ADDED RISK IN CASE OF RAIN: SOME RECENT RESULTS FOR FRANCE

R. Bergel[a], H. Rattaire[a,b], M. Aron[a], D. Doucet[c], E. Violette[c].

[a] UPE-INRETS/GRETIA - University Paris-Est, National Institute for Transport and Safety Research, Marne la Vallée, France
Ruth.bergel@inrets.fr
Maurice.aron@inrets.fr
[b] INSA - Institut National de Sciences Appliquées, Toulouse, France
Hugues.rattaire@free.fr
[c] CETE Normandie-Centre
David.doucet@developpement-durable.gouv.fr
Eric.violette@developpement-durable.gouv.fr

Abstract:
This paper provides some results demonstrating the impact of rain on road safety for France. The risk of injury accident and the added risk in case of rain are estimated for several types of injury accidents which occurred in France for the period 1995-2008. Estimations cover the whole of France, in average and according the category of network and element of the road. These results are relevant as they will contribute to implement specific road safety measures.

The risk of injury accident in case of rain is defined as the number of injury accidents per vehicle-kilometre by rainy conditions. The added risk in case of rain is defined as the ratio of the risk of injury accident by rainy conditions divided by the risk of injury accident by no rain. As the number of vehicle kilometres is partly unknown, the rain duration is used in this paper in the place of the number of vehicle-kilometres by rainy conditions. An approximation of the added risk is thus derived. For computing these estimations, two data sources related to injury accidents and rain duration were used: the BAAC (the French Injury Accident File) and Météo-France.

In addition, the changes in the added risk in case of rain over the period 1995-2008 are described with the help of time series analysis techniques. The results are commented in relation with more detailed results obtained for the Haute-Normandie region in France, and recommendations for improving the computation method are given.

Key-words: time series analysis; road safety; injury accidents; accident risk, added risk, rain.

ADDED RISK IN CASE OF RAIN: SOME RECENT RESULTS FOR FRANCE

R. Bergel[a], H. Rattaire[a,b], M. Aron[a], D. Doucet[c], E. Violette[c].

[a] UPE-INRETS/GRETIA   - University Paris-Est, National Institute for Transport and Safety Research, Marne la Vallée, France
Ruth.bergel@inrets.fr
Maurice.aron@inrets.fr
[b] INSA - Institut National de Sciences Appliquées, Toulouse, France
Hugues.rattaire@free.fr
[c] CETE Normandie-Centre
David.doucet@developpement-durable.gouv.fr
Eric.violette@developpement-durable.gouv.fr

1.   Introduction

Rainfall reduces the driver's vision and the friction of the vehicle on the roadway. The driver does not lower the speed of the vehicle accordingly, which induces a risk of running-off the road and a risk of rear end collision.
The researches led on these topics aim to improve the knowledge of the level of the additional accident risk in the case of rain, and, consequently, to implement safety preventive measures.

This paper is dedicated to the first objective - to improve the knowledge of the level of the added risk in case of rain. It provides aggregated results for the whole of France (Rattaire, 2009) which are compared to previous results obtained for a French region, the Haute-Normandie region, in the framework of the French project PREDITT (2004-2008) IRCAD-SARI[1] (Aron et al, 2006, 2007),

Following this introduction, a state of the art of the knowledge on the topic is briefly presented in section 2. The method for computing the injury accident risk and added-risk in case of rain is described in section 3. The estimated values for the accident risk and added risk are given in section 4, first for the Haute Normandie region and second for the whole of France. In section 5, some bias and limitations are discussed. We finally recall the results obtained, and give some research directions in order to improve them.

2.   Previous results

After reviewing 14 studies addressing the relative risk in case of rain or snow, Andrey et al. (2003) found a 70% increase in the risk of injury in case of rainfall in Canada.

---

[1] The 2004-2008 French program SARI, funded by the French Ministry of Transport and managed by LCPC (the French Public Works Research Laboratory) aimed to install on the road network a warning sign system to alert drivers at moments there is a risk of running off the road, due to a poor adherence between the road and the tires. The sub-project IRCAD addressed the meteorological risk. Researches were led in three directions prior to the experiment: the drying of the roadway after the rain, the risk of running off the road according to the vehicle and driver's characteristics and according to the dynamic of the vehicle during rain, wind and wet roadway, and the added-risk in case of rain –see Aron *et al.*, (2006, 2007). This third topic is discussed in this paper.

Keay and Simmonds (2006) noticed that, in Melbourne, the rain has an effect on the accident frequency and that this effect varies with the period in the day. They also demonstrated, as Lee & Saccomanno (2002) did before, that the amount of rainfall has a significant impact on accident occurrence.

In France, according to the French National Road Safety Observatory (ONISR, 2005), the proportion of road collisions during inclement weather was around 16% for the period 1995-2004, and 86% of these accidents occurred during rainfall. Rainfall is one of the weather variables used for monitoring the road safety level in the short term, both on a daily and monthly basis with the Giboulée model(Bergel et al., 1995) and is also explicitly used for explaining the road safety level in the medium term (Bergel, Depire, 2004).

A review of time series modelling of the road safety level at national level confirms that, among all weather variables, rainfall is the most significantly correlated to the number of injury accidents and victims(.see for instance (Scott, 1986), (Gaudry, Lassarre (Eds.), 2000), (Stipdonk(Ed.), 2008).
Researches have therefore focused on the value of his additional risk of injury accident (or added risk) due to rain.
Previous studies stated that the added-risk in case of rain is about 2 *(Le Breton 1990)* or comprised between 2 and 3 (Brodsky and Hakkert, 1988). In the case of France, studies led by both CETE of Normandie-Centre (the Technical Study and Engineering Centre of the French Ministry of Transport) and LCPC stated that the speed behaviour of drivers does not change sufficiently during adverse weather conditions, regarding the decrease of the braking performances of the vehicles (CETE, 2001). The availability of accurate and various weather data on the one hand, and of a huge traffic volume data set collected by CETE on the other hand, made it possible to estimate the value of the added-risk in case of rain accurately.

3.   Method

3.1.   Risk and added risk formulas

For a set of road sections A, and for a set of hours $h \in H$, let:

Q_R^h be the traffic volume for the hour h on the section r

Q_r be the total traffic volume on the section for the period H

$N_r^h(w)$ be the number of injury accidents for the hour h and weather condition w

$\alpha_r^h(w)$ be the proportion of the time during the hour h with the weather condition w

Lr   be the length of the road section r.

The risk[2] (number of injury accidents by vehicle kilometre) for that weather condition w is:

$$R(w) = \frac{\sum\limits_{r \in A} \sum\limits_{h=1}^{H} N_r^h(w)}{\sum\limits_{r \in A} L_r \sum\limits_{h=1}^{H} \alpha_r^h(w).Q_r^h} \qquad (1)$$

The added risk in case of rain, noted ρ, is the ratio R (rain)/R (no-rain):

---

[2] The term risk (in the place of "risk of injury accident") is used in this paper for commodity reasons.

$$\rho = \frac{\dfrac{rain\_accidents}{norain - accidents}}{\dfrac{rain\_vehiclekilometers}{norain\_vehiclekilometers}} = \frac{A}{K} \qquad (2)$$

where $A = \dfrac{rain\_accidents}{norain\_accidents}$ and $K = \dfrac{rain\_vehiclekilometers}{norain\_vehiclekilometers}$

3.2. Approximation

In (Saint-Pierre et al, 2007) a calculation is developed in order to take into account in K an incomplete information on the traffic variation in the case of rain., In this paper, the calculation will be done with the assumptions :

- either that there is no traffic variation in the case of rain. Then the ratio K is equal to the ratio $D = \dfrac{rain\_duration}{norain\_duration}$. These durations are known in all places where meteorological stations are installed, and its is widely assumed that, due to the number of installed meteorological stations, rainfall duration is well known, apart from very particular places;

- or that the traffic decreases by δ which amounts to 1% or 2% during rain (figures validated on rural roads for light vehicles and trucks (Keays & Simmonds, 2005) (Khattak & de Palma, 1997). Thus K=(1- δ) D and an approximation of the added risk is given by:

$$\rho = \frac{A}{(1-\delta)D} \qquad (3)$$

With these approximations, the calculation of the added risk is even possible when traffic data by rainy conditions are not available.

Formulas (1), (2) and (3) can be applied to categories of accidents, categories of vehicles (if the traffic demand or its changes during rain periods is known by type of vehicle) and categories of networks.

Even if the total length of elements of the road (bends, grades, intersections) is unknown and to compute the risk on these elements is thus not possible, the added risk by type of element is given by formula (3) - there are no more and no less curves on the road during rainfall than during no rain!

4. Results

4.1. The Haute-Normandie region

The 6 minutes rain gauge information from two French stations (Rouen and Evreux) has been validated with 1 minute human information f. A logistic regression model has been calibrated for each station, which led to increase the rain duration at Rouen and at Evreux. These adjusted meteorological data and the injury accident occurrence extracted from the French accident data files "BAAC" (Bulletin d'analyse des accidents corporels) have then been processed for the years 1995-2004.

By using hourly traffic counts available for the years 1997-2003 on 54 road sections of the region, the injury accident risk per vehicle-kilometre was estimated at 10 accidents for 100 millions of vehicle-kilometres during no rain periods, and at 20 accidents 100 millions of vehicle-kilometres during rain: the added risk, computed on these 54 counted sections, is thus *close to 2* (Saint-Pierre &all, 2007). However, when computing it all road stations of the region (and not only on the 54 counted sections), the added-risk is estimated *at.1.63 only*; this decrease cannot be due only to the traffic approximation[3] A good hypothesis, which will be confirmed from the results of the following section addressing the whole of France, is that traffic counts are not installed on very local roads where the risk is already high during no rain, and where the added risk[4] is relatively low.

On bends*, t*he added risk is higher (***1,9 in the place of 1,63***); among these accidents on bends, the added risk takes its highest value for front collisions (2.8), then for rear end or side-way collisions (2.2), then for isolated vehicles (1.6).
In intersection, the added risk is lower (1.5)
However the preceding remark about the influence of the non-rainy and non-wet periods on the added risk value is relevant in the case of bends, since the water evacuation and the drying of the road must be shorter because of the elevation in curves, which leads to increase the value of the added risk in the case of rain. This remark also applies to the added risk value on grades.

4.2.   The whole of France [5]

The 6 minutes rain gauge information from about a hundred of French meteorological stations and the injury accident information[6] extracted from the French accident data files "BAAC" have been processed for the years 1995-2008. Estimations of the added risk values for the whole of France were provided on a monthly basis over the period, and the raw values were still smoothed using a 12 months centered moving average filter (see Figure 1: Added risk in the case of rain for the whole of France for 1995-2008, raw data and smoothed data).
.A disaggregation according to several parameters (type of network, built-in/non built in areas, elements of the road) was also provided.

4.2.1.   The whole of France: average

The added risk appears high (***2.4 in average in 2004***)[7]. The trend is a decrease, from ***2, 8 in 1995, to 2, 4 en 2000 and to 2, 2 since 2005***.
This decrease is concomitant with a general decrease in the number of injury accidents, which has different causes: the road surface has been improved, the stability of vehicles has been enhanced, among others.
The introduction of the speed enforcement policy, launched in France at the end of 2002, resulted in a significant decrease of the practised speed (see ONISR, 2005), and undoubtedly played an important role in these decreasing trends, particularly from 2003 onwards.
 Although the rain duration was especially high during the year 2003, the trend of the number of accidents in case of rain decreased and the added risk in case of rain significantly decreased (Rattaire, 2009) during the year.

---

[3] According to our approximation, there is no traffic decrease due to rain
[4] According to our definition of the added risk
[5] We consider the "Metropolitan" France, i.e. the historical France inside its natural borders.
[6] Injury accidents with motorcycles have been disregarded here, since the decrease of motorcycles traffic during rain is likely to be significant but is not known

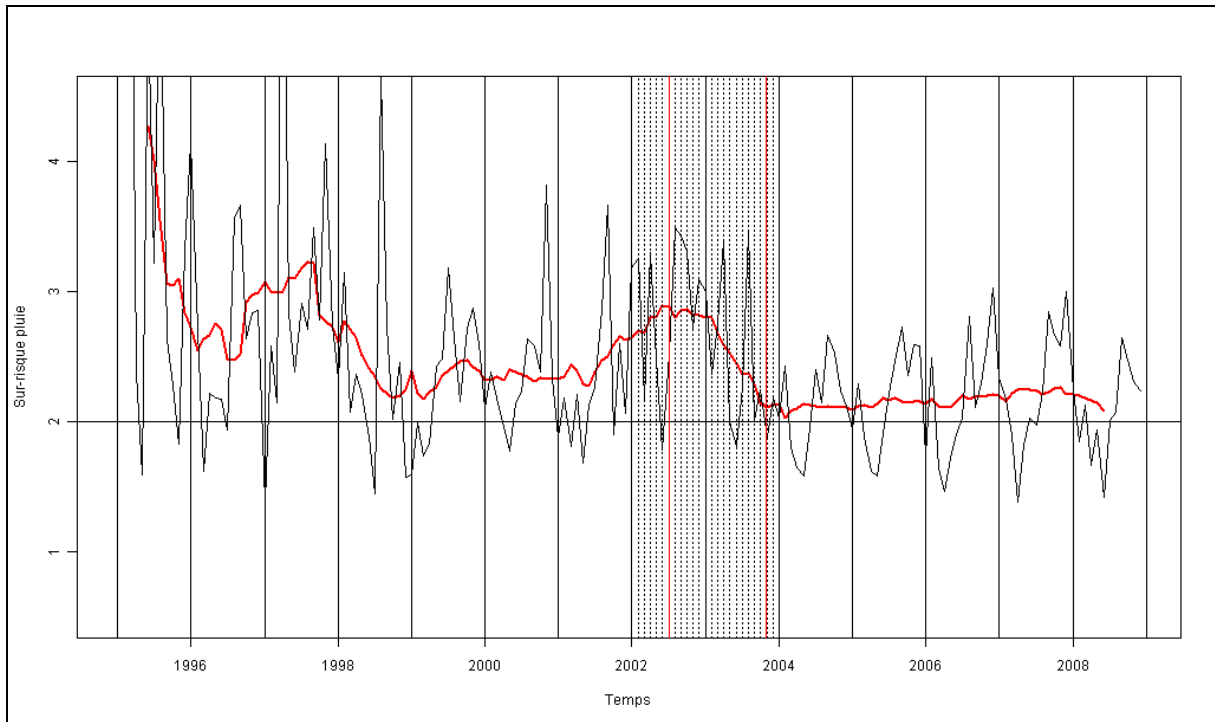[7] partly due to the fact that no correction on the rain duration has been brought

Figure 1 Added risk in the case of rain in France for 1995-2008 (raw and rmoothed data)

4.2.2.   The whole of France: type of network

In France as in other countries, motorways and local minor roads are at the two extrema of the security level (see Table 1: Risk by rain/no rain, according to several networks, for the years 2000 and 2005).

Table 1 provides the levels of risks for two particular years, before and after the speed enforcement implementation which took place in France in 2002. The decrease of the risk over time is clear.

Considering the type of network, the level of the risk increases from motorways to main roads, and to local roads.
.

	Motorways		Main Roads		Local Roads		Built-in Areas (*)		Total	
Year	2000	2005	2000	2005	2000	2005	2000	2005	2000	2005
Overall Risk	5	3	9	5	12	7	20	13	14	09
No rain	5	3	8	4	11	6	18	12	13	08
Rain	12	7	24	12	25	14	41	23	30	17

 (*) *More than 5,000 inhabitants. On built-in areas these figures must be taken cautiously, since the traffic levels on built-in areas are uncertain*
Source: BAAC, ONISR, Union Routière de France

Table 1. Risk (Number of Accident by 100 million vehicle kilometre) by rain/no rain, according to several networks, for the years 2000 and 2005

As far as added risk in case of rain is concerned (see Table 2.Added risk according to the year and to the type of network**,** this range is not valid as there are two risk playing a role: the network and the rain. Indeed, in 2005 for instance, the added risk is the highest on main roads (2.64), second on secondary roads (2.41 on our "routes départementales") and on motorways (2.38), third on minor roads (1.88 on our "voies communales"). The added risk decreases from 2000 to 2005 by about 0.2 for every type of network, with the only exception of the secondary roads, for which the added risk value was unchanged.

Years	End of 1995	2000	2005
Autoroutes (Motorways)	3.5	2.58	2.38
Routes Nationales (Main roads)	3.4	2.80	2.64
Routes départementales (Secondary roads)	2.9	2.42	2.41
Voies Communales (Minor roads)	2.5	2.09	1.88

Source: BAAC, ONISR.

Table 2.Added risk according to the year and to the type of network

4.2.3. The whole of France: inside/outside built-in areas

The added risk is higher outside built-in areas (2.6 in 2000 and since 2005) than the average value for the whole of France, and thus than inside built-in area (2 in 2005) (see.Table 3. Added risk according to the year and to inside/outside built-in areas.

It would be interesting to compute these two types of added risks according to the type of accident, to the period in the day, to the type of vehicles, in order to find an explanation to the differences of levels. Besides, the traffic flow is not very well known in built-in areas; and the assumption of an equal traffic whatever the meteorological condition need to be validated. .

The decrease in the trend of the added risk in built-in areas (from 3 in 1995 to 2 in 2005) is much more significant than the decrease in the trend outside built-in areas (from 3 in 1995 to 2.6 in 2000 and 2005). The reason of such differences in the trends may be the respect of the speed limitation in urban areas.

Years	End of 1995	2000	2005
Added Risk			
France	3.0	2.38	2.18
Built-in areas	2.8	2.24	1.95
Outside Built-in areas*(*)*	3.2	2.56	2.55

(*) outside built-in areas of more than 5,000 inhabitants

Source: BAAC, ONISR.

Table 3. Added risk according to the year and to inside/outside built-in areas.

4.2.4. The whole of France: elements of the road

It is well known that the added risk in case of rain varies according to some elements of the roadway (Shankar et all, 1995)(Shankar et all (2004).

Years	End of 1995	2000	2005
Bends (outside inters.)	4.3	3.75	3.47
Straight section (outside inters.)	2.8	2.05	1.86
Straight section (inters.)	2.5	2.26	2.12

Source: BAAC, ONISR.

Table 4. Added risk according to the year and to some elements of the road

In France, the added risk reaches its highest value on bends (3.5 from 2005 onwards). On straight sections (outside intersection) its value is below the average (1.9 from 2005 onwards). The decrease of the added risk between 1995 and 2005 is significant and about the same (0.9)

on bends and on straight sections (outside intersection). The added risk value at intersections is intermediate (2.1 from 2005)(see Table 4.Added risk according to the year and to some elements of the road).

5.   Discussion

The preceding results obtained for the whole of France are subject to bias as the rain duration is often under-estimated when it is measured with rain gauges. In addition, the influence of a wet roadway and of the presence of two-wheelers in the traffic flows need in all cases to be studied apart.
Nevertheless, the comparison of the added risk values according to several parameters, and the comparison of the trends of the added risk values for these categories are valid.

5.1.   Possible bias

A rain gauge containing 0.2mm of water tips over each time it is full. However the rain duration may be under-estimated due to the evaporation, or to some block off of the gauge. A validation of a French rain gauge was carried out, and showed an important under-estimation. With an under-estimation of c= %, the observed rain duration must be divided by (1-c). Thus the ratio D, defined in section 3.1, becomes:

$$\rho = \frac{rain\_duration}{(1-c)(norain\_duration) - c(rain\_duration)} \quad (4)$$

On the contrary, in the case of the Haute-Normandie region (see section 4.1), the computation of the added risk is not subject to this bias, as the measure of the rainfall was validated by human information.

5.2.   Influence of a wet roadway

It is widely accepted that risk increases during no-rain periods for which the roadway surface is still wet. A number of roadway surface treatments, improving the friction, have been proved to reduce the risk of accident during no rain period for which the roadway surface is still wet. It should be reasonable, rather than matching the accidents during rain and no-rain periods, matching accidents during rain versus accidents during {no-rain and non-wet} periods in order to identify the effect of rain. Let us take an example. If the added risk during these periods were quite also important that during rain, and if the total duration in the year on the no-rain & non-wet periods were very little, the added risk in case of rain would systematically appear close to the value one.However it is very difficult to quantify the drying time of the roadway and thus to estimate the risk or the added-risk in these periods.

5.3.   Influence of two-wheelers traffic

It is not possible to accept the assumption that the two-wheelers traffic does not decrease or decrease by δ= 1% or 2% only during rain. This assumption leads to an underestimation of the added risk in case of rain for two-wheelers, and therefore of the general added risk in case of rain. Moreover, as the percentage of traffic and accidents of two-wheelers increase in France, an apparent decrease of the added risk over time could be due to this assumption.

6.   Conclusion and perspectives

The results confirm that the level of the added risk in case of rain is around 2, but may differ from 2 in a relevant manner.

The most detailed computation carried out on all rural roads of Haute-Normandie leads to a lower value (1, 6 only, whereas it is 2 when the computation is carried out on counted road sections only).

A more approximate computation carried out for the whole of France provides higher values (2.4 in average in 2004, the estimations ranging from 1.9 to 2.6 according to the network and road characteristics). These aggregate results underestimate the rain duration and thus over estimate the added risk in case of rain.

However, the analysis of the changes in the added risk value wrt time is valid.
A downward trend (the added risk decreased from 2.8 in 1995 to 2.2 from 2005 onwards) appears over the period 1995-2008. That relevant reduction in the level of the added risk in case of rain is concomitant with an increase in the security level, as the risk of accident decreased over the period.

Three research directions for improving these results can be mentioned. The influence of a wet roadway and of the two-wheeler' risk has to be taken account of. At last, the impact of rain on the injury accident severity remains to be studied.

7. Acknowledgements

8. References

Andrey J., B. Mills, M. Leahy and J. Suggett. (2003) Weather as a Chronic Hazard for Road Transportation in Canadian Cities. Natural Hazards, Vol. 28, pp. 319-343.

Aron M., Bergel R., Louah G., Violette E. (2006) Sur-risque par temps de pluie, rapport du WBS 1.6 du Projet PREDIT IRCAD-SARI,, 107 pages, Arcueil

Aron M., Bergel-Hayat R., Saint-Pierre G., Violette E. (2007) Added risk by rainy weather on the roads of Normandie-Centre region in France. Some elements for the French IRCAD-SARI traffic monitoring and information system for drivers and operators WCTR, Berkeley

Aron M., R. Bergel, G. Saint Pierre and E. Violette (2006) Added risk in case of rain. Project IRCAD, program SARI, report of WBS 1.6 (in French).

Bergel R., Depire A. (2004) *Climate, road traffic and road risk - an aggregate approach.* Actes de la Conférence WCTR'2004, Istambul.

Bergel R., Girard B., Lassarre S., Le Breton P. (1995) **"*A model of seasonally corrected indicators of road safety*"**, Proceedings of the Conference Road Safety and Strategic Highway Research Program (SHRP) and Traffic safety on two Continents, Prague, September 20-22

Brodsky H. and S. Hakkert (1988) Risk of road accident in rainy weather. Accident Analysis and Prevention, Vol. 20, n°3, pp. 161-176.

CETE de Normandie Centre, DESGI (Division exploitation Sécurité Gestion des infrastructures) (2001). Accidents by rainy weather. Drivers behaviour. Bends on two-lanes road/ Departmental road RD928.

Fridstrom L. et al. (1995) **"Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts"**, *Accident Analysis & Prevention*, Vol. 27 n°1 p.1-20.

Gaudry M., Lassarre S.   (2000) *Structural Road Accident Models - The International DRAG Family*, Pergamon.

Keay, K. and Simmonds, I. (2005) The association of rainfall and other weather variables with road traffic volume in Melbourne, Australia. Accident Analysis and Prevention, 37 pp 109-124.

Keay, K. and Simmonds, I.. (2006) Road accidents and rainfall in a large Australian city. Accident Analysis and Prevention, Vol. 38, pp. 445-454.

Khattak, A.J., DePalma, A., (1997). The impact of adverse weather conditions on the propensity to change travel decisions: a survey of Brussels commuters. Transportation Res. A Policy Pract. 31 (3), 181–203.

Le Breton P. (1990) Study of the rain impact on road safety (main roads and motorways). Statistical analysis. Note d'information SETRA-CSTR N° 77.

Lee C., F. Saccomanno and B. Hellinga. (2002) Analysis of Crash Precursors on Instrumented Freeways. In Transportation Research Record 1784, TRB, National Research Council, Washington D.C., Paper n°02- 3790

ONISR(2005)The major themes of road safety - rain (results 1995-2004) (in French) http://www.securiteroutiere.equipement.gouv.fr/IMG/Synthese/Pluie.pdf Accessed July 25. 2006.

Rattaire H. (2009) Sur-risque pluie en France métropolitaine. Rapport de stage INSA, sous la direction de M. Aron et R. Bergel, INRETS, Marne-la-Vallée.

Saint Pierre G., M. Aron M., R. Bergel (2007) Reconstruction from various weather-related data sets using logistic regression: methodology and applications, proposed paper n°07-0916, TRB, 2007

Scott P. P. (1986) **"Modelling Time-Series of British Road Accident Data"**, *Accident Analysis & Prevention*, Vol. 18 n°2 pp.109-117.

Shankar V.N et al. (1995) Effect of roadway geometrics and environmental factors on rural freeway accidents frequencies. Accident Analysis and Prevention, 27 n°3 pp 371-389

Shankar V.N. *et al.* (2004) l Impacts of Design, Traffic, Weather, and Related Interactions on Roadside Crashes. In *Transportation Research Record 1897,* TRB, National Research Council, Washington D.C., pp. 156-163.

Stipdonk H. (Ed) (2008) *Time series applications on road safety developments in Europe*. Deliverable D7.10 of the EU FP6 project SafetyNet. http://www.erso.eu

————————