CLIMATE, ROAD TRAFFIC AND ROAD RISK: AN AGGREGATE APPROACH

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Abstract

This paper aims at analysing the influence of climate on the number of injury accidents and fatalities, aggregated for the whole of France, and for each main network category (main roads, motorways, secondary roads and urban roads).

A time series analysis including exogenous variables has been developed for each indicator of accident risk and gravity, on a monthly basis for the period 1975-1999. Risk exposure, when available, and transitory risk factors such as climate and calendar configuration have been taken into account. The climate variables measure rainfall and temperature. Both monthly averaged variables and atypicity variables – which take into account the extreme climate values in the month – have been used as climate variables.

The results of this analysis show significant links between the climate variables and the risk indicators, on the whole of France and on network categories as well. On main roads and motorways, the two road categories on which the traffic volume is measured on a monthly basis, the global effect of climate has been separated in two components: its direct effect on the number of injury accidents and fatalities, the traffic volume being constant, and its indirect effect via the traffic volume.

Variations of the risk level have been highlighted in certain situations, under the influence of rainfall and temperature variations. These aggregate results need to be analysed further on a daily basis, and the links with behavioural variables need to be studied, in order to complete these first results.

Keywords: Aggregate; Climate; Temperature; Frost; Rainfall; Road traffic; Road risk; Injury accidents; Fatalities
Topic Area: C2 Safety Analysis and Policy

1. Introduction

At a national level, risk models relate aggregate risk indicators to aggregate risk factors.

Time series models with explanatory variables – or exogenous variables -, constructed on a monthly basis and over a long period, constitute an appropriate tool for analysing the development of risk indicators, for taking into account a set of variables associated to risk factors and for assessing road safety measures, in the frame of a systemic approach (Hakim and al., 1991).

The variability of risk indicators, measured on a monthly basis is high and is largely due, obviously, to transitory factors. Weather conditions and calendar configuration, which can differ considerably from one day to the next, still differ from one month to the next when aggregated or averaged at a monthly level.

A bibliographical review of the first aggregate risk models developed on a monthly basis (Lassarre, 1994) highlights the different types of variables usually associated to risk factors. In addition to a variable measuring risk exposure - the number of vehicle-kilometres, when available - and to one or two economic variables - economic growth, the price of fuel -, a few variables associated to transitory factors - weather and calendar - help to account for a large part of the variance of monthly data. The influence of the climate is often modelled with the help of quantitative meteorological variables: the meteorological phenomena measured are at minima rain and temperature (Scott, 1966), but can also be quite numerous (Fridstrom and al., 1995). Obviously, the climate itself being dependant on geographical situation, the choice and the number of the meteorological phenomena significant at a national level has to be flexible.

In those aggregate models, the climate factor is a risk factor. Its influence on the two risk indicators – the accident's risk and the risk of being a victim in an accident - is modelled with the hypothesis that risk exposure, which the models takes into account, is constant. But climate also influences risk exposure, and the two levels of risk indirectly. Can one possibly evaluate these two direct and indirect effects - via the traffic volume – of the climate on the risk of accident and on its gravity?

2. Problematics

In the frame of the DRAG approach (Gaudry, 1984), three levels have been considered: risk exposure, accident risk and accident gravity. By using the same exogenous variables for modelling risk exposure, and the two risk levels as well, one can evaluate both their direct effect on the two risk levels, and their indirect effect via risk exposure. Most of the results obtained at a national level, related to climate influence, have been achieved using the DRAG approach, and are summarised in (Gaudry, Lassarre, 2000). Detailed results obtained for France can also be found in (Jaeger, 1998).

Nevertheless, disaggregate results by network category are not often found; besides, when it is the case, considering for instance the case of the city of Stockholm (Tegner, 1997), comparisons with results relative neither to other network categories in the same country, nor to the whole country, can be found.

This paper aims at analysing the influence of climate on the number of injury accidents and fatalities – the two main indicators of accident risk and of its gravity -, aggregated for the whole France, and for each main network category (main roads, motorways, secondary roads and urban roads).

On main roads and motorways, the two road categories on which the traffic volume is measured on a monthly basis, the direct effect of climate on the number of injury accidents and fatalities – the traffic volume being constant -, and the indirect effect of climate via the traffic volume, should be evaluated separately. On the other network categories and on the whole of France, the global effect of climate alone can be evaluated.

The question of how to measure climate is not simple. The climate variables can be qualitative – coding different types of weather (Ghilain, 1992) -, or quantitative – measuring meteorological phenomena. What phenomena have to be considered? Are just a few phenomena to be considered in order to favour the interpretation of the parameters, or numerous phenomena in order to quantify a global effect? And finally, which sort of information will represent a climatic situation representative on a geographical territory?

The climate variables considered in this paper measure rainfall on the one hand, which is the most frequent meteorological risk factor, and temperature on the other hand, which influences mobility most directly. In addition to temperature, the occurrence of frost (presence/absence of negative temperature in the day) has also been considered. Rather than use climate data collected from a central meteorological station, we decided to gather numerous data collected all over the territory from all existing meteorological stations.

3. Method

3.1. Structure of the model

A time series analysis including exogenous variables was applied to *the monthly number of injury accidents and fatalities, for the whole of France and for each main* *network category* (main roads, motorways, secondary roads and urban roads) for the period 1975-1999.

The explanatory factors are on the one hand *risk exposure*, measured with the traffic volume on the main network – or modelled with the help of its determinants on the secondary and urban networks -, and on the other hand *the climatic and calendar factor*[1].

The meteorological variables measure *the highest temperature of the day*, *the occurrence of frost (presence/absence of negative temperature in the day) and the daily rainfall height*, averaged on the whole territory and in the month. Additional meteorological variables were also considered, in a second phase, which code the number of days in the month with extreme climate values.

3.2. The data

Monthly data were gathered, or constructed, for the period 1975-1999: risk indicators (the statistics of injury accidents and fatalities), a measure of risk exposure (the traffic volume on the main network), climate factors aggregated on the whole territory, and calendar variables. We shall only comment on the three first types of data in this paper (see Table 1 and Figures 1 to 8 - in appendix).

The number of injury accidents (accidents with at least one person injured or killed), as well as the number of fatalities (victims in an accident, who die within a period of six days), were registered in the BAAC ("Bulletin for an analysis of the injury accident").

The variable that measures risk exposure is the traffic volume – more specifically the number of vehicle-kilometres, in hundreds of billions, registered for all types of vehicles (source: SNRD " the national system for collecting data"), on our main network (main roads and motorways – both toll and free motorways).

As for the climatic factors, daily climate variables were first calculated by averaging a hundred daily variables measured at meteorological observation points spread over the whole French territory; they were then aggregated or averaged over the month, in order to construct the monthly variables. Monthly "atypicity" variables were also constructed, which code the number of days in the month for which extreme values were registered. Both averages and atypicity variables were used in the model.

3.3. Econometric specification

The model developed for each indicator is the following:

$$\Phi(B)\left[\log Y_t - \sum_{i=1}^{I}\beta_i \log X_{i,t} - \sum_{j=1}^{J}\beta_j X_{j,t} - \mu\right] = \Theta(B)u_t$$

With: Y the endogenous variable: the number of injury accidents and the number of fatalities,

[1] Calendar variables were constructed, which code the days at the end of the week (Friday/Saturday/Sunday) – this way of cutting the week enables us to model *a weekly calendar effect* -, and three classes of days in the year where driver behaviour was modified – this way of coding enables us to model *an exceptional calendar effect*). The calendar factor was modelled independently from the climate factor, and the related results are not discussed in this paper.

Table 1: The data for 1998

	Main roads	Toll motorways	Free motorways	**Main network**	Secondary roads	Urban roads	**Whole France**
Injury accidents	11 807	2 426	3 484	**17 717**	36 278	70 392	**124 387**
monthly average	984	202	290	**1476**	3023	5866	**10366**
% whole France	*9,49%*	*1,95%*	*2,80%*	***14,24%***	*29,16%*	*56,59%*	
Fatalities	1 928	341	130	**2 399**	4 373	1 665	**8 437**
monthly average	161	28	11	**200**	364	139	**703**
% whole France	*22,85%*	*4,04%*	*1,54%*	***28,43%***	*51,83%*	*19,73%*	
Trafic volume (1O*8 veh-km)	886,28	595,15	373,81	**1855,24**			
monthly average	73,86	50	31,15	**154,6**			
% whole France				***about 1/3***			
Network length (km)	24000	6646	2117	32763			

Source: BAAC(ONISR)/SNRD(SETRA).

X_i i=1,..,I the I main exogenous variables, which measure risk exposure or its determinants[2],

X_j j=1,..,J the J secondary explanatory variables measuring the climate,

$\Phi(B)$ and $\Theta(B)$ two polynomials in B, the delay operator,

and u_t a white noise not correlated with the past of Y, of the X_i i=1,..,I and X_j j=1,..,.J.

The variables, whether endogenous or exogenous, were obtained by means of filtering the initial data with the (I-B^{12}) filter. This transformation guaranties, in all cases, the stationarity of the endogenous transformed, and corrected for the exogenous effects, variable.

3.4. Estimation

The parameters were estimated by means of maximising the log-likelihood (procedure AUTOREG and ARIMA in the SAS system): we made the hypothesis that the endogenous transformed variable, conditionally to the exogenous variables, is gaussian. This hypothesis was checked on the residual, but was not central: if the normality hypothesis is not validated, the likelihood calculation can be questioned, but the estimators can nevertheless have good asymptotic convergence properties.

3.5. Validation/Evaluation

The main validation tests have been carried out, and they are satisfactory: the main parameters, of the polynomials $\Phi(B)$ and $\Theta(B)$ and those of the exogenous variables X_i i=1,..,I, are significant at the usual 95% confidence level.

The parameters of the secondary exogenous variables X_j j=1,..,.J, are not always significant at the usual confidence level, but the secondary variables have nevertheless been kept for reasons of convenience.

The main hypothesis related to the residual, of non auto-correlation, has always been validated.

The model evaluation has been achieved by means of empirical performance tests.

Are given: the Akaike information criteria, the part of explained variance (on the endogenous variables, corrected for the exogenous effects, and first filtered by (I-B^{12})), and finally a measure of the average adjustment error for the whole period: the MAPRE[3].

The empirical performance varies considerably according to the indicator and to the network. The average adjustment error for the whole period is around 3% for the aggregate number of injury accidents, and around 5% for the aggregate number of fatalities. But it increases strongly for disaggregated network indicators, being near 7% (resp. 20%) on motorways, and even near 8% (resp. 25%) on toll motorways. These differences in the performances of the different models are no doubt due to the absence of specific factors of accident risk and of its gravity according to the network category, which have not or cannot be measured.

4. Results

We shall first give the results obtained with monthly averaged variables (see Tables 2 and 3). We shall then comment on the results obtained when atypicity variables are added to the average variables (see Tables 4 and 5).

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[2] On the main network (the main roads and the motorways, on which the number of vehicle-kilometres could be measured on a monthly basis, the model has also been applied to the traffic volume: this enabled us to model separately, for each of these two networks, the indirect effect of climate on the numbers of injury accidents and fatalities, via the traffic volume.

[3] The mean average percentage relative error.

Table 2: The model’s criteria and parameters, with averaged climate variables (1975-1999)

Whole France, secondary roads, urban roads

	AIC	MAPRE	R^2	LGA	CFM	ICARB	PAAU	PAAC	PARN	TE	TH	HPLUI	NGEL
Injury accidents													
ACCFE	-898,7	3,3%	65,6%	-0,07136 *	0,14396 **	0,13397 **				0,00075 ***	0,00121 ***	0,00003 ***	-0,00283 **
ACCRS	-753,5	4,3%	56,0%		0,04936 *	0,15490 **				0,00080 ***	0,00120 ***	0,00001 *	-0,00231 **
ACCAGG	-828,8	3,8%	93,7%		0,23402 **	0,14259 **				0,00056 ***	0,00122 ***	0,00002 ***	-0,00362 ***
Fatalities													
TUEFE	-672,0	5,1%	58,3%	0,12430 *	0,52255 ***	0,01522 *				0,00107 ***	0,00215 ***	0,00002 **	-0,00071 *
TUERS	-538,2	6,6%	51,2%		0,39507 **	0,17751 **				0,00092 ***	0,00251 ***	0,00002 *	-0,00027 *
TUEAGG	-448,3	8,0%	93,7%		0,80418 ***	-0,04087 *				0,00118 ***	0,00147 ***	-0,00002 *	-0,00530 **

Motorways, toll motorways, main roads

	AIC	MAPRE	R^2	LGA	CFM	ICARB	PAAU	PAAC	PARN	TE	TH	HPLUI	NGEL
Injury accidents													
ACCA	-522,8	6,9%	54,1%				0,89658 ***			0,00173 ***	0,00072 **	0,00009 ***	0,00678 ***
ACCAC	-419,5	8,2%	44,0%					1,08929 ***		0,00217 ***	0,00137 **	0,00009 ***	0,01212 ***
ACCRN	-735,2	4,7%	51,6%						0,46659 ***	0,00014 *	0,00003 *	0,00006 ***	-0,00190 *
Fatalities													
TUEA	39,1	20,5%	38,0%				2,03770 ***			0,00125 *	0,00186 *	0,00002 *	0,01136 **
TUEAC	160,0	26,2%	35,4%					1,77798 ***		0,00032 *	0,00397 **	0,00003 *	0,01831 **
TUERN	-425,9	8,4%	47,9%						0,42106 ***	0,00101 **	0,00134 **	0,00007 ***	0,00351 *
Traffic													
PAAU	-1061,7	2,3%	38,0%	0,10911 *	0,17788 ***	-0,11510 ***				0,00028 **	0,00050 ***	-0,00001 **	-0,00096 *
PAAC	-904,4	3,2%	41,2%	0,28189 **	0,27777 ***	-0,13394 **				0,00022 **	0,00038 **	-0,00002 ***	-0,00130 *
PARN	-1234,5	1,7%	51,0%		0,13221 ***	-0,06133 **				0,00031 ***	0,00075 ***	-0,00001 ***	-0,00123 **

*Parameter’s significance: ***(t-ratio > 2), **(1< t-ratio <2), *(t-ratio < 1)*

Table 3: Averaged climate effects

		TE	TH	HPLUI	NGEL
Injury accidents					
ACCFE	***global***	***0,08% ******	***0,12% ******	***0,003% ******	***-0,28% *****
ACCRS	global	0,08% ***	0,12% ***	0,001% *	-0,23% **
ACCAGG	global	0,06% ***	0,12% ***	0,002% ***	-0,36% ***
ACCA	indirect	0,03% **	0,04% ***	-0,001% **	-0,09% *
	direct	0,17% ***	0,07% **	0,009% ***	0,68% ***
	global	0,20%	0,12%	0,008%	0,59%
ACCAC	indirect	0,02% **	0,04% **	-0,002% ***	-0,14% *
	direct	0,22% ***	0,14% **	0,009% ***	1,21% ***
	global	0,24%	0,18%	0,007%	1,07%
ACCRN	indirect	0,01% ***	0,03% ***	0,000% ***	-0,06% **
	direct	0,01% *	0,00% *	0,006% ***	-0,19% *
	global	0,03% *	0,04% *	0,006% ***	-0,25% *
		TE	TH	HPLUI	NGEL
Fatalities					
TUEFE	***global***	***0,11% ******	***0,22% ******	***0,002% *****	***-0,07% ****
TUERS	global	0,09% ***	0,25% ***	0,002% *	-0,03% *
TUEAGG	global	0,12% ***	0,15% ***	-0,002% *	-0,53% **
TUEA	indirect	0,06% **	0,10% ***	-0,002% **	-0,20% *
	direct	0,13% *	0,19% *	0,002% *	1,14% **
	global	0,18% *	0,29% *	0,000% *	0,94% *
TUEAC	indirect	0,04% **	0,07% **	-0,004% ***	-0,23% *
	direct	0,03% *	0,40% **	0,003% *	1,83% **
	global	0,07% *	0,46% **	-0,001% *	1,60% *
TUERN	indirect	0,01% ***	0,03% ***	0,000% ***	-0,05% **
	direct	0,10% **	0,13% **	0,007% ***	0,35% *
	global	0,11% **	0,17% **	0,007% ***	0,30% *

*Parameter's significance: ***(t-ratio > 2), **(1< t-ratio <2), *(t-ratio < 1)*

Table 4: The model's criteria and parameters, with both averaged and atypicity climate variables (1975-1999)

Whole France, secondary roads, urban roads

	AIC	MAPRE	R^2	Cte	LGA	CFM	ICARB	PAAU	PAAC	PARN	DTE	DTH	DHPLUI	DNGEL	TE-S	TH-I	TH-S	HPLUI-S	NGEL-S	S1	S2	S3	VESADI
Injury accidents																							
ACCFE	*-1015,8*	*3,0%*	*71,0%*	*-0,042* ***	*0,13* **	*0,14* **					*0,00081* ***	*0,00040* **	*0,00001* **	*-0,00167* *	*0,00057* *	*-0,00936* ***	*0,00089* *	*0,00108* *	*-0,00133* *	*0,00366* **	*-0,00301* ***	*-0,00190* **	*0,0034* ***
ACCRS	-818,783	4,02%	58,9%	-0,025 ***	0,07 *	0,17 ***	-0,09 *				0,00080 ***	0,00029 *	0,00000 *	-0,00235 *	-0,00230 *	-0,00625 **	0,00386 **	0,00006 *	-0,00170 *				
ACCAG	-922,984	3,44%	58,9%	-0,045 ***	0,28 ***	0,19 ***	0,08 *				0,00054 ***	0,00041 *	0,00001 **	-0,00324 **	0,00447 *	-0,00931 ***	0,00067 *	-0,00002 *	-0,00129 *				
Fatalities																							
TUEFE	*-764,5*	*4,7%*	*65,5%*	*-0,037* ***	*0,13* **	*0,33* **	*-0,05* *				*0,00118* ***	*0,00097* **	*0,00002* *	*0,00139* *	*0,00585* *	*-0,01220* ***	*0,00207* *	*0,00054* *	*-0,00300* **	*0,00750* ***	*0,00291* **	*0,00402* *	*0,00972* ***
TUERS	-193,075	5,92%	52,3%	-0,017 ***	1,14 ***	0,05 *	0,29 *				0,00122 **	0,00026 *	0,00003 *	-0,00371 *	-0,00076 *	-0,01929 **	0,01132 **	-0,003 **	0,00763 **				
TUEAG	-488,904	7,43%	58,9%	-0,064 ***	0,55 ***	-0,22 ***	0,34 ***				0,00116 ***	0,00086 *	-0,00001 *	-0,00040 *	0,07296 ***	-0,00994 **	0,00273 *	0,00326 *	-0,00591 **				

Motorways, toll motorways, main roads

	AIC	MAPRE	R^2	Cte	LGA	CFM	ICARB	PAAU	PAAC	PARN	DTE	DTH	DHPLUI	DNGEL	TE-S	TH-I	TH-S	HPLUI-S	NGEL-S	S1	S2	S3	VESADI
Injury accidents																							
ACCA	-574,3	6,8%	54,6%	-0,022 ***				0,82 ***			0,00214 ***	0,00113 **	0,00013 ***	0,00723 ***	-0,00554 *	0,00532 **	0,00243 *	-0,00613 **	-0,00174 *				
ACCAC	-453,4	8,1%	47,2%	-0,046 ***					0,96 ***		0,00266 ***	0,00065 *	0,00011 ***	0,00795 **	-0,02594 **	0,00300 *	0,00676 **	-0,00509 **	-0,00091 *				
ACCRN	-784,0	4,9%	50,7%	-0,046 ***						0,49 ***	0,00039 **	-0,00021 *	0,00007 ***	-0,00139 *	0,00451 *	-0,00234 *	0,00001 *	0,00001 *	-0,00011 *				
Fatalities																							
TUEA	27,7	19,7%	42,3%	-0,089 ***				1,79 ***			0,00190 **	-0,00177 *	0,00020 ***	-0,00213 *	0,00072 *	-0,02817 **	0,02924 **	-0,04002 ***	0,01340 **				
TUEAC	175,2	25,8%	41,1%	-0,088 ***					1,63 ***		0,00030 *	-0,00079 *	0,00009 *	-0,01288 *	-0,07212 **	-0,02285 **	0,03428 **	-0,02028 **	0,03158 ***				
TUERN	-470,1	8,2%	51,1%	-0,041 ***						0,43 ***	0,00093 **	0,00043 *	0,00006 **	0,00274 *	-0,00302 *	-0,00621 **	0,00283 *	0,00325 *	-0,00126 *				
Traffic																							
PAAU	-1191,6	2,1%	57,0%	0,037 ***	0,41 ***	0,15 **	-0,13 ***				0,00014 *	0,00009 *	-0,00001 **	0,00038 *	0,00048 *	-0,00355 ***	0,00183 **	0,00039 *	-0,00218 **	-0,00137 *	0,00340 ***	0,00978 ***	-0,00017 *
PAAC	-1029,9	2,8%	59,0%	0,036 ***	0,52 ***	0,23 ***	-0,18 **				0,00021 **	0,00009 *	-0,00001 *	0,00098 *	-0,00211 *	-0,00317 **	0,00193 *	-0,00060 *	-0,00302 **	0,00321 *	0,00613 ***	0,01623 ***	0,00003 *
PARN	-1359,0	1,6%	58,0%	0,017 ***		0,11 ***	-0,07 ***				0,00028 ***	0,00022 **	-0,00001 **	0,00050 *	-0,00290 *	-0,00526 ***	0,00202 **	-0,00013 *	-0,00207 ***	-0,00278 **	0,00184 ***	0,00612 ***	-0,00021 *

*Parameter's significance: ***(t-ratio > 2), **(1< t-ratio <2), *(t-ratio < 1)*

Table 5: Averaged and atypicity climate effects

		DTE	DTH	DHPLUI	DNGEL	TE-S	TH-I	TH-S	HPLUI-S	NGEL-S	S1	S2	S3	VESADI
Injury accidents														
ACCFE	***global***	***0,08% ******	***0,04% *****	***0,001% *****	***-0,17%***	***0,06%***	***-0,94% ******	***0,09%***	***0,11%***	***-0,13%***	***0,37% *****	***-0,30% ******	***-0,19% *****	***0,34% ******
ACCRS	global	0,08% ***	0,03%	0,00%	-0,24%	-0,23%	-0,63% **	0,39% **	0,01%	-0,17%				
ACCAG	global	0,05% ***	0,04%	0,001% **	-0,32% **	0,45%	-0,93% ***	0,07%	0,00%	-0,13%				
ACCA	indirect	0,01%	0,01%	-0,001% **	0,03%	0,04%	-0,29% ***	0,15% **	0,03%	-0,18% **	-0,11%	0,28% **	0,80% **	-0,01%
	direct	0,21% ***	0,11% **	0,01% ***	0,72% ***	-0,55%	0,53% **	0,24%	-0,61% **	-0,17%				
	global	0,23%	0,12%	0,01% **	0,75%	-0,51%	0,24% **	0,39%	-0,58%	-0,35%				
ACCAC	indirect	0,02% **	0,01%	0,00%	0,09%	-0,20%	-0,31% **	0,19%	-0,06%	-0,29% **	0,31%	0,59% ***	1,56% ***	0,003%
	direct	0,27% ***	0,07%	0,01% ***	0,80%	-2,59% **	0,30%	0,68% **	-0,51% **	-0,09%				
	global	0,29% **	0,07%	0,01%	0,89%	-2,80%	-0,01%	0,86%	-0,57%	-0,38%				
ACCRN	indirect	0,01% ***	0,01%	-0,0005% **	0,02%	-0,14%	-0,26% ***	0,10% **	-0,01%	-0,10% ***	-0,14% **	0,09% ***	0,30% ***	-0,01%
	direct	0,04% **	-0,02%	0,01% ***	-0,14%	0,45%	-0,23%	0,00%	0,00%	-0,01%				
	global	0,05% **	-0,01%	0,01% **	-0,11%	0,31%	-0,49%	0,10%	-0,01%	-0,11%				

		DTE	DTH	DHPLUI	DNGEL	TE-S	TH-I	TH-S	HPLUI-S	NGEL-S	S1	S2	S3	VESADI
Fatalities														
TUEFE	***global***	***0,12% ******	***0,10% *****	***0,00%***	***0,14%***	***0,59%***	***-1,22% ******	***0,21%***	***0,05%***	***-0,30% *****	***0,75% ******	***0,29% *****	***0,40%***	***0,97% ******
TUERS	global	0,12% **	0,03%	0,00%	-0,37%	-0,08%	-1,93% **	1,13% **	-0,30% **	0,76% **				
TUEAG	global	0,12% ***	0,09%	0,00%	-0,04%	7,30% ***	-0,99% **	0,27%	0,33%	-0,59% **				
TUEA	indirect	0,03%	0,02%	-0,002% **	0,07%	0,09%	-0,64% ***	0,33%	0,07%	-0,39% **	-0,25%	0,61% ***	1,75% ***	-0,03%
	direct	0,19% **	-0,18%	0,02% ***	-0,21%	0,07%	-2,82% **	2,92% **	-4,00% ***	1,34% **				
	global	0,22%	-0,16%	0,02% **	-0,14%	0,16%	-3,45% **	3,25% **	-3,93%	0,95% **				
TUEAC	indirect	0,03% **	0,01%	0,00%	0,16%	-0,34%	-0,52% **	0,31%	-0,10%	-0,49% **	0,52%	1,00% ***	2,65% ***	0,00%
	direct	0,03%	-0,08%	0,01%	-1,29%	-7,21% **	-2,29% **	3,43% **	-2,03% **	3,16% ***				
	global	0,06%	-0,06%	0,01%	-1,13%	-7,56%	-2,80% **	3,74%	-2,13%	2,67% **				
TUERN	indirect	0,01% ***	0,01% **	-0,0004% **	0,02%	-0,12%	-0,23% ***	0,09% **	-0,01%	-0,09% ***	-0,12% **	0,08% ***	0,26% ***	-0,01%
	direct	0,09% **	0,04%	0,01% **	0,27%	-0,30%	-0,62% **	0,28%	0,33%	-0,13%				
	global	0,10% **	0,05%	0,01% **	0,30%	-0,43%	-0,85% **	0,37%	0,32%	-0,21%				

*Parameter's significance: ***(t-ratio > 2), **(1< t-ratio <2), *(t-ratio < 1)*

In each case, the global effects of climate were calculated, as well as the direct/indirect effects on main roads and motorways. For these two networks, the direct effect of climate is given by the model's parameter related to the exogenous climate variable; whereas the indirect effect of climate is obtained by multiplying the parameter of the traffic volume (the number of injury accidents' or the number of fatalities' elasticity with regard to traffic) by the parameter of the model related to the exogenous climate variable in the traffic volume model.

4.1. Models with averaged variables

Temperature was linked, positively, to the total number of injury accidents: an increase of one degree in the temperature in the month led to an increase of 1% (0,8% in the summer[4] and 1,2% in the winter) of the number of injury accidents.

This temperature effect on the number of accidents could be observed on each network, but it was stronger on motorways: on this network, the increase in the number of injury accidents was around 2% (and 2,8% on toll motorways). This was mainly a direct effect: the increase was of 1,7% (and 2,2% on toll motorways) with the traffic volume being constant, whereas the indirect effect, due to the traffic volume increase, was limited.

Temperature was also linked, positively, to the total number of fatalities: an increase of one degree in the temperature in the month led to an increase of 1% in the summer and 2% in the winter of the number of fatalities.

This link was significant on every network, but as before it was stronger on the motorway network, and it was mainly direct.

Occurrence of frost was linked, negatively, to the total number of injury accidents: one additional day of frost in the month led to a decrease of 0,3% in the number of injury accidents (whereas it was not significant in the case of the total number of fatalities). On the motorways network, this relation between the number of injury accidents and the occurrence of frost was inverse, and positive: one additional day of frost in the month led to an increase of 0,6% (to 1% on toll motorways) of the number of injury accidents, and the effect was mainly direct.

Rainfall height was linked, positively, to the total number of injury accidents and fatalities: an increase of 100 mm in the rainfall height led to increases of 0,3% and 0,2% in these two indicators. The analysis on main roads and motorways showed that the effect was mainly direct and that was stronger on the motorway network.

4.2. Models with both averaged and atypicity variables

The climate effects are now disaggregated into two parts: an effect of average in the month - less significant than the one described preceedingly – and an effect of atypicity in the month. The additional effects of atypicity, when significant, are the only ones that will be discussed now.

Temperature: A general result is that, when the extreme variations of temperature are also taken into account (superior temperature atypicity in the summer, inferior and superior temperature atypicity in the winter), the link to the average temperature appears to be less significant in the winter than in the summer. In the winter, extreme temperature plays a role too, and in a more significant manner than average temperature.

Inferior temperature atypicity was linked, negatively, to the total numbers of injury accidents and fatalities: one day of inferior temperature atypicity led to a decrease of 0,9% in the number of injury accidents, and of 1,2% in the number of fatalities. This link could

[4] Two variables : the temperature in the summer (from april to september) and the temperature in the winter (from octobre to march) were used in the model (see the list of variables).

be observed on each network; on main roads and on motorways, the indirect effect due to the decrease in traffic volume seemed to be the only significant effect.

As for all the other atypicity variables, no significant link to the aggregate indicators was found. We shall only mention here some significant results on some network categories. For instance, superior temperature atypicity was linked to the number of fatalities on the urban network.

Occurrence of frost: Superior occurrence of frost atypicity was linked to the number of injury accidents and fatalities on main roads and on motorways, the direct effect being positive.

Rainfall height: superior rainfall height atypicity was linked, negatively, to the number of injury accidents and fatalities on motorways: the direct effect was strong (one additional day of extreme rainfall led to a decrease of 0,6% and of 4% in these two indicators), whereas the indirect effect due to the traffic reduction was not significant.

5. Conclusions

The effects of rainfall and temperature on the number of injury accidents and fatalities were quantified, on a monthly basis and for the period 1975-1999. These climate effects were taken into account through monthly averages and extreme values in the month, for the whole of France and for each main network category. On main roads and on motorways, the direct effect of climate and its indirect effect via the traffic volume were evaluated separately.

The results of this analysis first concentrate on the positive link existing between the average temperature in the month and the total number of injury accidents and fatalities. This link appears to be much stronger on the motorway network than it is on the other networks; and the temperature effect would mainly seem to be a direct effect.

The link between average temperature and the two accident risk and gravity aggregate indicators is valid in the summer and in the winter. But, in the winter, extremely cold temperature is also significant - the link being negative - and it is more significant than the average temperature. Moreover, in the winter, a negative link between the occurrence of frost in the month and the number of injury accidents also appears to be significant. On motorways, the relationship between the occurrence of frost and the number of injury accidents and fatalities is positive, and the effect would seem to be mainly direct.

As for rainfall, the results concentrate on the positive link existing between the average rainfall height in the month and the total number of injury accidents and fatalities. This link appears stronger on motorways and on main roads than on the other networks; the effect would seem to be mainly direct, indicating an increase in the risk, and would seem to be far higher than the indirect effect related to traffic decrease. In the case of extreme rainfall, the link to the number of injury accidents and victims becomes negative; the direct effect is negative, indicating a decrease in the risk.

Variations of the risk level, in certain situations under the influence of rainfall and temperature variations, have been highlighted. These aggregate results need to be analysed on a disaggregated basis, for instance on a daily basis - the daily traffic volume being indeed measured on our main network.

The link with behavioural variables such as the practised speed needs to be studied on our main network in order to complete these first results.

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Annex: List of variables

Variable	Definition	Unit	Source
ACCFE	***Number of injury accidents for the whole France***		***BAAC***
ACCRS	*Number of injury accidents on secondary roads*		"
ACCAGG	*Number of injury accidents on urban roads*		"
ACCA	*Number of injury accidents on all motorways*		"
ACCAC	*Number of injury accidents on free motorways*		"
ACCANC	*Number of injury accidents on toll motorways*		"
ACCRN	*Number of injury accidents on main roads*		"
ACCRRN	*Number of injury accidents on the main network (main roads and motorways)(*)*		"
TUEFE	***Number of fatalities for the whole France***		"
TUERS	*Number of fatalities on secondary roads*		"
TUEAGG	*Number of fatalities on urban roads*		"
TUEA	*Number of fatalities on all motorways*		"
TUEAC	*Number of fatalities on free motorways*		"
TUEANC	*Number of fatalities on toll motorways*		"
TUERN	*Number of fatalities on main roads*		"
TUERRN	*Number of fatalities on the main network (main roads and motorways)(*)*		"
PAAU	Traffic volume on all motorways	10^8 vehicles-km	SNRD
PAANC	Traffic volume on free motorways	10^8 vehicles-km	"
PAAC	Traffic volume on toll motorways	10^8 vehicles-km	"
PARN	Traffic volume on main roads	10^8 vehicles-km	"
PAERN	Traffic volume on the main network (main roads and motorways)(*)	10^8 vehicles-km	"
CFM	Final household consumption	10^9 constant 1980 francs	estim. Inrets
ICARB	Car fuel price index	base 100 in 1980	estim. Inrets
LGANC	Length of the free motorways	kilometre	SETRA
LGAC	Length of the toll motorways	kilometre	"
LGAU	Length of the motorways	kilometre	"
TE	Temperature in the summer (april to september)	0,1° C	Météo France
TH	Temperature in the winter (octobre to march)	0,1 °C	Météo France
HPLUI	Rainfall height	mm	Météo France
NGEL	Number of days of frost	day	Météo France
ATYTES	Number of "superior" atypical days regarding temperature, in the winter	day	Météo France
ATYTHI	Number of "inferior" atypical days regarding temperature, in the summer	day	Météo France
ATYTHS	Number of "superior" atypical days regarding temperature, in the summer	day	Météo France
ATYHS	Number of "superior" atypical days regarding rainfall height	day	Météo France
ATYNGELS	Number of "superior" atypical days regarding occurrence of frost	day	Météo France
S1, S2, S3	Number of days coding a calendar exceptional effect, gathered in three classes	day	
VESADI	Number ok week-end days (Friday/Saturday/Sunday)	day	

(*)not modelled directly

Appendix

Figures

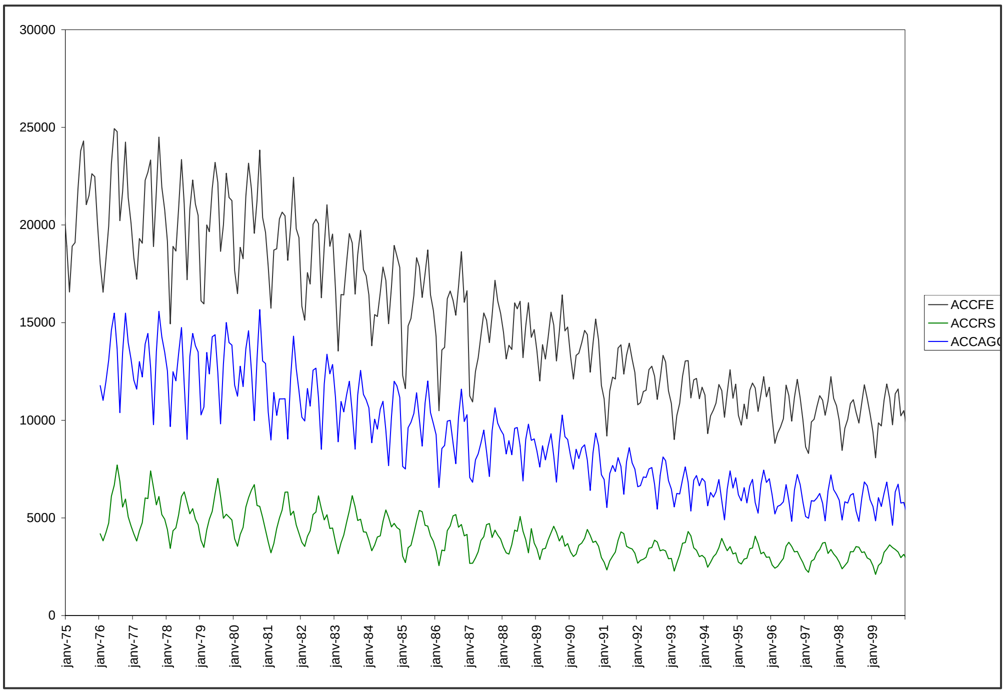

Figure 1 : Number of accidents (the whole France, secondary roads, urban roads)

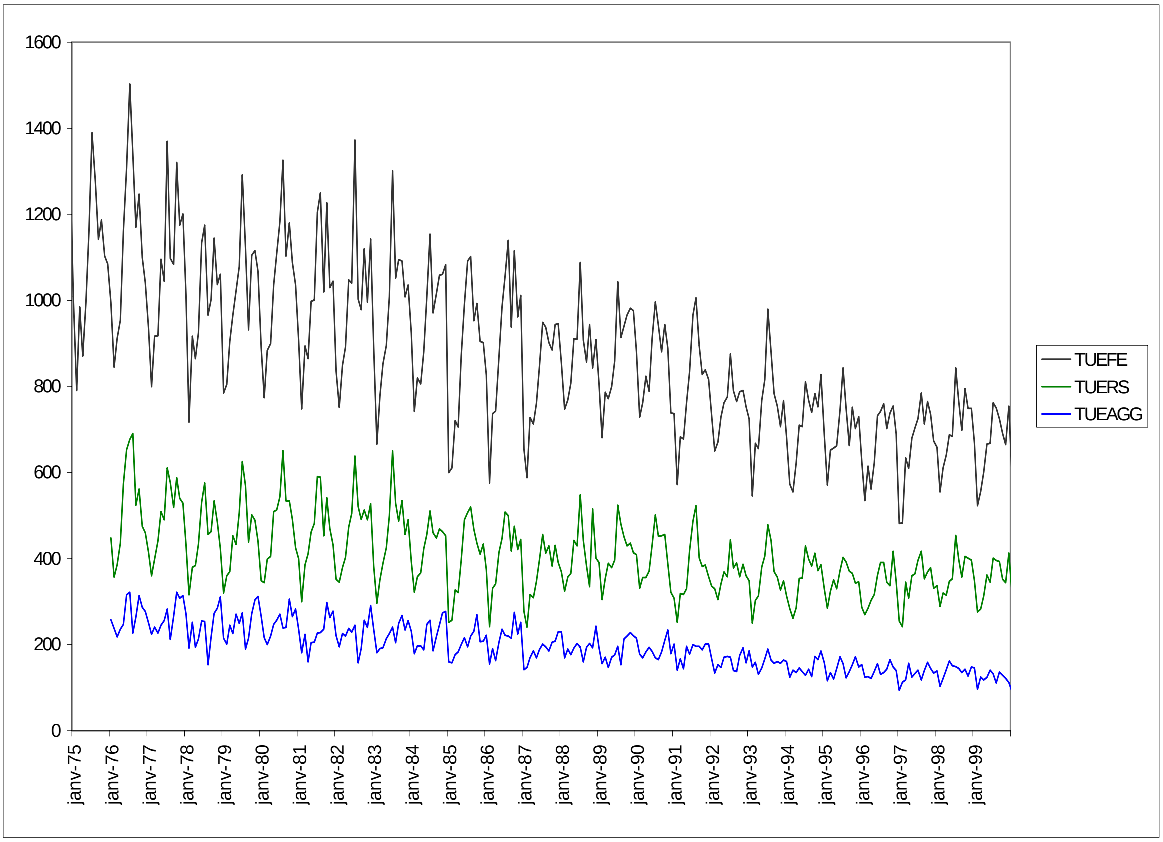

Figure 2 : Number of fatalities (the whole France, secondary roads, urban roads)

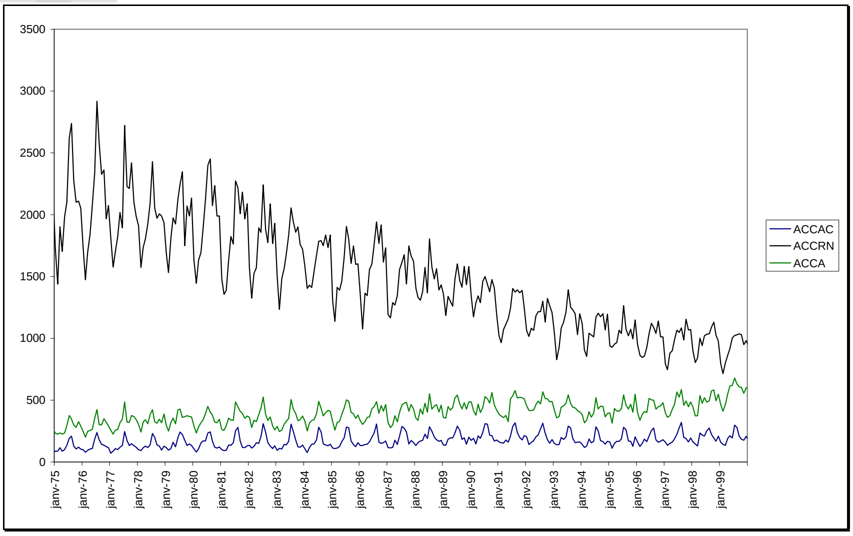

Figure 3 : Number of injury accidents (main roads, motorways, toll motorways)

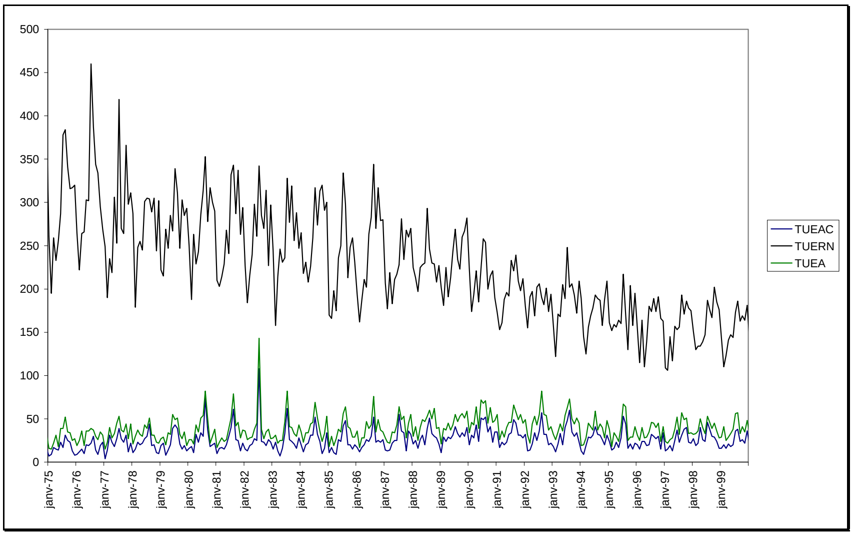

Figure 4 : Number of fatalities (main roads, motorways, toll motorways)

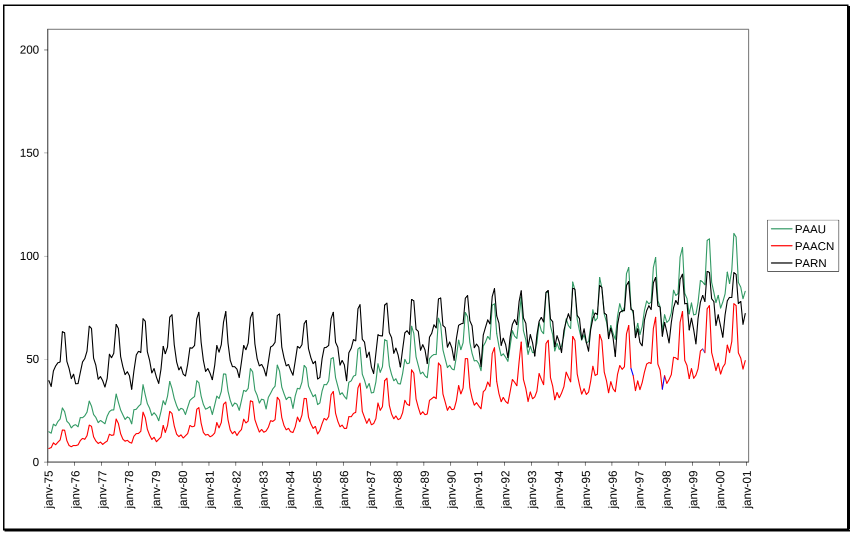

Figure 5 : Traffic volume (main roads, motorways, toll motorways) in billions of veh-kms

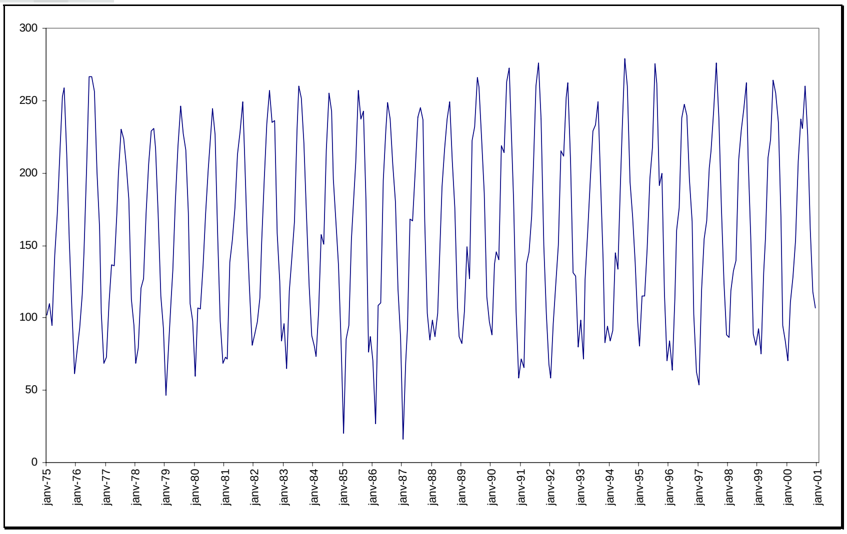

Figure 6 : Temperature (0,1°C)

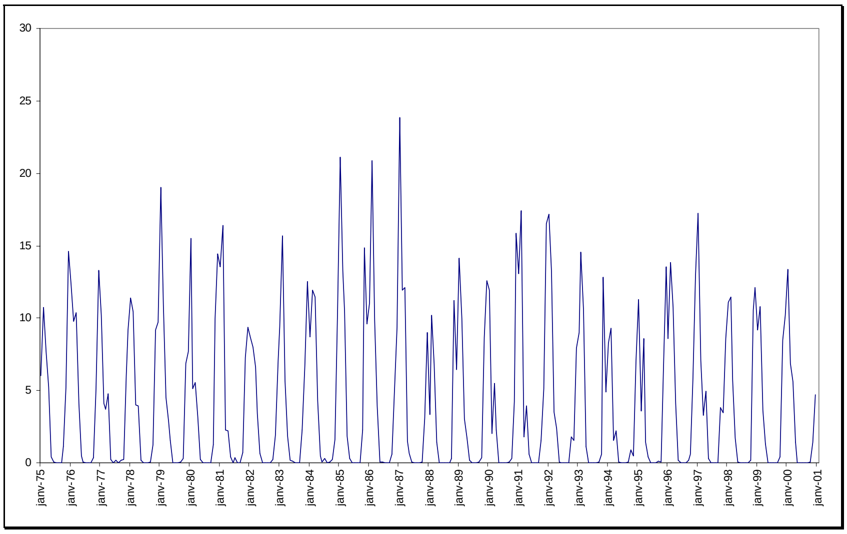

Figure 7 : Occurrence of frost (days)

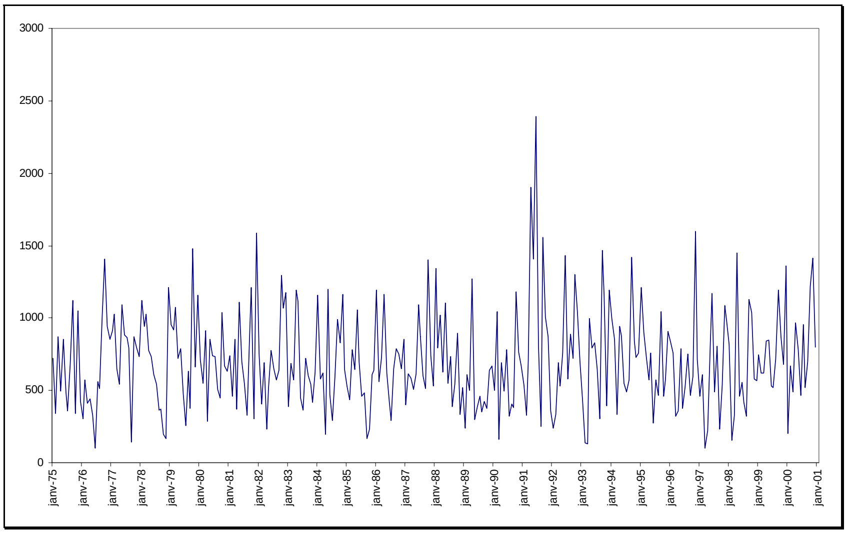

Figure 8 : Rainfall height (mm)