How Safe is Vehicle Safety? The Contribution of Vehicle Technologies to the Reduction in Road Casualties in France from 2000 to 2010

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ABSTRACT – In France, over the last 10 years, road fatalities have decreased dramatically by 48%. This reduction is somewhat close to the target fixed by the European Commision in 2001 for the whole of Europe (-50 %). According to the French govnerment, 75% of this reduction was due to the implementation of automatic speed cameras on the roadsides from 2003 onwards. Yet, during this period, there was also a significantly increase in safety technology, new regulations in front and side impacts, and developments in Euro NCAP to improve passive safety in the vehicles. This paper set out to estimate the extent that vehicle safety technologies contributed to the road safety benefits over this decade. Using a combination of databases and fitment rates, the number of fatalities and hospitalized injuries saved in passenger car crashes was estimated for a number of safety technologies, individually and as a package including a 5 star EuroNCAP rating. The additional benefits from other public safety measures were also similarly estimated. The results showed that overall safety measures during this decade saved 240,676 fatalities + serious injuries, of which 173,663 were car occupants. Of these, 27,365 car occupants and 1,083 pedestrian savings could be attributed directly to vehicle safety improvements (11% overall). It was concluded that while public safety measures were responsible for the majority of the savings, enhanced vehicle safety technologies also made a significant improvement in the road toll in France during the last decade. As the take-up rate for these technologies improves, is expected to continue to provide even more benefits in the next 10-year period.

INTRODUCTION

In France, over the last 10 years, road fatalities decreased dramatically (7,643 fatalities in 2000 and provisionnally 3,994 in 2010, i.e. 48% overall). In Europe, fatalities reductions over the same period are various (-38% on average, -55% in Portugal, -53% in Spain, -45% in Germany, -39% in Italy, -35% in the UK, -40 % in the Netherlands, -39% in Sweden, -27% in Poland, -32% in Hungary, etc.), This reduction is somewhat close to the target fixed by the European Commision in 2001 for the whole Europe (-50 %). According to the French govnerment, 75 % of the reduction in France was due to the implementation of automatic speed cameras on the roadsides from 2003 onwards (ONISR, 2008). This 'speed camera' policy followed a declaration by the French President, on the 14th of July 2002 (National day), who outlined 3 health priorities in France for the continuation of his mandate (till 2007): (1) traffic safety, (2) cancer and (3) care of the disabled. From 2003 onwards, the govnerment installed 2,800 fixed speed cameras on the roadside (Figure 1), in addition to the 1,000 mobile speed cameras available to the police forces and the cameras installed at traffic lights.

During the same decade, a lot of other safety measures were also implemented and they undoubtedly produced some safety benefits as well. Vehicle safety measures are a certain kind of these safety measures. The automobile industry already made remarkable progress with regard to safety in the second part of the 20th century (Page and Labrousse, 2007; Labrousse et al., 2011): improvement in safety of vehicle elements, introduction of specific safety restraint devices such as the 3-points seat belt and airbags, enhanced crashworthiness of the vehicle, and improved integrity of the occupant compartment.

Figure 1. Fixed Speed cameras and their sign up to 2 kilometers ahead

However, model years 2000 onwards offer an unprecedented level of safety improvement, due to a series of recent measures: Directive 96/79/CEE and ECE.R94 about frontal impact performance standard; Directive 96/27/CEE and ECE.R95 about side impact standard; introduction of the Euro CAP consumer tests, mainly oriented towards crashworthiness and the efficiency of passive safety measures; as well as voluntary large fitment of Antilock Braking Systems (ABS), Electronic Stability Control (ESC) and Emergency Brake Assist (EBA). In parallel, some luxury car brands after the mid-2000's started fitting active safety devices such as lane departure warning systems, anti-collision systems, adaptive cruise control, and night vision systems, made it possible by the availability of embedded technology, such as radars, lidars, ultrasonic sensors and cameras.

Traffic safety literature about the so-called 'Advanced Driving Assistance Systems' or Safety Systems pertinence and effectiveness is getting larger and larger as well as research about the effectiveness of passive safety and NCAP tests. Evidence about the relevance of vehicle safety and its contribution to traffic safety is available but dissemination, within the scientific community is sparse. Safety benefits from vehicle safety seems somehow underestimated.

The objective of the paper is therefore to estimate to what extent vehicle safety contributed to the overall road safety benefits in France over the decade 2000-2009. We focus our study on passenger car safety exclusively, i.e. crash benefits involving at least a car, excluding those crashes involving powered-two-wheelers or buses and trucks without cars. The following main questions were addressed:

1. Between 2000 and 2009, in France, how many lives were saved and how many severely injured were mitigated (compared to the late 1990's)?

2. Compared to the total number of lives saved and severely injuries avoided over the same period, how many of them (vehicle occupants and pedestrians) are due to vehicle safety?

3. To what extent can we consider that the 'French miracle' over the last decade was the main outcome of the combination of an efficient speed camera policy and a progressive increasing proportion of safer vehicles in the fleet?

4. Can we anticipate the number of people who will continue to benefit from the vehicle safety in the future, considering the continuous deployment of safety systems in the fleet?

METHODS

The general principal of the method is depicted in the following sub-section. The different steps of the method and the data needed are depicted in the second sub-section.

We chose a time series quasi-experimental design in France only (with no control, e.g. another country) for the following reasons::

- A methodological reason: Epidemiology teaches that there are many experimental or quasi-experimental designs to assess the impact (or effectiveness) of an intervention: the most popular designs are the 'with/without (i.e. with the intervention and without the intervention) combined with before/after studies' i.e. before the intervention and after the intervention). Less powerful designs are the only 'with/without' design or the only 'before/after' study. Another design is the time series design able to model many interventions at different moments in time on a same space unit, e.g. a country. Another design could be the multiple time series design, modelling different interventions at different times in various space units (e.g. different countries). Before/after or case./control designs were not appropriate because we intended to assess a series of road safety and vehicle safety measures overtime and not only one safety measure on one point in time. Time series was then the remaining design relevant to our objectives.

- A practical reason: making international comparisons would have demanded to get access to specific data in other countries (especially the crash data per crash types and the safety technologies fitment rates in the car fleet over ten years). It would have taken too much time and too much effort. We then dropped this option and conducted the study with French data only.

General Principle

We first calculate the number of fatalities and severely injured (so-called victims) who were saved between 2000 and 2009 compared to the late 1990's thanks to safety measures taken over the period. Let V be this number.

$$V = V_s - V_a \quad (1)$$

V_a is the observed number of victims over the period. V_s is the simulated number of victims that would have been observed in the absence of any new safety actions during this period. V_s is the reference level of unsafety, which is nevertheless taking into consideration the outcome of safety measures taken before the period and that continue to produce results.

Let then V_c be the same number, but for injury crashes involving at least passenger cars:

$$V_c = V_{sc} - V_{ac} \quad (2)$$

V_{ac} is the observed number of victims in crashes involving passenger cars over the period. V_{sc} is the simulated number of victims in such crashes that would have been observed in the absence of safety actions in the period. V_{sc} is similar to V_s, only for crashes involving at least cars.

We then calculate the percentage of V_c which is due to vehicle safety. We do it in three steps. First, we estimate the intrinsic effect of vehicle safety, i.e. the percentage of victims that could be avoided if 100% of the fleet was fitted with the vehicle safety applications. Let I_e be this intrinsic effect. Secondly, by applying the intrinsic effect to V_{sc}, we obtain the total number of victims who would be saved thanks to the safety applications if 100 % of the fleet is fitted with the applications. Let S_{sc} be this number.

$$S_{sc} = I_e * V_{sc} \quad (3)$$

Thirdly we then apply to S_{sc} the actual rate of fitment of the vehicle fleet with the safety applications. Let R_c be this rate and S_{rc} be the actual number of victims saved over the period thanks to vehicle safety:

$$S_{rc} = R_c * S_{sc} \quad (4)$$

Finally $S_{rc}*V_c$ is the final percentage of victims in car crashes saved thanks to vehicle safety and $S_{rc}*V$ is the final percentage of overall victims saved thanks to vehicle safety.

For the sake of clarity, we did not mention above that all calculations are performed annually. We furthermore underline that the intrinsic effect is actually a series of intrinsic effects that are applied to sub-categories of cars (depending on their equipment) and different sub categories of crashes depicted in the following sections since different vehicle safety applications address different crash configurations.

Steps in the method

The detailed method lies in 7 steps depicted in more details here after:

1. Calculation of actual number of victims resulting in car crashes over the period

From the French national crash database, we calculate annual time series of the following figures:

- The number of overall injury crashes and the resultant number of overall fatalities and serious injuries. The sum of fatalities + serious injuries is called 'victims'.

- The number of victims in crashes involving cars are also calculated with a breakdown by user types (car occupants, pedestrians, others). As for car occupants, the number of victims is calculated with breakdown by impact types (frontal, side, roll-over, others) and by collision types (head-on, frontal-side collisions, rear-end collisions, and collisions with more than 3 vehicles involved). These different time series are necessary since different vehicle safety measures address different types of crashes and different types of users. Subsequently, there are as many time series as there are breakdowns identified.

- The total numbers of victims are then summed over the 10 years-period (2000-2009). These are the observed numbers of victims who died or were seriously injured in France over the 10 year period. They are calculated with the same breakdowns as above.

2. Calculation of simulated number of victims that could have resulted in car crashes in the absence of any new safety measures over the period

These observed numbers are to be compared to a simulated number of victims that would have been observed in the absence of safety measures over the same period. We suggest that these latter numbers would be the mean estimates of these figures over the years 1997 to 1999, multiplied each year of the decade by the percentage of annual mean decrease between 1995 and 1999 in order to take into account the effect of safety measures or other effects (such as changes in registered vehicles and population), that took place before 2000 and that could continue producing safety benefits afterwards. The sum of this simulated annual figures from 2000 to 20009 are the expected numbers of victims that would have been observed over 10 years if nothing (regarding safety) had happened over the decade.

3. List of vehicle safety measures introduced over the period

As we wish to estimate the impact of vehicle safety technologies on the number of victims, we have to define what these safety technologies are. Actually, there are two types of safety technologies. We must first distinguish between vehicle elements that can bring additional safety compared to what can be considered as *a reference* (for example there are many brake systems, some being more effective than others), and safety applications, which can be considered as an additional system, or another application, additional to the *state-of-the-art* system. For example, an emergency brake assist is considered as an additional application and not only as an outstanding brake system.

However, sometimes, the safety improvement is brought by the combination of safer elements and safety applications due to the obligation of compliance with a regulation or a consumer test. For example, the compliance with EuroNCAP is achieved by modifications in the car body structure (geometry, stiffness, mass) and improvements of existing restraint systems (e.g. seat belt with pretensioners, load limiters, airbags, etc.).

We propose a list of vehicle safety measures that are either stand-alone safety applications or a combination of applications and safety organ improvements aimed at passing regulations or consumer tests. These applications, regulations and tests are depicted in the next section.

4. List of public safety measures introduced over the period

Similarly, we also compiled a comprehensive list of all public safety actions that took place over the period with regard to regulation, education, communication, enforcement, etc. This list was extracted from the annual publication of the National Road Safety Department of the Public Authorities (ONISR, 2006, 2009).

Both vehicle technologies and main public actions are supposed to provide us with the principal safety measures put into action over the period. It is understood that there are considerable other actions concerning safety that might produce safety benefits and that we selected only part of them. We nevertheless assume that vehicle technologies and public actions can explain the main short and mid-term variations in safety whereas road improvements and other actions (mainly local actions) are longer-term actions or difficult to evaluate. Their safety impacts are assumed included in the long term variations explained in number 2 above.

5. Intrinsic safety effects of vehicle technology

We collected from the scientific literature studies that estimated the intrinsic effectiveness of new vehicle technologies. The intrinsic effect is defined as the number of fatalities and severely injured persons likely saved in passenger car crashes (i.e. involving at least one passenger car), if the technology was fitted to 100 % of the vehicle fleet.

As there are different technologies under consideration, we applied different intrinsic effects by technology and crash configuration. In some cases, the literature also provides intrinsic effects for a combination of safety applications. These intrinsic effects were estimated for the whole period and correspond of the 'I_e' of formula (3).

6. Percentage of passenger cars annually equipped with the vehicle safety technology compared to the passenger cars in traffic

From different statistical sources, and especially from the national file estimating annually the fleet in traffic with breakdown by vehicle age and vehicle brand (Comité des Constructeurs Français d'Automobiles), and from the EuroNCAP releases showing the awards obtained by the newest vehicles, we estimate:

- the percentage of vehicles in traffic equipped with the safety devices mentioned above,

- the percentage of vehicles in traffic passing the new safety regulations in place since the early 2000's,

- the percentage of vehicles in traffic awarded a certain number of stars at the newly introduced EuroNCAP tests in 1996.

These percentages are estimated annually and correspond of the 'R_c' of formula (4).

7. Actual safety effects of vehicle technology

As specified above, the actual number of saved victims in car crashes over the period is the multiplication of the simulated number of victims with the intrinsic effect and the fitment rate, i.e. S_{rc}.

By comparing this actual number with the simulated number, we can then calculate how much vehicle safety contributed to the reduction in victims in car crashes and in overall crashes. The remaining number (Simulated – actual number of saved victims – observed number of victims) is considered to be the number of saved lives because of other safety actions.

RESULTS

For the sake of clarity, the results are presented in the same order as the method section.

1. Calculation of actual number of victims resulting in car crashes over the period

From 2005 onwards, definitions of fatalities and serious injuries were modified. Prior to 2005, a fatality was a person who died within 7 days after the crash and a severe injured person was someone who was admitted as an in-patient in a hospital more than 6 days after the crash. After 2005, a fatality is a person who dies up to 30 days after the crash and a severely injured ('hospitalized') is a person who is admitted in a hospital for more than 1 day. The consequence of this change is approximately 5% more fatalities overall when they are counted up to 30 days. As for the severely injured, INRETS proposed this formula, based on a crash injury register carried out in the 'Rhone' region of France:

Hospitalized =
Severe injuries + 0,253 Slight injuries (5).

Tables 1 and 2 show the hospitalized figures. Up until 2004, these figures were reconstructed from the initial severely and slightly injured figures available from the BAAC database and according to formula (5).

Table 1 shows annual time series for fatalities and hospitalized on French roads from 2000 to 2009. It also shows these figures for passenger car occupants only.

Similar time series are available but not displayed in the paper for the following injury crash types:

- Crashes with no passenger cars involved
- Crash with at least one passenger car (PC) involved:
  - against pedestrians
  - against two-wheelers
  - PC alone off-road and frontal impact
  - PC alone off-road and side impact
  - PC alone off-road and rollover
  - PC alone off-road and other impact
  - PC alone on-road and frontal impact
  - PC alone on-road and side impact
  - PC alone on-road and rollover
  - PC alone on-road and other impact
  - Head-on crashes
  - Front-Side crashes and front impact
  - Front-Side crashes and side impact
  - Rear-end crashes and front impact
  - Rear-end crashes and rear impact
  - Other crashes

Table 1. Fatalities and severely injured in France (2000-2009). Source: crash national databse (BAAC)

	All injury crashes		As passenger car occupants only	
	V_a		V_{ac}	
	Fatalities	Hospitalized	Fatalities	Hospitalized
2000	7,643	61,478	5,005	34,349
2001	7,720	58,502	4,998	32,753
2002	7,242	52,856	4,599	29,257
2003	5,721	43,328	3,509	22,335
2004	5,226	40,250	3,185	20,207
2005	5,312	39,532	3,065	18,297
2006	4,695	40,376	2,626	18,081
2007	4,608	38,356	2,464	16,486
2008	4,262	34,729	2,205	14,127
2009	4,264	33,142	2,160	13,594
Total	56,693	442,549	33,816	219,486

These different time series are used depending on the safety applications under consideration. Some of the safety applications can of course address one crash configuration, and a crash configuration can be addressed by a few safety applications.

2. Calculation of simulated number of victims that could have resulted in car crashes in the absence of safety measures over the period

Table 2 shows the mean numbers of fatalities and hospitalized between 1995 and 1999. As specified in the method section, we considered the means between 1997 and 1999 as being the reference values for the calculation of the simulated time series.

Table 3 displays the simulated number of fatalities and hospitalized over the studied period taking into consideration the mean figures for 1997-1999 as a starting point. The mean percentage of reduction between 1995 and 1999 for each of the four parameters, i.e.:

- For fatalities: - 1%
- For hospitalized: - 3%
- For fatalities as car occupants: - 1%
- For hospitalized as car occupants: - 3%

… is used to estimate each of the annual simulated figures.

Table 2. Fatalities and hospitalized in France (1995-1999). Source: crash national databse (BAAC)

	All injury crashes		As passenger car occupants only	
	Fatalities	Hospitalized	Fatalities	Hospitalized
1995	8,409	75,160	5,413	42,925
1996	8,075	70,026	5,259	40,461
1997	7,985	69,540	5,088	39,247
1998	8,435	67,976	5,510	39,027
1999	8,029	65,972	5,161	37,358
Mean (97-99)	8,150	69,735	5,253	39,803

As for 2005, because of the change in definitions, we applied to the simulated time series the same increase in fatalities that we observed the same year in the real-world data in table 1.

Table 3. Simulated Fatalities and hospitalized in France (2000-2009)

	All injury crashes		As passenger car occupants only	
	V_s		V_{sc}	
	Fatalities	Hospitalized	Fatalities	Hospitalized
Ref.	8,150	69,735	5,253	39,803
2000	8,068	67,643	5,200	38,609
2001	7,987	65,614	5,148	37,450
2002	7,908	63,645	5,097	36,327
2003	7,829	61,735	5,046	35,237
2004	7,750	59,883	4,996	34,180
2005	7,874	58,087	4,846	33,155
2006	7,796	56,344	4,797	32,160
2007	7,718	54,654	4,749	31,195
2008	7,640	53,014	4,702	30,260
2009	7,564	51,424	4,655	29,351
Total	78,137	661,781	49,236	377,729

Again, similar time series are available but not displayed in the paper for the other injury crash types.

3. List of vehicle safety measures introduced over the period

There were actually three types of vehicle safety measures that deserve consideration: vehicle regulations, consumer tests, and safety technologies. Of course, regulations and consumer tests induce new safety applications such as improvements in body structure or restraint systems. We then consider that the so-called ‘safety’ applications are safety systems that are not required by regulations or compliance to consumer tests.

Regulation

- As for passive safety, there were mainly two new vehicle regulations that were introduced for new cars starting in 1998 and to all cars starting in 2003: Directive 96/79/CEE and ECE.R94 on frontal impact; Directive 96/27/CEE and ECE.R95 on side impact. The frontal impact directive mainly introduced the test against a deformable barrier at 56 km/h with a 40% offset and performance requirements on dummies. The side impact directive introduced a side test with a progressive deformable barrier.

Another test was introduced concerning pedestrian protection: it concerns head and leg impacts. But it was made mandatory in November 2009, which is at the end of the study period, we did not consider it.

- As for active safety, ACEA-JAMA-KAMA-CE all committed themselves, without any specific regulation, to install ABS on cars for the sake of pedestrians and pedal cyclists protection. This commitment (Memorandum of Understanding) states that 100% of the new cars were to be fitted with ABS in July 2004 in the initial 15 countries of Europe, then in July 2000 for 10 additional countries and finally in January 2009 for all member states (27). The ABS is supposed to obey performance requirements of the ECE 13H600 annex 6.

Other regulations concerning braking were also introduced:

- In February 2002 homologation of selective braking (e.g. ESC) and automatic braking;
- in April 2005 concerning prescriptions about stop lights; and
- in June 2007 (ECE 13H-00 complement 4) concerning specifications about modalities of lighting of emergency braking (if any).

We examined all these regulations but finally considered that they were minor compared to the passive safety ones that we selected.

Consumer testing

Apart from new regulations discussed in the 1990’s about frontal impact and side impact performances, the principal event regarding passive safety over the period was the introduction of EuroNCAP in 1996. We consider EuroNCAP as a genuine revolution in vehicle safety as it drove considerable improvements in car structure and restraint systems. From 1997 onwards, the car industry progressively chased the fourth and fifth star of performance. The stars were mainly awarded thanks to the compliance with frontal and lateral impact tests.

As for the passive safety systems, the whole car is designed to offer an overall protection, given the compliance to the regulations and the number of stars targeted. Car structure is stiffer than in the past in order to avoid intrusion in the compartment, which was shown to be one of the major causes of injuries. Load limiters prevent injuries from the belt webbing; airbags prevent injuries to the head and the chest from hitting the steering wheel or another hard element of the compartment; pretensioners couple the occupant to his seat in order to reduce submarining and a hump over the seat and under the base also prevent the pelvis from rotating under the belt. In some cases, knee airbags also prevent submarining by stopping the legs and then the occupant body displacement under the belt during the crash. Other devices such as padding and non-aggressive structures in the door panel, the dashboard, the windshield, the seats and the headrest also provide improved protection.

The whole package of passive safety is then very difficult to evaluate separately from the others. Therefore, we decided to consider that we would evaluate as the safety of the **whole passive safety package** measured by the number of stars awarded at the EURO NCAP test. This is simplistic but is much more operational and reflects anyway the level of performance of an overall passive safety protection.

Safety applications (preventive and active safety)

There are currently not so many active safety technologies in widespread use in the European fleet that can be assessed. A quick glance at the market shows that if some systems are already fitted in cars (night vision, ACC, lane departure warning, etc.), they are usually fitted in luxury cars with a very low penetration rate. Thus, they are difficult to include in this analysis. Hence, we selected only 3 preventive or active safety systems for our evaluation: Antilock Braking System (**ABS**), Electronic Stability Control (**ESC**), and Emergency Braking Assist (**EBA**).

4. List of public safety measures introduced over the period

There are of course many safety measures introduced over the 10-years period. We have made a selection of what we considered the main ones:

2001

- Introduction of a regulation concerning mandatory 2-seconds distance between two vehicles.

- Regulation concerning the mandatory drugs tests for drivers involved in fatal crashes.

2002

- Mandatory license and scholar road safety certificate to use a moped at the age of 16.

- Declaration by the French President, who mentioned 3 priorities for the continuation of his mandate (till 2007): traffic safety, cancer and care of the disabled.

- Enhanced punishments in case of severe violations.

2003

- Regulation concerning the mandatory drugs tests for drivers involved in injury crashes.

- Deployment of automatic speed cameras.

2004

- Gradual licensing for novice drivers.

- Enhanced punishments in case of speed violations above 50 km/h.

2005

- 1,000 additional speed cameras were installed.

2007

- Extension of daytime running lights from motorcycles to light powered two-wheelers.

- Modification of the demerit points system, especially the progressive acquisition of the max 12 points for novice drivers.

- The French president fixes a new safety target: less than 3,000 fatalities in 2012.

2009

- Launch of discussions about the reform of the driving license.

- Installation of automatic red lights violation systems.

Even though there were a lot of safety measures over the period, the most striking event was the progressive installation of speed cameras on the roadsides, which is considered, by far, as the major measure introduced since the mandatory speed limits and seat belt wearing measures in the 1970's.

5. Intrinsic safety effects of vehicle technology

As specified earlier, we retained four main vehicle safety measures:

The EuroNCAP rating score, and the deployment of ABS, EBA and ESC in the fleet.

We then estimated the intrinsic effects of these 'vehicle safety measures'.

As for the EURO NCAP, in 2005, Newstead et al. stated that the Mass Adjusted Crashworthiness estimates between 3 stars and 4 stars rated cars in France did not differ significantly. We can then consider that the injury risk between these two types of cars are not so different.

In a previous paper, Page et al (2009) estimated the intrinsic effects of different combinations of presence / absence of ESC, EBA and 5 stars cars. These intrinsic effects are reported in Table 4. They are the 'I_e's of formula (3). These effects are calculated for cars equipped with ABS and concern car occupants only.

As for pedestrians, Page et al. estimated the effect of EBA being approximately 10% of fatalities and severe injuries (Page et al., 2005).

As for ABS, the effectiveness studies are controversy (Broughton and Baughan, 2002; Farmer, 2001; Cummings and Grossman, 2007). We considered that the effect is nil.

Table 4: Safety benefits of safety configurations for car occupants (Page et al, 2009)

	Reduction in hospitalized + fatalities
Safety benefit of EBA given that the car has four stars.	14.6%
Safety benefit of ESC given that the car has four stars and an EBA.	16,8%
Safety benefit of ESC given that the car has five stars and an EBA.	23.4% (*)
Safety benefit of the fifth star given that the car has four stars, an EBA and an ESC.	35,1% (*)
Safety benefit of EBA and ESC given that the car has four stars.	42,3%
Safety benefit of EBA and a fifth star given that the car has four stars.	37,5% (*)
Safety benefit of ESC and a fifth star given that the car has four stars and an EBA.	37,1% (*)
Safety benefit EBA, ESC and a fifth star given that the car has four stars.	69,5% (*)

* Statistically significant

These intrinsic effects extracted from the literature were applied to the time series specified above.

6. Percentage of passenger cars in the fleet annually equipped with the vehicle safety technology compared to the passenger cars in traffic

Table 5 presents these estimates (the R_c's) for each year of the period. 2009 are extrapolated figures since the fleet figures for this particular year are not yet available.

This Table presents estimates of equipment rates for combination of safety applications since the intrinsic effects much depends on combination of functions (Table 4). Not surprisingly, the rates of equipment are increasing overtime even though equipment in ESC is still moderate (20% in 2009).

7. Actual safety effects of vehicle technology

Table 6 displays the calculations made and provides the necessary outcomes to estimate the real-world contribution of vehicle safety to overall road safety over the study period. It presents the observed victims (fatalities + hospitalized) in the real-world; the simulated victims if no safety measures had been taken (according to our assumptions); the simulated victims pertinent to the vehicle safety measures (all victims involved in crashes with frontal or side impact or in a rollover with exclusion of crashes against two-wheelers or crashes in rear impacts); the simulated victims as pedestrians in a car crash; the savings calculated with the help of intrinsic effects and equipment rates.

About 500,000 persons were victims (56,693 fatalities + 442,549 hospitalized) of road crashes over the 2000's. Approximately half of them were car occupants.

Table 5: Estimates of car fleet fitting rates with safety application or compliant with NCAP Stars

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Proportion of 4*	10,5%	15,1%	19,5%	23,0%	25,4%	26,7%	27,2%	27,7%	28,5%	29%
Proportion of 5 *	0,4%	1,6%	3,0%	5,2%	8,3%	13,4%	18,0%	22,4%	27,3%	34%
Proportion of ABS	17,1%	24,2%	31,0%	37,4%	43,8%	50,2%	55,0%	59,5%	64,8%	70%
Proportion of EBA	2,9%	6,3%	10,4%	14,8%	19,3%	23,1%	28,1%	32,9%	38,5%	44%
Proportion of of ESC	0,0%	1,3%	3,4%	5,8%	8,5%	11,1%	13,7%	16,0%	17,9%	20%
Proportion of 4* without EBA, ESC	8,7%	10,8%	12,6%	14,3%	15,1%	15,7%	15,5%	15,2%	15,2%	15%
Proportion of 4* with EBA	1,8%	3,6%	5,3%	6,3%	7,3%	7,5%	8,0%	8,4%	9,2%	10%
Proportion of 4* with ESC	0,0%	0,4%	0,4%	0,4%	0,4%	0,4%	0,4%	0,3%	0,3%	0%
Proportion of 4* + EBA + ESC	0,0%	0,3%	1,2%	2,1%	2,7%	3,1%	3,4%	3,7%	3,7%	4%
Proportion of 5* without EBA, ESC	0,0%	0,0%	0,0%	0,2%	0,6%	2,8%	3,0%	3,3%	3,5%	4%
Proportion of 5* + EBA	0,4%	1,1%	1,6%	2,3%	3,0%	3,8%	5,8%	7,8%	10,6%	14%
Proportion of 5* + ESP	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0%
Proportion of 5* + EBA + ESC	0,0%	0,5%	1,4%	2,7%	4,7%	6,9%	9,2%	11,3%	13,2%	16%

Table 6. Estimated fitting rates of cars with safety application or compliant with NCAP Stars

	Real-world		Simulated		Simulated		Simulated	
	All Victims (V_a)	Victims as passenger car occupants (V_{ac})	All Victims (V_s)	Victims as passenger car occupants (V_{sc})	Victims as passenger car occupants (pertinents)	Savings (occupants) due to Vehicle safety (S_{rc})	Pedestrians	Savings (pedestrians) due to Vehicle safety (S_{rc})
2000	69,121	39,354	75,711	43,809	38,552	165	6,321	15
2001	66,222	37,751	73,601	42,598	37,486	553	6,004	30
2002	60,098	33,856	71,553	41,424	36,453	1,062	5,705	48
2003	49,049	25,844	69,564	40,283	35,449	1,639	5,419	64
2004	45,476	23,392	67,633	39,176	34,475	2,294	5,148	79
2005	44,844	21,362	65,961	38,001	33,441	2,908	4,891	90
2006	45,071	20,707	64,14	36,957	32,522	3,650	4,647	104
2007	42,964	18,95	62,372	35,944	31,631	4,317	4,414	116
2008	38,991	16,332	60,654	34,962	30,767	4,958	4,193	130
2009	37,406	15,754	58,988	34,006	29,925	5,819	3,984	140
Total	499,242	253,302	739,918	426,965	340,701	27,365	50,728	816

DISCUSSION

The findings obtained here are summarized in terms of the four questions raised at the beginning of the paper:

1. **Between 2000 and 2009, in France, how many lives were saved and how many severely injured were mitigated (compared to the late 1990's)?**

Because of the changes in injuries definition in France in 2005, it was not possible to count the severely injured. The definition of 'hospitalized' was adopted instead of the former definition ('severely injured').

We estimated that 240,676 victims were saved from 2000 to 2009 thanks to the overall safety measures introduced during this period (739,918 – 499,242). Moreover, 173,663 victims were saved as car occupants (426,965 – 340,701).

2. Compared to the total number of lives saved and hospitalized avoided over the same period, how many of them are due to vehicle safety?

Among these 173,663 people saved, we estimated that 27,365 car occupants and 816 pedestrians were saved because of vehicle safety measures. Therefore, vehicle safety contributed to save 16 % of victims as car occupants, and 11 % of overall victims.

3. To what extent can we consider that the 'French miracle' over the last decade is the main outcome of the combination of an efficient speed camera policy and an increasing proportion of safer vehicles in the fleet?

Between 2000 and 2009, the observed annual number of fatalities decreased by 44% and the observed annual number of hospitalized by 46%.

Following our assumptions, the decrease in fatalities and hospitalized due to overall safety measures taken over the period was estimated to be 33% [i.e. 1-(240,676 / 739,918)], which is 72% of the overall decrease (33% / 46%). The other 28% were assumed to have been due to other factors, especially safety actions taken before the assessment period.

Considering the principal safety measures introduced over the assessment period, the installation of speed cameras on the French roadsides was considered to be more important than gradual licensing, enhanced punishments for severe violations and drugs tests in case of an injury crash.

There was a mean reduction in daytime driving speeds by passenger cars between 2002 and 2009 from 90km/h to 80km/h on rural roads and from 126km/h to 118km/h on motorways (ONISR, 2006, 2009). These decreases are considerable and would have noticeably influenced the crash occurences and their severity. Thus, it is safe to assume that the installation of speed cameras was the main factor explaining the ‘French miracle’ in the 2000’s.

4. Can we anticipate the number of people who will continue to benefit from the vehicle safety in the future, considering the continuous deployment of safety systems in the fleet?

Looking at the results in Tables 5 and 6, the intrinsic effect of 5 stars + ESC + EBA is high (70%) but the equipment rate at the end of the period is still quite (16%). The expected increase in fitment of this ‘safety package’ in future vehicles will undoubtedly produce further safety benefits once all the fleet is 5 stars rated and fitted with ESC and EBA.

Limitations of the study

There were several limitations in the study that need to be underlined here:

- **The data**: the French national crash database was used and the ‘hospitalized’ time series had to be reconstructed since the definition of injuries changed in the middle of the period (2005). The estimate (formula 5) is an approximation and may have introduced some inaccuracies in the calculations. Furthermore, Table 5 does not exist by itself – it was produced by looking closely and individually at 30 brand and model vehicles sold in France (70% of the market) for 20 years to state their equipment. Some equipment is optional. It might, again, have introduced some bias in the results.

- **The model**: we have simulated the ‘expected number of victims’ in the absence of safety measures with a simplistic extrapolation of a linear tendency of reduction in victims observed in the late 1990’s. This needs to be addressed with a more thorough analysis in forecast and previsions.

- **The intrinsic effect**: the intrinsic effects were calculated for crashes that occurred in 2005 and 2006 (Page et al, 2009). As the mean car driving speeds dropped dramatically over the period, it is reasonable to assume that the intrinsic effects might be different at different driving speeds and subsequently at different crash speeds. The intrinsic effects need to be calculated for different periods. This could eventually lead to estimation of the combined effects of reduction in driving speeds and improvements in vehicle safety.

- The **vehicle safety systems**: we were only able to evaluate some safety systems out of all systems available on the market. No doubt other systems that were progressively introduced in the market (navigation systems, speed limiters, lane departure warnings, blind spot detection, night vision systems, etc.) may have also exerted some influence in these results, but to a lesser extent considering their small deployment. Those that were selected seem to be the main popular ones and it was not expected to introduce too much bias. In addition, the 3 main passive safety measures were taken at the same time, including the revision of frontal and side impact regulations, and the implementation of the EURO NCAP. There are a variety of responses by the car industry to these regulations and to EuroNCAP. We assumed that compliance with EURO NCAP was predominant and encompassed the response to the regulations. In doing so, it was assumed that the EuroNCAP score was an aggregated index of the overall passive safety improvements.

- **The estimations**: confidence limits of the estimates were not calculated since the intrinsic effects are not all statistically significant and the equipment rates are only rough estimates. The confidence intervals would be expected to be quite large.

- **The international comparison issue**. We acknowledge that adding international comparisons would have further validated the explanation of the fatalities and hospitalized trends in France over the study period. However, data was hardly accessible in European countries and we have not been able to run the model in other countries. We nevertheless intend to continue this kind of studies by expanding the data to other countries in the future. This paper is then a first step in a more general approach of international comparisons and the assessment of the effectiveness of vehicle technologies in Europe

CONCLUSION

The objective of the paper was to estimate the extent that vehicle safety improvements contributed to the entire road safety benefits over the 2000's decade in terms of lives and hospitalized persons saved. The 7-step method comprised the availability of national crash data; estimates of the rate of fitment of safety applications in the fleet; estimates of the intrinsic safety benefits of new vehicle technologies (defined as the number of fatalities and hospitalized in passenger car crashes savable, would 100% of the fleet being fitted with such or such technology); inclusion of a limited range of proven safety technologies (such as frontal airbags, side airbags, ESC, brake assist or as a package, e.g. technologies for passing new regulations or getting 5 stars at the EURO NCAP, and a list of other safety measures).

The results showed that the combination of recent passive and active safety technologies is highly effective in reducing road fatalities and 'hospitalized' in France and that the intrinsic effect of the whole package (passive safety, as grouped in the EuroNCAP '5 stars', ESC, and brake assist) is close to 70% of relevant vehicle crashes. This translates to an overall real-world saving of 11% in road trauma because of the moderate deployment of these technologies. This is expected to improve as the fitment rates of these technologies increases on newer cars.

Importantly, it was acknowledged that the installation of speed cameras did produce the highest safety benefits during the period from 2000 to 2009 in France. It led to significant driving speed reductions which would translate to sizeable crash speed reductions, less severe injuries, and fewer crashes.

It is important, however, to acknowledge both the contribution of vehicle safety and the implementation of speed cameras to the French road safety miracle in the 2000's. Much higher vehicle safety benefits are expected in the future as the fleet will progressively be compliant with EuroNCAP 5 star ratings and equipped with preventive and active safety systems. Moreover, a current jump in vehicle safety with the forthcoming affordable ADAS based on radars and front cameras will produce even greater safety benefits, due to safer passenger cars.

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