EVALUATION OF THE CAR SAFETY ENHANCEMENTS DURING THE LAST THREE DECADES

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ABSTRACT

The objective of this work is to assess the enhancement of new cars (designed in the 2000's) compared to cars designed in the 1980's and in the 1990's. The improvement is evaluated according to two criteria: the involvement rate in an accident and the protection offered to the driver in case of a crash. Within each decade of conception, cars are also defined and evaluated regarding their classes (supermini, small family car, large family car, Mpv and executive).

Protection is analyzed through the risk of fatal and severe injuries among drivers involved in a crash. Regarding involvement, as no data on the circulating fleet and on the characteristics of the circulating drivers are available, the involvement rate is estimated by the risk of being responsible for an accident. Logistic regressions were fitted for the two indicators, in order to avoid confounding factors.

Data sources consist on the French accident national data base from year 2007 to 2009. This data base gathers all injury accidents occurred each year in France. Information regarding the circumstances of the accident, the vehicles, the people involved and their injury severity are available. Cars designed in the 1980's, the 1990's and in the 2000's were selected, and the class of the cars is assigned for each vehicle. The study is based on a final sample of 97 600 car drivers.

Results are given in term of safety benefits with their 95% confidence intervals. The increase or decrease in the risk of being responsible for an injury accident is presented for each category of cars, as well as the risk of being killed or severely injured. Cars are then compared according to their decades of conception and to their classes.

The study enlightens the safety improvements made since the 1980's, in term of risk of being involved in an injury accident but also in term of protection offered by car. The magnitude of the improvement turns up to be dependant on the category of the car.

The sample used is mostly European but the methodology could be applied on different countries accident databases.

This study provides an evaluation of car protection on recent accident and also brings new data on involvement risk according both to the conception and class of the cars.

INTRODUCTION

In France, the number of people killed in a road accident is in constant decline since 2002. The figures of year 2009 allow recording a total reduction of 20 % during the last 5 years.

The figures of the road accidents in France are supplied by the National Inter-Departmental Observatory on Road Safety (Observatoire National Interministériel de Sécurité Routière: ONISR), which collects the reports on injury traffic accidents (Bulletins d'Analyse d'Accident Corporel de la circulation: BAAC) compiled by the Police and Gendarmerie. In 2009, 4273 persons died in a road accident (immediately or at 30 days), against 5318 in 2005. If the mortality rate of the road accidents goes down, the improvement does not concern all the users in the same way. The decline observed concerns essentially drivers and passengers of passenger cars.

The objective of this work is to assess the enhancement of the most recent vehicles compared to vehicles of the other generations. The improvement is evaluated according to two criteria: the protection offered to the driver in case of a crash and the involvement rate in an accident.

DATA

The study is carried out on the French accident national data base (BAAC) of year 2007 to 2009. Police officers fill up a form for each injury road accident happening in France, these forms

contribute to populate the database. The information provided by the database deals with the general characteristics of the accident (such as luminosity, rural/urban area, junction related accident…), the type of infrastructure where the accident took place. The vehicles involved are described (type, year of first registration), also with their type of impact and obstacle. Regarding the occupants, their age, gender, status of wearing or not the seat belt are documented. The injury severity is coded for each occupant involved in an injury accident. Since January 2005, the injury severity is assigned as follows:
- Fatally injured: occupant killed within 30 days after the accident.
- Severely injured: injured occupant who stayed at hospital more than 24 hours.
- Slightly injured: injured occupant who stayed at hospital less than 24 hours.
- Not injured

The makes and models of the vehicles are established from the Vehicle Identification Number (VIN) filled in the database by the Police forces. The accident data are linked with a fleet data which also provides the year of conception of the models. The year of conception stands for the first year the model appears on the French market. There may be some missing or incorrect value for the VIN. As a result, 70% of the involved vehicle has been identified in the database. The analysis is performed on the vehicle for which the makes, model and year of conception are known. Accidents against pedestrians or two wheelers are not taking into account in the study, as passenger car occupants involved against vulnerable road users are commonly uninjured whatever the year of conception of the car. Those types of crashes don't allow grasping the enhancement of protection through the years.

At the end, our sample consists of 97 747 drivers with makes, models and year of registration of the passenger car known. Vehicles are then classified by class and year of conception. Classes of vehicles are available on EuroNCAP website: Supermini (Sm), small family car (Sfc), large family car (Lfc), and executive cars (Exe). Small and large MPV are grouped together as MPV (Mpv). Picks up, small and large off-road 4x4 are kept in the sample but no results will be provided as their number is small. Year of conception were set up in three groups: 1980-1989, 1990-1999, 2000-2009. On the whole, 18 classes of vehicles could be defined as presented in table 1.

Table 1.

Table 1.
Distribution of the classes and phase of conception of the crashed passenger cars in France (BAAC 2007 - 2009)

Class – phase of conception	n
Supermini car 1980-1989	7 045
Supermini car 1990-1999	27 861
Supermini car 2000-2009	8 171
Small family car 1980-1989	3 317
Small family car 1990-1999	14 057
Small family car 2000-2009	6 678
Large family car 1980-1989	2 940
Large family car 1990-1999	6 519
Large family car 2000-2009	2 860
Executive car 1980-1989	1 250
Executive car 1990-1999	2 496
Executive car 2000-2009	1328
Mpv 1980-1989	161
Mpv 1990-1999	6 366
Mpv 2000-2009	4 092
Pick-up 4x4 1980-1989	502
Pick-up 4x4 1990-1999	836
Pick-up 4x4 2000-2009	1268
Total	97747

The figure 1 below illustrates the frequency of the different year of conception of the crashed cars, in accidents occurred between 2007 and 2009.

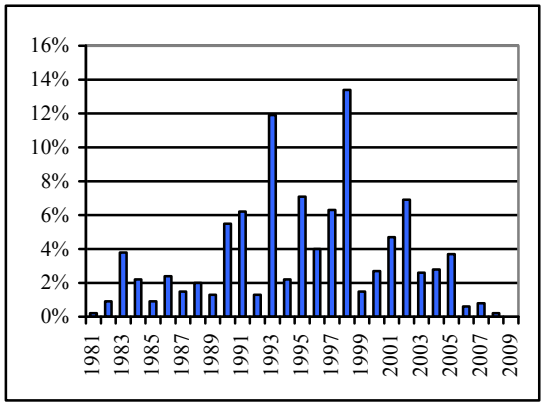

Figure 1. Distribution of the year of conception of the crashed cars, accidents without vulnerable road users, years 2007 to 2009 France.

These most recently designed vehicles (year conception 2007-2009) only represent 1% of the sample. Therefore a focus on these vehicles would have lead to very few statistically significant results.

METHODOLOGY

Protection

The evaluation of the improvement of the protection for drivers of cars designed in the 2000' compared to the 1990' and 1980', is made through the use of Odd ratio (OR). Proportion of fatally and severely injured drivers in vehicles X of a given make, model and phase of conception is compared to the proportion observed in vehicles R of another make, model and phase of conception chosen as a reference (Equation 1).

$$OR = [(Fatal+severe)/(slight+uninjured)]_{in\ veh.\ X} / [(Fatal+severe)/(slight+uninjured)]_{in\ veh.\ R} \quad (1).$$

The safety benefit observed is calculated as in Equation 2 [1]:

$$Safety\ Benefit = 1- OR \quad (2).$$

This is a measure of the decrease (or increase) in the risk of being killed or severely injured for drivers of vehicle X compared to driver of vehicle. Confidence intervals at 95% are calculated as stated in [2].

Involvement in accident

In order to quantify and compare the accident involvement of each category of cars, a measure of exposure, as the mileage driven by each class of vehicle or the circulating fleet by type of cars, is needed. These figures would be the best estimator of the exposure to the risk of accident. As they are not available, the quasi induced exposure method is applied. The assumption of this methodology is that the non-responsible drivers involved in accident are likely to behave as the non involved drivers and thus they could give good approximation of the characteristic of the traveling vehicles [3]. In the database used for the analysis, responsibility for the crash is assigned to each vehicle by the police forces (responsible or non-responsible). The non responsible drivers will be the reference group, with precise characteristics known from the database (age and gender of the driver, circumstance of travel), in place of the French vehicle fleet. Responsible drivers are compared to the non-responsible ones, and accident involvement is approximated by the risk of being responsible of an injury accident. A comparison is made between the number of responsible drivers and the number of non responsible drivers of a given vehicle X, relative to the figure observed for a reference vehicle R. This can be made through the use of Odd ratio (equation 3).

$$OR = (Responsible)/(Non\text{-}responsible)_{in\ veh.\ X} / (Responsible)/(Non\text{-}responsible)_{in\ veh.\ R} \quad (3).$$

Adjusted Odd Ratio

Logistic regression is performed to take into account possible confounders in the estimation of the OR linked with the protection and involvement. Safety benefits, as expressed in equation 2, are then calculated with the adjusted OR. Table 2 details the confounding factors taken in the regression models for the protection and involvement evaluation.

Table 2.
Variable used as possible confounding factor for involvement and protection evaluation.

Variables	Involvement	Protection
type of impact (front, lateral, back, roll over, unknown)		x
Gender of the driver (female/male)	x	x
Age of the driver (<26, 26-45, 46-55, 56-65, 66+)	x	x
Seat belt worn (yes/others)		x
Accident at a junction (yes/no)		x
Luminosity (day/dark)	x	x
Slippery pavement (yes/no)	x	x
Scene (urban area, highway, national road in rural area, secondary road in rural area)	x	x
Blood Alcohol Concentration BAC (under the limit, over the limit, unknown)	x	x

RESULTS

Protection

This paragraph presents the comparison of the proportions of fatally and severely injured users according to the passenger car generations and classes. Logistic regression requires selecting a modality in each variable that serves as a reference for comparison. Being the most numerous, the vehicles of the Supermini class designed in the 1990s will serve as reference.

Variables with a significant impact on the risk of being severely, injured or killed according to the generation and the category are as follows: blood alcohol concentration, type of impact, scene of the accident, age of the driver, seat belt worn, the luminosity, gender of the driver and some interactions.
The table 3 indicates adjusted Odd ratios associated with each vehicle of the supermini class 1990's, as well as the 95% confidence intervals.

Table 3.
Odd ratios associated with the risk of being severely injured or killed for the drivers of light vehicles. Crash without pedestrian or two wheelers. 2007-2009 BAAC.

comparison	odd ratio	confidence intervals (95%)	
Sm 80s vs Sm 90s	1,511	1,418	1,609
Sm 90s vs Sm 90s	1		
Sm 00s vs Sm 90s	0,762	0,714	0,814
Sfc 80s vs Sm 90s	1,215	1,114	1,325
Sfc 90s vs Sm 90s	0,93	0,883	0,979
Sfc 00s vs Sm 90s	0,629	0,584	0,677
Lfc 80s vs Sm 90s	1,11	1,011	1,22
Lfc 90s vs Sm 90s	0,817	0,761	0,876
Lfc 00s vs Sm 90s	0,515	0,46	0,577
Exe 80s vs Sm 90s	0,961	0,834	1,109
Exe 90s vs Sm 90s	0,675	0,605	0,754
Exe 00s vs Sm 90s	0,502	0,424	0,595
Mpv 80s vs Sm 90s	0,782	0,523	1,169
Mpv 90s vs Sm 90s	0,724	0,673	0,78
Mpv 00s vs Sm 90s	0,57	0,518	0,628

The figure 2 indicates Odd ratio values associated with each vehicle of the supermini class 1990's, as well as the 95% confidence intervals.

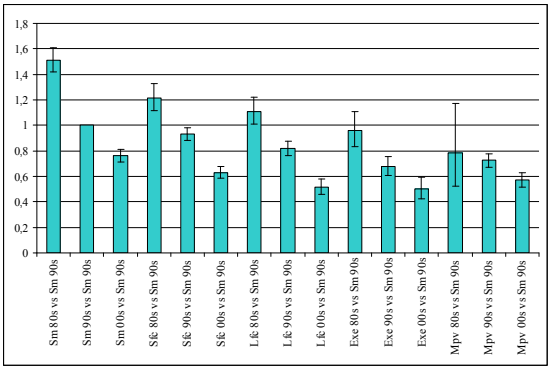

Figure 2. Odd ratios associated with the risk of being severely injured or killed for the drivers of passenger cars. Crash without pedestrian or two wheelers. 2007-2009 BAAC.

The table 4 presents the safety benefits (calculated as in equation 2) in protection according to the generations of conception for each vehicle classes. For example, the first line of table 4 compares the level of protection in supermini 90's to supermini 80's: the risk of being fatally or severely injured is reduced by 34% [29% ; 38%] for drivers of supermini 90's. None significant results are shown by a star (*).

Table 4.
Benefits in protection. Comparison between two decades for the same class.

	1990s vs 1980s		
	Benefits	CI low	CI high
Supermini	34%	29%	38%
Small familly car	23%	16%	30%
Large familly car	26%	18%	34%
Executive	30%	16%	41%
Mpv	7%*	-39%	38%
	2000s vs 1990s		
Supermini	24%	19%	29%
Small familly car	32%	27%	38%
Large familly car	37%	29%	44%
Executive	26%	10%	39%
Mpv	21%	12%	30%
	2000s vs 1980s		
Supermini	50%	45%	53%
Small familly car	48%	42%	53%
Large familly car	54%	47%	60%
Executive	48%	35%	58%
Mpv	27%*	-10%	52%

One can see the severity decreased by 23 to 30% when we compare the 90's passenger cars to 80's passenger cars. The decrease is identical when we compare 2000's passenger cars to 90's passenger cars (21 to 37% according to the vehicle classes). The overall decrease is evaluated between 48 and 54% according to the vehicle class when we compare 2000's to 80's passenger cars.

If we compare the level of protection between the classes, the same downward trend is observed whatever the decades of conception: class supermini (less protective), small family car, large family car and executive (more protective). Nevertheless, all the related differences between classes in different decade are not statistical significant. Note the protection differences between supermini class and executive class are constant through the decades (36-33-34% respectively).

Involvement in accident

For evaluation of accidental involvement via the risk of being responsible for an injury accident, the references for the logistic regression will be the supermini 90's.

Variables kept in the logistic regression to explain the risk of being responsible for a traffic accident according to the class and to the generation of the vehicle are the following ones: blood alcohol concentration, age of the driver, scene of the

accident, driver gender and slippery pavement and some interactions.
The table 5 details adjusted odd ratios associated to every type of vehicles, for the accidental involvement.

Table 5.
Odd ratio associated with the risk of being responsible for a traffic accident for the drivers of passenger cars. Accidents without pedestrian or two wheelers. 2007-2009 BAAC.

comparison	odd ratio	confidence intervals (95%)	
Sm 80s vs Sm 90s	1,096	1,037	1,159
Sm 90s vs Sm 90s	1		
Sm 00s vs Sm 90s	0,885	0,84	0,932
Sfc 80s vs Sm 90s	1,163	1,077	1,257
Sfc 90s vs Sm 90s	1,06	1,015	1,107
Sfc 00s vs Sm 90s	0,804	0,759	0,852
Lfc 80s vs Sm 90s	1,129	1,04	1,225
Lfc 90s vs Sm 90s	0,983	0,928	1,042
Lfc 00s vs Sm 90s	0,764	0,703	0,83
Exe 80s vs Sm 90s	1,237	1,094	1,398
Exe 90s vs Sm 90s	1,159	1,061	1,266
Exe 00s vs Sm 90s	0,783	0,696	0,882
Mpv 80s vs Sm 90s	1,135	0,811	1,589
Mpv 90s vs Sm 90s	0,816	0,769	0,865
Mpv 00s vs Sm 90s	0,744	0,693	0,799

The figure 3 indicates Odd ratios values associated with each vehicle of the supermini class 1990s, as well as the 95% confidence intervals.

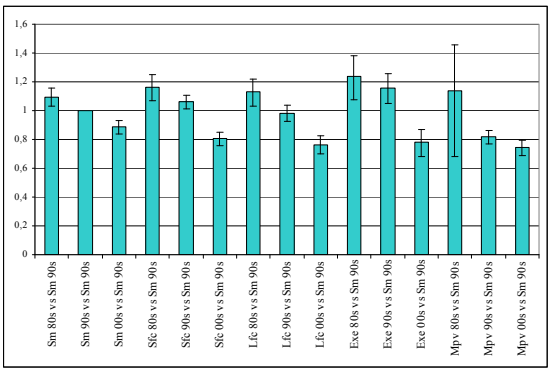

Figure 3. Odd ratio associated with the risk of being responsible for a traffic accident for the drivers of passenger cars. Accidents without pedestrian or two wheelers. 2007-2009 BAAC.

The table 6 presents the safety benefits (calculated as in equation 2) in involvement according to the generations of conception for each vehicle classes. For example, the first line of table 6 compares the level of involvement in supermini 90's to supermini 80's: the risk of being responsible for injury accident is reduced by 9% [4% ; 14%] for drivers of supermini 90's. None significant results are shown by a star (*).

Table 6.
Benefits in involvement. Comparison between two decades for the same class.

	1990s vs 1980s		
	Benefits	CI low	CI high
Supermini	9%	4%	14%
Small familly car	9%	1%	16%
Large familly car	13%	4%	21%
Executive	6%*	-8%	19%
Mpv	28%*	-1%	49%
	2000s vs 1990s		
Supermini	12%	7%	16%
Small familly car	24%	19%	29%
Large familly car	22%	15%	29%
Executive	32%	22%	41%
Mpv	9%	1%	16%
	2000s vs 1980s		
Supermini	19%	14%	25%
Small familly car	31%	24%	37%
Large familly car	32%	24%	39%
Executive	37%	25%	46%
Mpv	34%	8%	53%

Concerning the accident involvement, Supermini class, small and large family car classes respectively decreased by 9 and 13% from 90's to 80's. The other class differences are not statistical relevant for 80's to 90's comparisons. The accident involvement is lower in 2000's than 90's with a decrease of 12 to 32% according to the classes. The overall accident involvement decrease fluctuates from 19 to 37% between 2000's and 80's passenger cars according to the respective classes.

For comparison of classes within the 1980 decade, no accident implication difference is shown between the classes. In 90's classes, an under-involvement of the Mpv and an over-involvement of executive and small family cars compared to supermini are observed. In 2000's classes, an under-involvement of the Mpv and large family car classes compared to supermini class is observed.

Protection and involvement in accident

The figure 4 allows showing simultaneously the results in terms of adjusted Odd ratios for protection and involvement. Each class and decade is compared to supermini 90's.

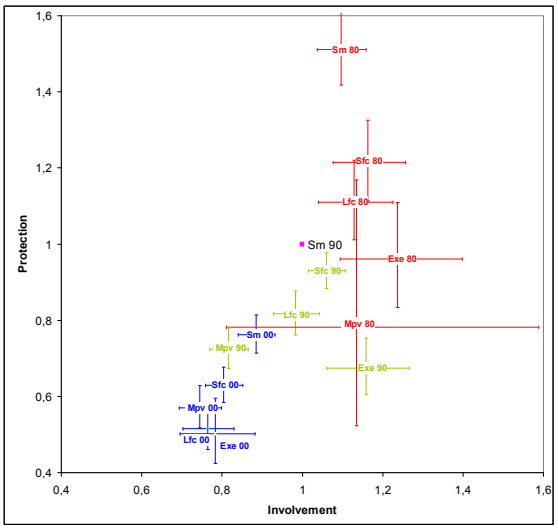

Figure 4. Involvement and protection of the light vehicle according to the class and the decade of conception.

On this graph, the important decrease of the risk of being fatally or severely injured between cars of the 1980's and the 1990's is observable. Between these two decades the decrease regarding involvement is less important. And important decrease in the risk of being fatally or severely injured and in involvement between 1990's and 2000's is revealed.

The maximum protection benefits are observed between the supermini class 1980s and the executive class 2000s with 67% [60%; 72%]. According to the involvement the maximum benefits is observed between executive of the 1980's and the Mpv of the 2000's 40% [31%; 48%].

DISCUSSION

Our study concerns 3 years of accident observation from 2007 till 2009, thus we benefit from a period of homogeneous observation, with the same road safety policy and the same infrastructure characteristics.

On the other hand, this approach does not allow taking into account vehicle use which can be different between a recent vehicle and a vehicle of more 20 years of age. Although this was partially taken into account in the logistic regression, we are not certain about completely erasing use biases because we do not have all the characteristic variables of the vehicle use.

In collisions between two vehicles, a recent vehicle has a strong probability to come up against an older vehicle than him (due to the average age of the park: 8 years). The older vehicle will have not the same crashworthiness as the recent one, favoring the injury balance in the recent vehicle.

The BAAC counts only accidents with at least one injured person. Our indicator is thus an indicator of the involvement in injury accident and not the involvement in damage only accident.

Accident involvement can't come down to active safety and accident severity to passive safety. Active safety could play a role in the crashworthiness by changing the crash configuration and consequently changing the accident severity such as ESC could do. Moreover, the passive safety plays a role with the restraint systems by providing a protection that could shift from an injured accident to property damage accident.

Note that the sample is mainly made up of European passenger car models.

CONCLUSION

This study highlights the downward trends of the accident involvement and the crash severity for the new passenger car generations (2000-2009). One explanation could be the great development of the crashworthiness and active safety devices fitted in these passenger cars. Car manufacturers have engaged a lot of energy to reach this level of safety. The consequence is obvious with the decrease of the number of injured accidents or their severity when the crash was not avoided.

Severity decreased 23 to 30% when the 90's passenger cars are compared to 80's passenger cars. Identical is the decrease when 2000's passenger cars are compared to 90's passenger cars (21 to 37% according to the vehicle groups).
The overall decrease is 48 to 54% according to the vehicle class between 2000's and 80's passenger cars. Note the crash severity differences between supermini class and executive class are constant through the decades (36-33-34% saved respectively).

Concerning the accident involvement, supermini class and large family car class respectively decreased of 9 and 13% from 90's to 80's. The other class differences are not statistical relevant. The accident involvement is lower in 2000's cars than in 90's cars with 12 to 32% according to the classes. The overall accident involvement decrease is evaluated between 19 and 37% for 2000's compared to 80's passenger cars according to the respective classes.
Comparing the classes, no accident implication difference is shown when the passenger's car classes are evaluated within the 80's. In 90's

classes, an under-involvement of the Mpv and over-involvement of executive and small family car classes compared to supermini class are noticed. In 2000's classes, an under-involvement of the Mpv and large family car class compared to supermini class is observed.

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