the accidents into three types and predictions

By analogy with the Marius network where detailed traffic data was available, 70% of type-3 accidents concerning at least 2 vehicles have been assigned in a low density period, and 30% in high density periods.

Table 2. Observed accidents and predicted accidents by accident type according to speed limit compliance assumptions

Accidents, areas A to I	Observed before	Predicted by FDs	Compliance $\tau=100\%$	Compliance rate $\tau=50\%$	$\rho=50\%$ (-10km/h)
2003-2010 Type 1	46.0	46.0	46.0	46.0	46.0
2003-2010 Type 2 (due to speed)	99.0	85.9	88.5	93.5	90.8
2003-2010 Type 3 density<24 (*)	140.0	137.8	139.8	139.9	139.8
2003-2010 Type-3 density>24 (**)	60.0	68.7	60.9	60.3	60.7

(*) 70% of type-3 accidents (**) 30% of type-3 accidents

Table 3. Observed and predicted speed and density, according to speed limit compliance assumptions

Global predictions speed, density, accidents	Observed	FDs	$\tau=100\%$	rate $\tau=50\%$	$\rho=50\%$
Speed (km/h)	93.60	88.04	89.33	91.47	90.30
Decrease for the 99 Type-2 accidents	0.00	-13.10	-10.50	-5.50	-8.20
2009-2010 millions vehicle-km density<24	652.30	641.90	651.20	651.90	651.40
2009-2010 millions vehicle-km density>24	71.50	82.00	72.60	71.90	72.40
% vehicle-km density>24	9.88%	11.32%	10.03%	9.94%	10.00%
% increase in high density vehicle-km	0.00%	14.60%	1.50%	0.60%	1.20%
2003-2010 Accidents (total)	345.00	338.40	335.20	339.70	337.30



Empirical speeds are rather low compared with the actual speed limits, but the predicted FDs are lower even by medium density; their use leads to a big decrease in speed, bringing high densities instead of medium densities and thus a high increase in high-density type-3 accidents. Conversely, when the new speed is a function of the speed limit and compliance (in the last 3 columns), the decrease in speed (and in the number of type-2 accidents) is lower and effective only at high speeds and low densities; the passage from medium to high density is more rare and the increase in high-density type-3 accidents is very low.

Since traffic data covers two years and accident data covers eight years, risks per vehicle-kilometre are computed with the assumption that the traffic in 2003-2008 was the same as in 2009-2010.

Table 4. Empirical and predicted risks according to speed limit compliance assumptions

Risks per 100 million vehicle-kilometres	Observed before	Predicted by FDs	Compliance $\tau=100\%$	Compliance rate $\tau=50\%$	$\rho=50\%$ (-10km/h)
Type-1 risk	1.59	1.59	1.59	1.59	1.59
Type-2 risk	3.42	2.97	3.07	3.24	3.15
Type-3 risk	6.91	7.13	6.93	6.91	6.93
Type-3 risk density<24/lane/km)	5.37	5.37	5.37	5.37	5.37
Type-3 risk density \geq 24 vehicle /lane/km)	20.98	20.95	20.97	20.97	20.96
Total risk	11.92	11.69	11.59	11.75	11.66

Type-3 risk for high density is four times greater than for low density. For 8 traffic flow regimes of the fundamental diagram, (Golob, 2004) gave the accident rate (property damage/injury/fatality) per million vehicle-miles):

- On the non-congested branch of the FD, the accident rate passes from 1.28 per million vehicle-miles (light flow) to 1.49 (mixed free flow), then 1.03 (heavy, variable free flow) and lastly 0.55 (approaching capacity).
- On the congested branch of the FD, the accident rate passes from 1.24 (heavy flow at moderate speed) to 2.97, then 3.21, and lastly 5.99 (heavily congested flow).

Since in (Golob, 2004) the units differ from ours, and injury/fatality accidents are only in 28% of his accident database (which includes property damage), multiplying these accident rates by $100 \cdot 0.28 / 1.852$ is required before any matching with our results. Having said this, what is important is the range of the accident rate according to the traffic flow regime (which is very high in both researches) rather than the numerical values.

The accident count decreases from 345 to 338.4 (-1.9%); in the case of full compliance with the new speed limits it would reach 10.5 accidents (3% of the accidents). This decrease might be underestimated, due to conservative approximations:

- Use of average speeds, which decrease the link between speed and number of accidents.
- The factor $(V/V_b)^{2,3}$ has been applied here on the average speed and an “average lane” over the two years 2009-2010, and not for each 6-minute period (weighted per vehicle-kilometre) and lane. Given the convexity of the function $(x)^{2,3}$, the application of this function on the average is greater than the average of the applications on every point; thus $(V/V_b)^{2,3}$ is overestimated (although remaining less than 1), leading to an overestimated speed and an underestimation of the decrease in accidents.
- No decrease in the risk of accidents concerning several vehicles at low density, although relative speed should decrease; no decrease in type-1 accidents (due to fatigue), although it should be easier to control a slower vehicle.
- The night speed exponent (between 4.1 and 6.1, see Table 1.) was discarded because it was insignificant, and because type-1 accidents were not excluded from the calibration set.
- The rain exponent was discarded because it was insignificant; the predicted decrease in accidents should be higher.

Three problems have not been considered here, due to a lack of knowledge for modelling them:

- A possible change in lane assignment and thus in density in certain lanes;
- An increase in motorcycles between the lanes.
- Inside a lane, an increase in relative speed if some drivers comply and others not.



Results are highly sensitive to the speed model. This becomes more evident when the two parts of the network are analysed independently. In “interurban areas” A, C, D (where the speed limit decreases from 130 km/h to 110 km/h) and “urban areas” E, F, G, I (where the speed limit decreases from 110 km/h to 90 km/h), variations in speed (and therefore in the number of accidents) are quite different, as shown in Tables 5-6.

Table 5. Observed accidents and predicted accidents, interurban part

130 km/h → 110 km/h	Observed before	Predicted by FDs	Compliance $\tau=100\%$	Compliance rate $\tau=50\%$	$\rho=50\%$ (-10km/h)
Average speed	102.4	89.7	101.4	101.9	101.4
Type-2 accidents	44.0	32.5	42.9	43.4	43.0
Millions vehicle-km, density <24	235.3	228.4	235.3	235.3	235.3
Millions vehicle-km, density >24	11.8	18.7	11.8	11.8	11.8
Type-3 accidents, low density	30.8	29.9	30.8	30.8	30.8
Type-3 accidents, high density	13.2	20.9	13.2	13.2	13.2
Type-2+ Type-3 accident decrease		-4.7	-1.1	-0.6	-1.0

Table 6. Observed accidents and predicted accidents, urban part

110 km/h → 90 km/h	Observed before	Predicted by FDs	Compliance $\tau=100\%$	Compliance rate $\tau=50\%$	$\rho=50\%$ (-10km/h)
Average speed	89.1	87.2	83.1	86.1	84.5
Type-2 accidents	55.0	52.4	46.1	50.4	48.2
Millions vehicle-km, density <24	417.0	413.5	416.0	416.6	416.2
Millions vehicle-km, density >24	59.7	63.3	60.8	60.2	60.6
Type-3, accidents low density	109.2	108.3	108.9	109.1	109.0
Type-3, accidents high density	46.8	49.6	47.6	47.1	47.5
Type-2+ Type-3 accident decrease		-0.7	-8.4	-4.4	-6.3

Because of the non-linearity of the power model, the decrease in type-2 accidents is not “additive”, i.e. equal to the sum of the decreases obtained when the power model is applied independently on the two parts (urban and interurban) of the network. A better application would have been to apply the power model by speed class.

Variations in the number of type-3 accidents on the urban and the interurban parts of the network are not additive either. Let:

- $N_u, N_i, N=N_u+N_i$ be the vehicle-kilometres travelled in the urban or interurban parts, or the whole network,
- $n_u, n_i, n=n_u+n_i$ be the vehicle-kilometres passing from low to high density due to the new speed limit,
- $\delta_u, \delta_i, \delta$ be the differences between the high density and the low density risks per vehicle-kilometre.

The variations in the number of type-3 accidents are respectively $n_u \cdot \delta_u, n_i \cdot \delta_i, n \cdot \delta$. However $(n_u+n_i) \delta \neq n_u \cdot \delta_u + n_i \cdot \delta_i$, since δ is an average between δ_i and δ_u , weighted by N_u and N_i and not by n_u and n_i (Tables 5-6).

With the FD model, most decreases in accident count are obtained in the interurban part (Table 5), where speed decreases from 102.4 to 89.7 km/h; in the urban part, when the speed limit passes from 110 km/h to 90 km/h (Table 6) the speed and accident decreases are very low. It is quite the opposite with the full compliance model (speed decreases from 89.1 to 83.1 km/h on the urban part)! There are two possible explanations:

- An underestimation of the speed in the FD established for a 110 km/h speed limit would imply an overestimation of the decrease in accidents (Table 5) when passing from 130 km/h to 110 km/h, and an underestimation of the decrease in accidents when passing from 110 km/h to 90 km/h (Table 6). Indeed, the speed in the central lane, in the 110km/h FD (Fig.2b), is always less than 100 km/h, which means that following this FD leads to a lower speed than compliance in the 110 km/h speed limit. In the fast lane (Fig.2c) the FD speed is always less than 110km/h. The FD speed was not really underestimated, but using for the interurban part of the network an FD coming from the urban part of the network, where the network



configuration (with more ramps) and driver behaviour are different, is questionable. Furthermore, is it correct to say that, regarding the urban part of the network, a speed lower than 100 km/h or 110 km/h has incited traffic operators to decrease the speed limit?

- Low compliance with the 90 km/h speed limit in France, which limits the decrease in accidents (Table 6).

6. The fourfold validation of the approach.

The approach is based on two traffic models and on two models linking traffic conditions to accidents. Some assumptions intervene either in the models themselves, or in their calibration, or in their use. Validation will therefore concern the models, their calibration, their use and the results.

6.1. Validation of the models

Two traffic models are used to predict the traffic conditions, and two models linking accidents to traffic:

- The first traffic model (prediction of what will be), based on FDs, does not manage a change in the queues from one period to the next. Changes in lane assignment are also ignored. If, when considering the ex-post traffic conditions, these assumptions are not validated, the use of a simulation model is required.
- The second one (prediction of what should be) replaces the actual speed (when higher than the new speed limit) by a function of this limit, based on the compliance rate. This must be applied on individual (and not average) speeds. The impact of aggregation will be computed in a network where individual speeds are available (like the Marius network) in order to validate or invalidate this model.
- The form of the relationship between speed and accident (the power model) is commonly accepted by the scientific community, although confidence in the exponential model is progressing.
- The accident/ density relationship is simplified, thanks to the assumption that there will be no change in the density distribution, conditional to density < 24 vehicles/lane (respectively density > 24 vehicles/lane). If this is not validated, the calibration and use of another model is required.

6.2. Validation of the calibrations

New calibrations of the relationships between traffic conditions and accidents (for instance with the ALLEGRO traffic and accident database, on the before period) will validate/invalidate the relationships used:

1. For the first accident type, validating “no relationship with traffic condition” requires, first of all, the calibration of a model such as a logistic model linking the risk of accident to speed and/or density. In the second step, the part of the accident variance explained by this model has to be analysed. The logistic model can be withdrawn (e.g. the assumption that there is no relationship for type-1 accidents is validated) if this part of the variance is low (10% or 20% of the variance, say) or if the parameters α' obtained are close to zero.
2. For the second accident type, a new calibration α' of the exponent of the speed power model is necessary.
3. For the third accident type, a new calibration of threshold separating low and high densities is necessary.

Let traffic operators define, by type of accident, a maximum bias (positive or negative) on the predicted accident count. It is possible to convert these biases into positive and negative deviations round parameters α of the relationships linking accident counts with the traffic conditions, and thus to define an “acceptable” interval round α ; the relationships used will be validated if α' falls within this interval.

6.3. Verification/Validation of the use of the models

- It is not recommended, in a speed limit reduction framework, to use traffic conditions/accident relationships that are calibrated without any specific speed limit decrease. But road safety measures cannot wait.
- Using the 110 km/h FD which has been calibrated on an urban network for an interurban network is questionable; this urban FD should be compared with the ex-post interurban one.

6.4. Comparisons with the final results

- An ex-post analysis of the traffic conditions will improve the understanding of the speed limit reduction, and will validate/invalidate the predicted speed and occupancy distributions. The distance between the predicted and the new empirical distributions can be measured by the Kullback–Leibler divergence (Kullback, 1987), which is the basis of the Akaike Information Criterion, or tested using the Kolmogorov–Smirnov statistics. A discrepancy between the two distributions corresponding to a shift of 2 or 3 km/h in speed seems acceptable.
- Unfortunately, due to the low number of accidents, it is not expected that the comparison of the ex-post accident count with the ex-ante prediction will provide statistically significant elements for validation.



7. Conclusions.

A speed limit decrease generally induces a decrease in the road injury and fatality accident count. This paper presents a method for the ex-ante assessment of such a decrease, and its application on a French motorway network. Some results on the calibration and the use of relationships linking traffic density or speed to accident counts are given. The envisaged decrease in the speed limit by 20 km/h should lead to a 1.9% decrease in the accident count with the current compliance, and to a 3% decrease with full compliance. These figures are a trade-off between a null trend for certain accidents (due to driver or vehicle failure), a decrease in accidents linked to speed, and an increase in accidents linked to a high density. However, this prediction is very sensitive to the traffic and safety models, to their calibration and to the conditions of their use.

Breaking down the prediction into the urban and interurban parts of the network shows that most decreases are located on the interurban part of the motorway network (4.7 accidents) where the speed limit decreases from 130 km/h to 110 km/h and the average speed decreases by 13.7 km/h. On the urban part, where the speed limit decreases from 110 km/h to 90 km/h, the predicted speed and accident decreases are much lower (0.7 accidents).

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