Chapter 17
Car Safety:
A Statistical Analysis for Marketing Management

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ABSTRACT

Car safety is an essential feature of marketing strategies for automobile companies. In this work, a statistical analysis on crash tests is conducted based on data available from European New Car Assessment Programme (Euro NCAP). The research work developed in this chapter presents a statistical analysis of the information produced by Euro NCAP, using the SPSS and MATLAB software, and seeks to answer the following research questions: - are there statistically significant differences on adult occupant safety in the six years under study? - are there statistically significant differences among the best-selling car classes regarding safety in frontal collisions? - are electric and hybrid automobiles less secure than their traditional counterparts with respect to frontal collisions?

INTRODUCTION

Car marketers know that car buyers need far more than the basic transportation needs. Marketing cars is a kind of art: from the necessity to by a new car because the previous one broke down, or new needs arise for everyday activity, one realizes that hedonic considerations like excitement (power sliding a sports car through a rain-slick city) or emotional attachment (freedom sensation driving thought beautiful landscapes) among advertising themes used by car marketers are well more familiar to car buyers than utilitarian considerations like gas mileage, airbags, safety rating, and number of seats.

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Although hedonic aspects are very important to position vehicles characteristics as speed, price, shape, handling, and prestige in the consumer minds, most people shopping a brand new car resorts to utilitarian aspects, such as gas mileage, and airbags.

When advertising cars, marketers take the consumer needs into account placing high emphasis on complementing utilitarian with hedonic considerations in order to create new needs among consumers. Moreover, car marketers know they can develop attitudes and associations toward specific brands based on aggressive marketing campaigns that include excitement and emotional attachment when developing their brands. However, one thing is clear: most people have difficulties analyzing how different cars and brands perform on safety performance.

Institutional marketing seeks to work the identity, the formation and the image consolidation of an organization. As such, public recognition and exerting a strong influence on decision-making of the public are essential for institutions that seek to promote a solid reputation of their activities. Institutional marketing seeks to develop methodologies that can be developed to facilitate communication with the general population, with the aim of clarifying and involving the public in its decision making.

The chapter is structured in four sections. The first section presents the introduction of the chapter. The second section presents the importance of safety tests, a description of the Euro NCAP safety tests and the way they are performed. While the third section presents the methodology, the results of the study and its discussion, the fourth section presents the conclusions and suggestions for future work.

THE IMPORTANCE OF CAR SAFETY

Safety has an increasingly important role in vehicle research because of its economic and social importance. Car safety needs have been disclosed quite long time ago (Seidel, Loch, & Chahil, 2005). For example, Marin and Lenguerrand (2008) show that the risk of a driver being killed in two-car crashes is larger than in single-car crashes. Moreover, the study also shows that when a recent car collides with an older car the driver of the former is more protected than the driver of the latter, which clearly indicates that there has been an improvement of safety and production systems among carmakers. Gronostajski, Bandola, and Karbowski (2006) analyzed the effect of crashworthiness parameters on the behavior of car-body elements, which might have important consequences for passive safety and a threat to life of passengers and persons involved in car accidents. Modelling techniques have also been used to predict the effect on passengers (Orsi, Marchetti, Montomolli, & Morandi, 2013; Pawlus, Karimi, & Robbersmyr, 2013), which is a clear indication of how important car safety has become.

Although research on car accidents has been increasing, papers on how major car brands differ in terms of performance are still scarce (Huang, Li, & Zeng, 2016; Huang, Hu, & Abdel-Aty, 2014). While Huang et al. (2014) analyzed crash worthiness and crash aggressivity involving 34,356 cars of 23 major brands, concluding that European cars have relatively good self-protection when compared with Japanese cars, South-Korean cars being associated with the lowest crash worthiness, Huang et al. (2016) investigated vehicle's crash protectiveness on occupant injury and vehicle damage using Bayesian bivariate hierarchical ordered logistic model for 23 major brands in total of 7,335 two-vehicle-crash. Huang et al. (2016) found that occupant protectiveness index is relatively coherent with the crash worthiness index found by Huang et al. (2014).

The Euro NCAP

The European New Car Assessment Programme (Euro NCAP) was founded in 1997. It performs safety tests and evaluates accident prevention systems in passenger light and business cars that are available in the European market. It is composed by ten members from European government institutions and motoring organizations, with testing facilities in six countries.

The Euro NCAP provides information for anyone wishing to purchase a new car, aiming to draw attention to the importance of vehicle safety and convey the message that "safety is not a luxury" (Euro NCAP, 2014). In addition, Euro NCAP aims to encourage improvements in safety and security issues in the design of new cars and to increase the safety requirements the law provides. Road fatalities decreased by 17% in the European Union between 2010 and 2013 (Campos, 2014), and it was estimated that about nine thousand lives have been saved, as stated by Siim Kallas, Commission Vice-President and European Commissioner for mobility and transport, quoted by Campos (2014). However, Campos (2014) recalls that around 70 people die every day on Europe's roads. As such, there is plenty to be done to stop those numbers.

Since it is not possible for the Euro NCAP test neither all cars nor all variants/models of each car, each year a selection of the best-selling models to the general public is made. In most cases, the Euro NCAP tests cars that are not yet on the market, as it is important to publish the results as soon as possible so that more consumers can make an informed choice. However, occasionally, cars that are already on sale can also be tested.

In order to evaluate a model of a car, the Euro NCAP requires at least four cars. If they are already in the market, automobiles are anonymously purchased from car dealers, in the same way that consumers do. Before being tested, it is asked the manufacturer to check (through the vehicle identification number) if any change was introduced during production. If it was introduced, for example, a new security equipment, it will also be installed in the vehicle being tested in order to ensure that the results are representative of the current car production. If the vehicle is not yet in the market, cars are randomly selected in factories or from a list provided by the manufacturer. In such a way, it is assured the randomness of the sample.

The rating is sponsored by the Euro NCAP member organizations (each member organization sponsors the evaluation of at least one car per year) and sometimes by the car manufacturers themselves.

The Euro NCAP rating involves a five-star classification for three different areas for cars tested until 2009, and four areas for cars tested from 2010 onwards. For vehicles tested before 2009 the three areas are: adult protection (for the driver and passenger), child protection, and pedestrian protection. From 2010 onwards, the overall score, besides being more demanding involves the following new area: safety assist technologies, that includes the alert speed assistance system, the electronic stability control, the seat belt reminders control (that formerly was part of the adult protection test), among others.

Generally, the number of stars mirrors the car performance in Euro NCAP tests, although it is also influenced by the safety equipment the manufacturer incorporates. So the higher the number of stars, the better the result, and the more safety equipment in the tested model is readily available to all European consumers. According to the Euro NCAP (2016), the meaning of the number of stars is the following:

- **5 Stars Safety:** Overall good performance in crash protection. Well equipped with robust crash avoidance technology;
- **4 Stars Safety:** Overall good performance in crash protection; additional crash avoidance technology may be present;

- **3 Stars Safety:** Average to good occupant protection but lacking crash avoidance technology;
- **2 Stars Safety:** Nominal crash protection but lacking crash avoidance technology;
- **1 Star Safety:** Marginal crash protection.

To carry out safety tests, the Euro NCAP uses steel and rubber dummies that simulate the adult and child passengers. In all tests, it is used a dummy from which the intensities of the injuries that a human could possibly suffer are measured. Each dummy may have a cost of 100,000 euros.

The head is made of aluminum and covered with rubber. Inside the dummy there are three accelerometers, each providing information on the forces that the brain is subjected in an accident. A device is placed in the neck in order to measure the forces to which it is subject during an impact. The steel ribs dummy is a device that records the forces applied to the chest in a frontal impact. Since the dummy used to simulate side impacts is equipped with three different ribs that record the compression of the thorax and the velocity of this compression. Similar equipment (measuring forces and impact velocity) are placed in the abdomen, pelvis, thighs, legs, ankles, and feet (Euro NCAP, 2016).

Thanks to its stringent crash tests, Euro NCAP has rapidly become a booster of the greatest advances in the safety of new vehicles. Success during the Euro NCAP tests may contribute to the increase of the brand reliability, as well as to clarifying the public opinion.

Adult Occupant Protection

The Adult Occupant Protection score is determined from frontal impact (Offset-Deformable Barrier (ODB) test, and frontal full width rigid barrier test), side impact (side mobile barrier and side pole tests), whiplash tests, and Autonomous Emergency Breaking (AEB), which are carried out to evaluate the protection of adult driver and passengers offered by the vehicle.

In the ODB crash test the crash forces needed to be safely and efficiently absorbed when the vehicle structure is put to the test. As the front end of the vehicle collapses, the passenger compartment needs to remain as undeformed as possible. Moreover, in order to avoid serious injuries to the passenger, the steering wheel and the pedals rear movement must be limited as much as possible.

The frontal full width rigid barrier, which was introduced in 2015, is another frontal crash test that simulates a head-on collision between two oncoming cars at moderately high speeds. This test has placed stricter limits, namely on the degree of chest deflection. With stiffer car structures and higher compartment decelerations, this test has also contributed to the reduction of lower leg and head injuries.

The side mobile barrier test seeks to ensure that critical body regions are adequately protected. This test has led vehicle manufacturers to strengthen the structures of vehicles around the between the doors pillar, the fitment of side impact as well as the development of less obvious energy-absorbing structures in seats and door panels.

The side pole test involves simulating a car travelling sideways into rigid roadside objects such as a tree, which might have lethal consequences for drivers or passengers. This test seeks to test the vehicle's ability to protect the driver's head. This test has led to the introduction of head protection airbags.

Whiplash is a trauma caused by sudden movements of the neck, associated with rapid and excessive distortion of the spine. Although whiplash injuries can occur in all kind of accidents, they are very common in rear-end collisions (Ratingen et al., 2009). It is the most common injury in road accidents with about two million records per year in Europe (cases where the problem does not manifest immediately and cases where one does not need police or toeing assistance are not included in the statistics)

(Ratingen et al., 2009). It is a serious problem with enormous implications for the individual and for society because, in addition to personal suffering, implies high economic costs (Watanabe et al., 2000).

According to Carmen Rodarius, a research scientist in the vehicle safety area, a good seat can protect the occupant to jointly support the back and neck, reducing the "S" curve between the head and the back and hence the risk of injury. If the car seat is poorly designed, it just supports the back leaving the head and neck unrestrained (Euro NCAP, 2014).

Euro NCAP's whiplash tests are designed to test excessive head movement, i.e. to approve those designs that provide the most effective protection. The dynamic sled tests indicate how effectively the seat and head restraint operate to provide whiplash protection in typical crash scenarios.

The Euro NCAP integrated neck protection tests on the rear-end collision testing program in 2009. This procedure aims to promote improvements in seat design, headrest and ease of adjustment (Euro NCAP, 2014).

The AEB City systems intervene by applying the brakes to try to avoid a collision at low speed. It simulates a rear-end collision in which the driver of the striking car is distracted and does not notice that the car ahead has stopped (Euro NCAP, 2016). Such accidents can cause neck injuries to the occupants of both cars. This AEB function allows the driver to brake detecting when there is an eminent danger or when an accident is likely to occur. In this case the systems intervene by applying the brakes in order to avoid a collision. The AEB test was introduced in 2014.

When the collision is avoided maximum points are awarded during tests. However, some points are granted if the speed of collision has been reduced, as even small speed reductions can mitigate the likelihood of collision.

Child Occupant Protection

The assessment of Child Occupant Protection (COP) covers three aspects: the protection offered by the Child Restraint Systems (CRSs) in the frontal and side impact tests, the accommodation of child restraints of various sizes and designs, and the availability of CRSs installation checks for safe transport of children in the car. The results of these tests are a contribution to reduce the misuse of child restrain installation conditions and to improve the safety of children (Euro NCAP, 2016).

Euro NCAP CRS performance test checks how well different child restraints fit and verifies the protection offered by the recommended child restraints in the event of a front or side crash.

To assess this COP parameter, some of the most used chairs that have shown to provide good protection in independent tests are installed. The Euro NCAP also evaluates how children's chairs are accommodated in the vehicle, its stability, the seat length, seat belt length and the belt buckle location. It is also checked whether the child seat can be installed properly in all appropriate places of the vehicle and if it is possible to place the child seat facing backwards. The vehicle handbook should clearly mention the seating positions where a CRS cannot be installed.

In another part of the assessment, child dummies are placed in the car seat, properly installed according to the safety recommendations. The vehicle is subject to bumps and head movement, neck loads and chest accelerations are the main child dummy criteria in the allocation of classification. The lower the head movement, neck loads and chest accelerations, the larger the score of the vehicle. They are also awarded points if the dummy is maintained inside the vehicle during the accident. The score also takes into account whether the child chairs are adequate to the various child ages and weights.

The Euro NCAP rewards extra points if the vehicle supplies other resources that provide important features that facilitate safe transport of children, as front seat airbag-disabling switch with clear user instructions, integrated child seats, among others.

Pedestrian Protection

According to Euro NCAP (2014), the deaths of pedestrians account for 14% of deaths recorded in road accidents in Europe. As such it is essential to encourage the improvement of security systems to halt the numerous human losses and the emotional and psychological trauma that drivers that injured pedestrians endure. The inclusion of the score obtained in the pedestrian safety tests aims to contribute to improving performance in this area.

In the pedestrian protection tests, the potential risk at injuries to pedestrian head, pelvis, upper and lower leg are assessed. The score is determined from tests to the most important vehicle front-end structures such as the bonnet and windshield, the bonnet leading edge, and the bumper.

In order to score the vehicles, accidents involving adults and children pedestrians are simulated. As it is difficult to simulate the accident with a complete dummy – it is difficult to predict the point of impact on the head – the Euro NCAP carries out the tests separately, i.e. one test simulates and evaluates the impact of the lower leg with the bumper, another evaluates the impact of hip with the hood, and another test evaluates the impact of the head with the hood. The score in this pedestrian protection tests results from the performance of the vehicle in the various tests. From tests performed one can conclude that the impact is not as severe when it reaches the leg away from the knee and when the impact force is spread over an area of the leg. Unnecessary rigid structures in front of the automobile should be avoided.

The AEB pedestrian test, introduced in 2016, is meant to reduce the risk of pedestrian accidents in real world driving as AEB pedestrian technology is able to bring the car to a safe halt before a pedestrian is struck or which can at least reduce the speed of the collision.

One major factor that influences pedestrian injury outcome during a collision is the vehicle speed at the point of impact. An increasing number of vehicle manufacturers are offering systems which are able to bring the car to a safe halt before a pedestrian is struck or which can at least reduce the speed of the collision. For this reason, Euro NCAP only rewards the technology if the pedestrian impact tests show that the car has a forgiving front design (Euro NCAP, 2016).

Safety Assist Score

The safety assist score is determined from tests to the most important driver assist technologies that support safe driving to avoid accidents and mitigate injuries. The safety assist score is meant to prize the functionality and the performance of the safety system during normal driving and in typical accident scenarios.

The Electronic Stability Control (ESC) system varies among European Union countries and among brands. In its development car manufacturers perform various tests in order to verify its response under different circumstances: different speeds, different road conditions, different maneuvers and different responses of the driver. Studies of real accidents have shown that vehicles with electronic stability control system are involved in fewer and less severe accidents than vehicles that do not have this system available. However, it was not possible to differentiate the security offered among the different types of electronic stability control systems.

To evaluate this system, the Euro NCAP tests are carried out at speeds of 80 km/h with sudden steering wheel rotations up to 270 degrees. The sideway displacement, the stability and the vehicle's ability to follow a straight path are evaluated. The ESC was introduced in Euro NCAP's tests in 2009. In 2014, the fitment of ESC systems has become mandatory for all new vehicles and therefore Euro NCAP has stopped testing the system (Euro NCAP, 2016).

The seat belt is a key component in any vehicle and the statistics confirm that the majority of accidents where the vehicle occupants were driving without wearing their seatbelts end in serious and fatal injuries. Studies also show that occupants are more likely to travel without a seat belt when the car is not equipped with a seatbelt warning signal (Euro NCAP, 2014).

The Euro NCAP evaluates the intensity and duration of the beep, the position and clarity of visual warning, in how many places is the Seatbelt Reminder (SBR), and if the belt responds properly and attempts to recreate all possible scenarios that occupants can be subjected when not wearing their seatbelts. The position and clarity of any visual warning is checked to ensure that it is visible to occupants of different sizes, rewarding manufacturers who fit intelligent SBR systems on all seating positions (Euro NCAP, 2016).

As is well known, speeding, voluntary or involuntary, is a factor that has strongly contributed to car accidents. Driving within the expected speed limits, not only can prevent accidents, but also contributes to ensuring the safety of motorists and other road users. In this sense, the Euro NCAP evaluates and encourages the installation Speed Assistance Systems (SAS) that support drivers to control their speed. The main function of SASs are: (1) to inform the driver of the current speed; (2) to warn the driver when the speed limit is exceeded; (3) to prevent the car from exceeding a threshold limit (Euro NCAP tests if the threshold limit set is not exceeded) (Euro NCAP, 2014). The functionality of the system is considered to make sure that the system can be used without undue distraction to the driver.

According to Euro NCAP (2016), car-to-car rear impacts are one of the most frequent accidents. The AEB Interurban systems tests, introduced in 2014, are meant to support drivers in avoiding a rear-end crash by warning and supporting adequate braking or ultimately stopping the vehicle by itself. High scores are awarded to AEB systems that are able to avoid a collision in all test conditions, or to significantly reduce the severity of the crash.

Lane Support Systems (LSS) can assist and warn drivers when they unintentionally leave the road lane or when they change lane without indication. The LSS are important to avoid any unintentional lane departure, which can lead the vehicle to run off from the road, or to impact an obstacle or collide with another vehicle (Euro NCAP, 2016). This test was introduced in 2014.

Literature Support

There are several studies comparing the results of tests conducted by Euro NCAP with the real accident consequences. For example, taking into account the police data, Lie et al. (2001) conducted a comparative study of the results of the Euro NCAP tests with data from accidents and injuries in the real world and concluded that there is, overall, a relationship between the Euro NCAP classification in stars and police data.

Similar conclusions were drawn by Fails and Minton (2001), where a comparative analysis showed a good correlation between the results of the Euro NCAP and the actual data. The protection of collision identified during the tests is often visible in real life and the damage caused is realistic when compared to accidents.

In another comparative study by Lie and Tingvall (2002), in which children and pedestrian scores were not considered, it was concluded that the vehicles classified with three or four stars were approximately 30% more secure compared with two-star or unrated vehicles.

Taking into account police and insurance injury data, Kullgren et al. (2010) concluded that the Euro NCAP five-star vehicles occupants have a lower risk of injury compared to two-star vehicle occupants. This difference in risk is about 10 ± 2.5%. For serious and fatal injury the difference was 23 ± 8% and for fatal injuries alone the difference was 68 ± 32%, i.e. the most significant one.

In short, the literature shows a good relationship between the results published by Euro NCAP and what actually happens in real life. In addition, there is also a good agreement between the state of the vehicles after the simulated crash tests by Euro NCAP and the damage observed in real accidents.

RESEARCH MEHODOLOGY AND MAIN RESULTS

The statistical analysis performed in this work is based on some well-known descriptive statistics techniques and hypothesis testing theory, namely normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) and nonparametric tests (Mann-Whitney U and Kruskal-Wallis). For an overview on these methodologies see Wilcox (2003) and Mittelhammer (2013).

Data for analyzing the number of stars, adult occupant protection score, child occupant protection scores, pedestrian scores, and safety assist score were withdrawn from Euro NCAP website, for the 2010-2015 period. After an initial presentation of descriptive statistics regarding the main car brands and the main car classes, the rating of number of stars is analyzed taking into account its evolution per year and per vehicle class. The adult protection score is also analyzed per year and per class. The child protection score is analyzed taking into account its evolution over the six-year period. The pedestrian protection score is analyzed per class for every year. Finally, the safety assist score is analyzed over the six-year period.

In what pertains to the three research questions raised, we used inferential statistics to draw our conclusions.

Main Car Brand and Car Classes Analyzed

Forty-one different car brands were tested during the six-year term of this study, as well as several different classes, namely Supermini, Small Family Car, Large Family Car, Executive, Small MPV, Large MPV, Small off-road 4x4, Large off-road 4x4, Pick-up, Roadster Sport, and Business and Family Vans. The frequency table describing the vehicle brands tested throughout the six-year study period is presented in Table 1.

According to Table 1, Ford was the brand with more models tested by Euro NCAP – to be more precise, 14 vehicles – which corresponds do 5.9% of the automobiles tested during the analysis period. The brands with the least reviewed models are Alfa Romeo, Landwind, Geely Emgrand, Qorus, Maserati, Porsche and Tesla, with a single tested model.

During this six-year period Euro NCAP reviewed 236 automobile models, belonging to 11 classes. It is possible to check from the frequency table (Table 2), that the Small Family Car was the class which had more tested models, followed by the Supermini class. Among the vehicles with fewer reviews are the Roadster Sport class, with three tested models, and the Pick-up class, with five tested models, which corresponds to a percentage of 1.3% and 2.1%, respectively.

Table 1. Main car brands

	Frequency	Percent	Cumulative Percent
Audi	8	3.4	3.4
Citroen	13	5.5	8.9
Nissan	11	4.7	13.6
Suzuki	4	1.7	15.3
Alfa Romeo	1	0.4	15.7
Honda	5	2.1	17.8
Seat	5	2.1	19.9
VW	13	5.5	25.4
BMW	9	3.8	29.2
Jaguar	4	1.7	30.9
Mercedes Benz	13	5.5	36.4
Ford	14	5.9	42.4
Kia	12	5.1	47.5
Landwind	1	0.4	47.9
Mini	3	1.3	49.2
Opel	10	4.2	53.4
Toyota	9	3.8	57.2
Hyundai	10	4.2	61.4
Mazda	7	3.0	64.4
Chevrolet	6	2.5	66.9
Fiat	6	2.5	69.5
Mitsubishi	6	2.5	72.0
Lexus	4	1.7	73.7
MG	2	0.8	74.6
Renault	12	5.1	79.7
Subaru	3	1.3	80.9
Geely Emgrand	1	0.4	81.4
Peugeot	11	4.7	86.0
Volvo	4	1.7	87.7
Lancia	3	1.3	89.0
Dacia	4	1.7	90.7
Land Rover	3	1.3	91.9
Jeep	4	1.7	93.6
Skoda	5	2.1	95.8
Isuzu	2	0.8	96.6
Qorus	1	0.4	97.0
Infiniti	2	0.8	97.9
Maserati	1	0.4	98.3
Smart	2	0.8	99.2
Tesla	1	0.4	99.6
Porsche	1	0.4	100.0
Total	**236**	**100.0**	

Table 2. Main car classes

	Frequency	Percent	Cumulative Percent
Supermini	50	21.2	21.2
Small Family Car	54	22.9	44.1
Large Family Car	22	9.3	53.4
Executive	10	4.2	57.6
Small MPV	31	13.1	70.8
Large MPV	8	3.4	74.2
Small off - road 4x4	32	13.6	87.7
Large off-road 4x4	8	3.4	91.1
Pick-up	5	2.1	93.2
Business and Family Vans	13	5.5	98.7
Roadster Sport	3	1.3	100.0
Total	**236**	**100.0**	

Distribution of the Classification According to the Number of Stars

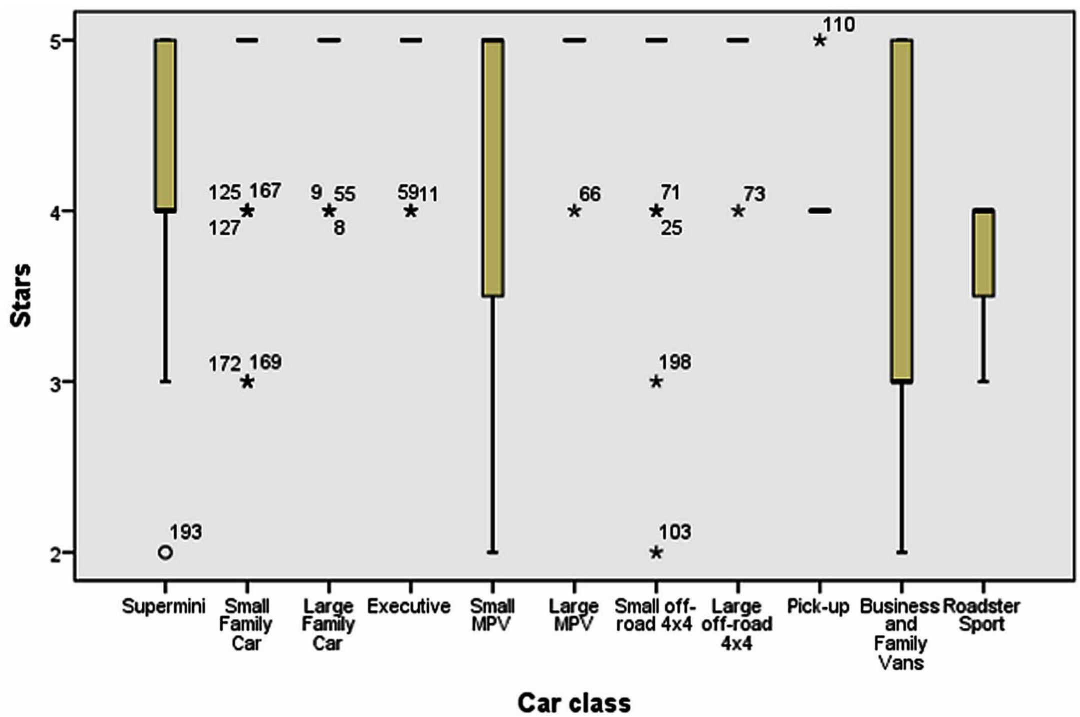
The star rating is a discrete quantitative variable, which awards each tested automobile a rating using a scale from 1 to 5. The statistical information about the star ratings regarding each of the tested automobiles is presented in Table 3 and in Figure 1.

From all the information gathered, one can witness that the most frequent rating during the six year period of this analysis was the five star rating, and that the average rating was approximately 4.5 stars. Due to the fact that the levels of requirement and rigor were changed, the collected data is not directly comparable from year to year. However, it is important to mention that despite the fact that the rating in 2015 having been the most demanding of all the six years analyzed, only one vehicle, the Lancia Ypsilon 1.2 Gold, obtained the minimum rating of two stars out of the 44 evaluated vehicles; 28 (63.6%) obtained the maximum five star rating, with special focus on the Volvo XC90 D5 Momentum, which achieved a score of 100% in what concerns safety equipment and 97% in adult occupant score.

Table 3. Rating of number of stars

Year	N	Minimum	Maximum	Mean	Std. Deviation
2010	27	2	5	4.52	0.753
2011	46	4	5	4.74	0.444
2012	44	2	5	4.48	0.952
2013	33	3	5	4.64	0.603
2014	42	3	5	4.24	0.790
2015	44	2	5	4.50	0.762

Figure 1. Star rating, per car class
Source: Own preparation.



Adult Occupant Protection Scores per Year and per Class

The score referring to adult safety (%) is a continuous quantitative variable. Between 2010 and 2013 its calculation accounted for the scores obtained from frontal, rear and side impact poles. In 2014 the AEB city score was introduced, and in 2015 the ratings for the frontal impact pole was split in frontal offset deformable barrier and frontal full width rigid barrier. Table 4 presents the comparative study on the achieved ratings for these parameters throughout the six-year period and for all the considered classes. They include results for some of the central location measures (mean, median and 5% trimmed mean), relative location (minimum and maximum), dispersion (range, inter-quartile range, standard deviation and variance), asymmetry and kurtosis. All these measures allow for a description of the scores relating to adult safety, through numerical characteristics that summarize the available information. For instance, there is the presence of a negative skewness in all the studied years, which means a concentration of frequencies for higher sample values. This analysis is supported by the skewness value, since it holds a negative value in every year.

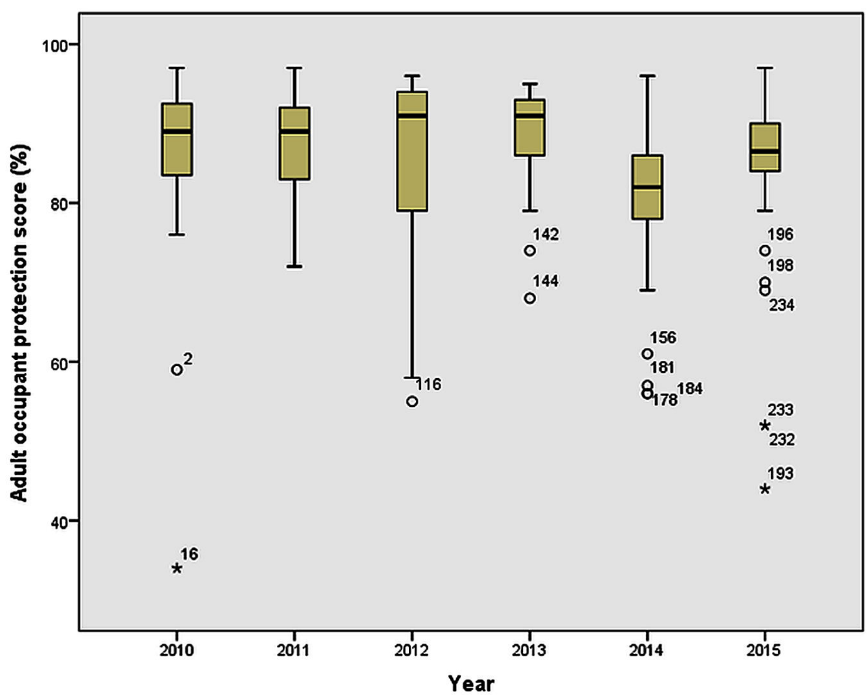
Figure 2 presents the comparative boxplots from the scores obtained in regards to adult occupant protection within the six-year study. They provide indications in what concerns central location, quartiles, extremes, dispersion, symmetry and the existence of outliers. The use of the same scale for all the boxplots allows for a global idea of the differences between all six years of study.

Through the observation of the boxplots one observes that the medians in the first four years are almost identical, whereas the medians of the last two years are lower, particularly in 2014. It was in 2010 that a wider range of the data was registered. This is the result of the presence of an outlier – Landwind

Table 4. Adult occupation protection score (%), per year

		2010	2011	2012	2013	2014	2015
Mean		85.11	86.91	84.75	88.58	80.31	89.93
95% Confidence Interval for Mean	Lower Bound	79.96	84.73	80.80	86.34	77.36	80.57
	Upper Bound	90.26	89.10	88.70	90.81	83.26	87.30
5% Trimmed Mean		86.94	87.18	85.68	89.23	80.87	85.25
Median		89.00	89.00	91.00	91.00	82.00	86.50
Variance		169.718	53.992	168.610	39.814	89.536	122.577
Std. Deviation		13.028	7.348	12.985	6.310	9.462	11.071
Minimum		34	72	55	68	56	44
Maximum		97	97	96	95	96	97
Range		63	25	41	27	40	53
Interquartile Range		10	10	17	7	8	6
Skewness		-2.734	-0.738	-1.212	-1.658	-1.184	-2.277
Kurtosis		9.032	-0.490	-0.043	2.784	1.419	5.334

Figure 2. Adult occupant protection score (%), per year
Source: Own preparation.



CV9 – the first Chinese brand to be commercialized in Europe. This is a severe outlier as its score (34) is below the second inferior barrier for outliers

$$1^{st}Q - 3\times(3^{rd}Q - 1^{st}Q) = 83 - 3\times(93-83) = 53)$$

2011 is the year that presents the narrowest range and lowest negative skewness (Table 4).

Another relevant analysis is the comparison of the adult safety scores from all analyzed vehicles classes. Table 5 summarizes some statistical measures of interest.

Analyzing Table 5, one can conclude that the highest mean regarding adult safety belongs to the Large off-road 4x4 class, whereas the Business and Family Vans class presents the lowest mean value. It is also shown that Small MPV, Small Family Car and Large off-road 4x4 classes obtain the highest scores. It is interesting to note that the lowest score belongs to a Small MPV class (Landwind CV9), thus making it the class with the widest range in the collected data.

Figure 3 illustrates a comparative analysis of the adult occupant protection scores for the various classes under study. It should be noted that it is positive that the values are concentrated near the highest scores, despite some exceptions.

Child Occupant Protection Scores

The child occupant protection score is also a continuous quantitative variable. The weighting for this classification includes the evaluation of the supplied instructions, the ease and safety of the installation of child car seats of various sizes and designs, and the evaluation based on the vehicle (seatbelt length, seat depth, among others).

In the six years of study, one can witness a strong concentration in the upper values (Table 6), which accounts for the existence of negative skewness of the frequency distribution. This is, undoubtedly, good news in what pertains to child occupant protection, although it would be desirable that the score could have been larger.

Table 5. Adult occupant protection score (%), per class

Class	N	Minimum	Maximum	Mean	Std. Deviation
Supermini	50	44	95	81.58	10.014
Small Family Car	54	71	97	88.50	6.598
Large Family Car	22	75	95	89.05	5.232
Executive	10	78	95	86.70	6.290
Small MPV	31	34	97	81.32	14.531
Large MPV	8	79	96	87.63	6.323
Small off-road 4x4	32	61	96	87.56	7.641
Large off-road 4x4	8	81	97	92.00	5.182
Pick-up	5	79	96	85.00	6.671
Business and Family Vans	13	52	93	70.08	19.950
Roadster Sport	3	69	84	78.00	7.937

Figure 3. Adult occupant protection score (%), per class
Source: Own preparation.

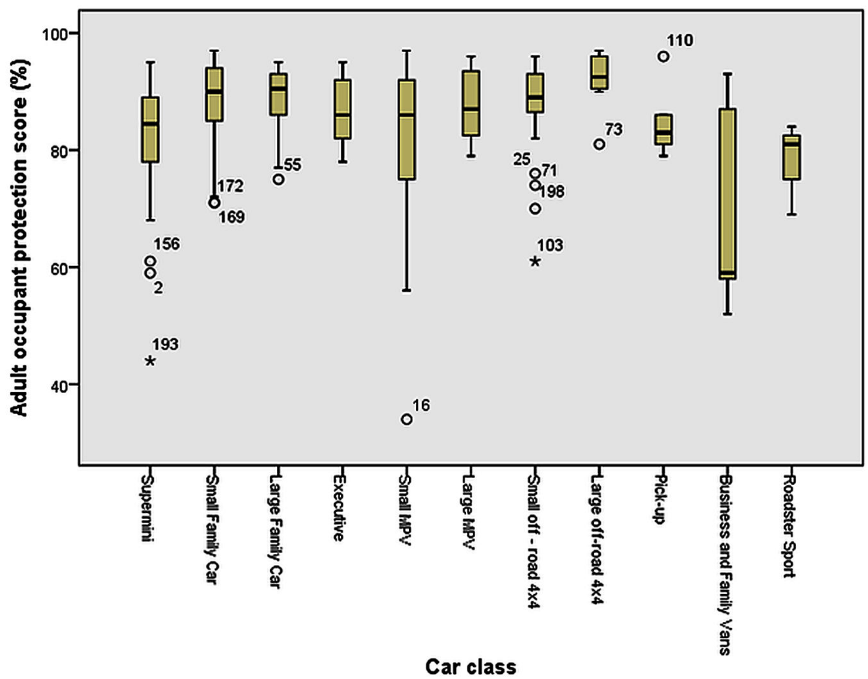


Table 6. Child occupant protection score (%), per year

Year	N	Minimum	Maximum	Mean	Median	Skewness	Std. Error Skewness
2010	27	45	88	77.00	79.00	-1.866	0.448
2011	46	63	90	80.54	81.00	-0.983	0.350
2012	44	67	92	82.84	83.50	-0.613	0.357
2013	33	69	88	80.06	80.00	-0.386	0.409
2014	42	71	88	80.40	80.50	-0.192	0.365
2015	44	61	91	82.93	85.00	-1.323	0.357

Pedestrian Protection Scores

The score relating to pedestrian protection is a continuous quantitative variable. Scores regarding the protection of the head, pelvis and legs are taken into consideration for its calculation. This is a variable that is only directly comparable in 2010 and 2011.

Some statistics regarding this variable are gathered in Table 7, and Figure 4 shows the boxplots for each class and year.

The scores of Business and Family Vans class stand out negatively from the observation of Figure 4. The highest mean value (approximately 89%) belongs to Roadster Sport in 2015, followed by Executive (80%) in the same year, and Large MPV (80%) in 2013. In 2010, 2011, 2012 and 2014, the mean scores are inferior to 70% in any of the classes.

Table 7. Pedestrian protection score (%), per year and per class

Car Class	N	Range	Minimum	Maximum	Mean
Year: 2010					
Supermini	4	13	49	62	56.00
Small Family Car	3	28	43	71	59.00
Large Family Car	2	4	50	54	52.00
Executive	3	35	43	78	60.00
Small MPV	8	38	31	69	54.75
Large MPV	1	0	46	46	46.00
Small off-road 4x4	5	21	43	64	51.40
Pick-up	1	0	47	47	47.00
Year: 2011					
Supermini	12	19	41	60	48.25
Small Family Car	13	23	37	60	49.00
Large Family Car	5	17	40	57	44.60
Executive	3	21	41	62	54.00
Small MPV	4	15	49	64	55.50
Large MPV	3	4	46	50	47.67
Small off-road 4x4	5	25	28	53	44.40
Large off-road 4x4	1	0	45	45	45.00
Year: 2012					
Supermini	6	13	53	66	58.50
Small Family Car	15	31	57	88	68.00
Large Family Car	3	14	64	78	69.00
Small MPV	3	23	44	67	58.67
Small off-road 4x4	6	50	23	73	59.67
Large off-road 4x4	3	11	60	71	64.67
Pick-up	2	30	51	81	66.00
Business and Family Vans	6	22	26	48	31.33
Year: 2013					
Supermini	7	15	57	72	64.29
Small Family Car	10	28	57	85	68.60
Large Family Car	2	0	66	66	66.00
Executive	2	7	67	74	70.50
Small MPV	6	12	56	68	62.17
Large MPV	1	0	80	80	80.00
Small off-road 4x4	4	4	64	68	66.25
Business and Family Vans	1	0	32	32	32.00

continued on next page

Table 7. Continued

Car Class	N	Range	Minimum	Maximum	Mean
Year: 2014					
Supermini	13	18	56	74	65.62
Small Family Car	9	35	54	89	64.22
Large Family Car	4	11	66	77	69.75
Executive	1	0	66	66	66.00
Small MPV	7	8	55	63	60.14
Small off-road 4x4	6	15	60	75	67.50
Business and Family Vans	1	0	67	67	67.00
Year: 2015					
Supermini	8	20	64	84	74.50
Small Family Car	4	20	71	91	79.25
Large Family Car	6	14	67	81	73.33
Executive	1	0	80	80	80.00
Small MPV	3	16	58	74	67.67
Large MPV	3	9	70	79	76.00
Small off-road 4x4	6	32	50	82	69.50
Large off-road 4x4	3	9	70	79	73.67
Pick-up	2	2	76	78	77.00
Business and Family Vans	5	11	53	64	59.60
Roadster Sport	3	11	82	93	88.67

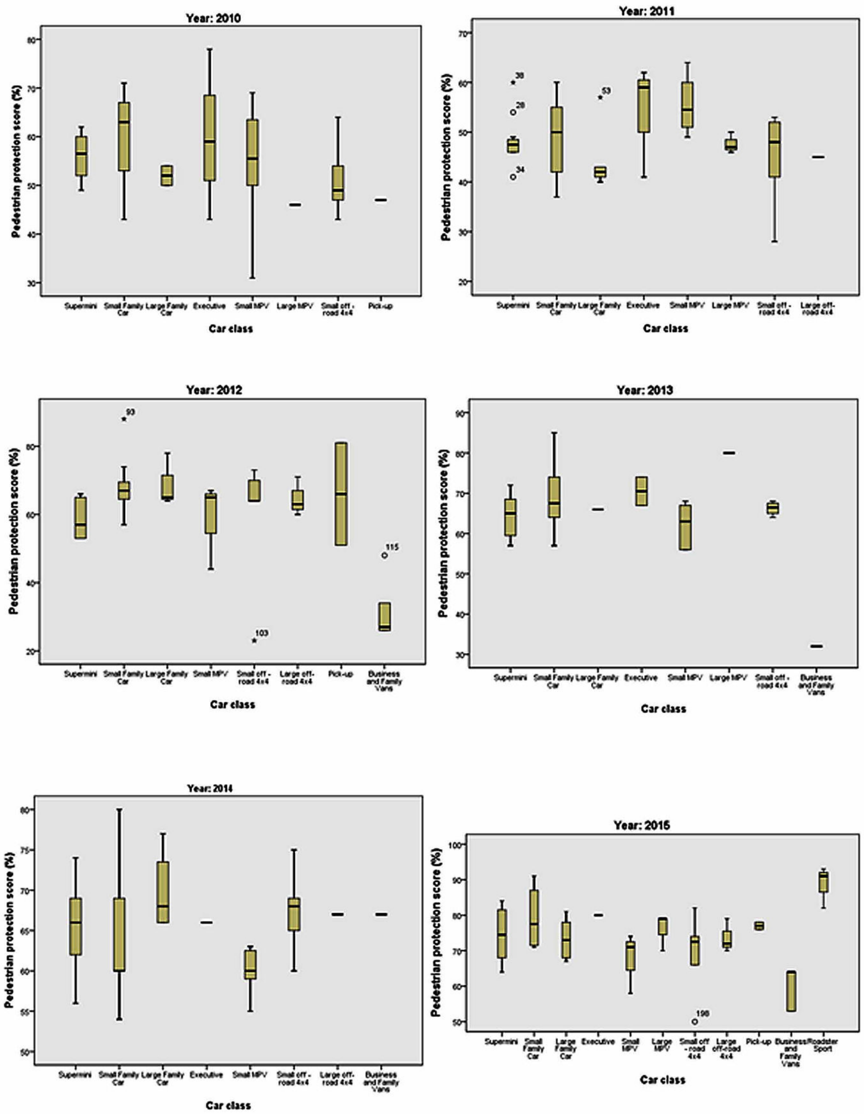
Safety Assist Score

Just like the adult, children, and pedestrians protection scores, the safety assist score is also a continuous quantitative variable. Its measure is expressed in percentage values. Driver and passenger seatbelt reminders, electronic stability control, speed assistance (taken into consideration since 2013), AEB interurban and lane support (introduced in 2014) are included in weighting this score. In 2013, the speed assistance score became differentiated depending on the type of assistance (standard, speed limit information system, and speed assistance system).

Figure 5 presents the comparative boxplots of all the six years of study. Table 8 presents some descriptive statistics.

The analysis of this information must be carefully done, as it is only possible to establish a direct comparison between the data from 2010 and 2012, and 2014 and 2015. Although the obtained scores present a decreasing tendency, this may be due to the fact that the exigency level of this parameter has been increasing.

Figure 4. Pedestrian occupant protection score (%), per class, per year
Source: Own preparation.



Inferential Analysis

Are electric and hybrid automobiles less safe than their traditional counterparts in what concerns frontal collision?

Considering that electric and hybrid automobiles are relatively recent in the market, it is relevant to verify if there are differences in terms of safety, comparing them to classic fuel automobiles. Since some changes were introduced in the last few years, which make the comparison more difficult, the following analysis merely contemplates the period between 2010 and 2013. To that end, and with the purpose of choosing the appropriate statistical method, this analysis is initiated by conducting normality tests, according to Table 9.

Figure 5. Safety assist score (%), per year
Source: Own preparation.

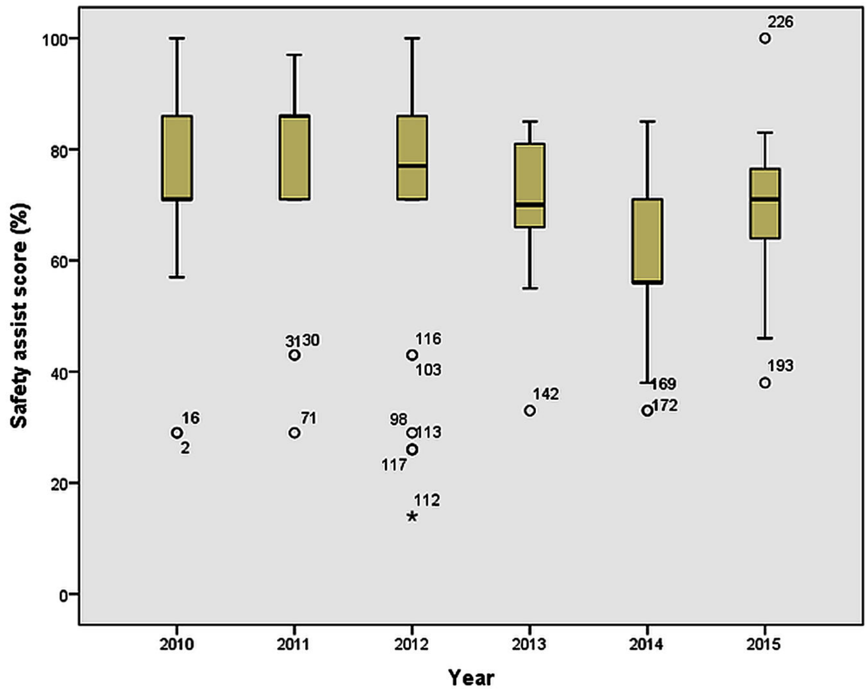


Table 8. Score statistics on safety assist equipment, per year

Year	N	Minimum	Maximum	Mean	Std. Deviation
2010	27	29	100	73.30	16.938
2011	46	29	97	77.85	13.627
2012	44	14	100	74.00	22.271
2013	33	33	85	70.73	12.089
2014	42	33	85	60.07	13.506
2015	44	38	100	70.30	10.663

Table 9. Normality tests for frontal impact score

Fuel	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Classic	0.175	137	0.000	0.849	137	0.000
Electric and hybrid	0.210	13	0.122	0.868	13	0.049

a. Lilliefors Significance Correction.

From the p-value obtained from Table 9 regarding the Kolmogorov-Smirnov test (appropriate for large samples), there is a clear rejection of the null hypothesis of normality for the scores of frontal impact in classic fuel automobiles and for any level of usual significance, since the p-value is approximately zero. As the electric and hybrid automobiles sample is very small (13 vehicles), the recommended test is Shapiro-Wilk's, which also leads to the rejection of the null hypothesis of normality for levels of significance greater than or equal to 4.9%, in which the usual 5% and 10% are included. The potential absence of normality is also identified by the comparison of the sample quartiles and the normal distribution quartiles (Normal Q-Q plots of frontal impact score, which are not shown). Therefore, since normality is not validated for both types of fuel, the comparison of central tendency between the scores obtained from frontal impacts on classic fuel automobiles and on electric and hybrid automobiles should be conducted in a non-parametric context, being Mann-Whitney's U test the most appropriate for this case.

In a non-parametric context, the median becomes the location parameter in evaluation, which means that, while the t-Student test compares the population means based on two random independent samples, the Mann-Whitney U test compares the medians (location centers) of both populations.

The initial question is reflected in the following hypothesis test:

$$H_0 : \mu_{classic} = \mu_{electric+hybrid} \ vs. \ H_1 : \mu_{classic} \neq \mu_{electric+hybrid}$$

where μ represents the population median of the frontal impact score.

Through the analysis of Tables 10 and 11, the null hypothesis of equal population medians for the usual 1% level of significance is not rejected, since the obtained asymptotic p-value (0.019) is greater than 0.010. On the other hand, in what concerns the usual levels of significance of 5% and 10%, there is a clear rejection of the null hypothesis of equal population medians, since the asymptotic p-value is inferior to 0.05 and 0.10. The obtained conclusion is different for different levels of significance, which is not unusual (briefly summarizing, the null hypothesis is rejected for levels of significance that are greater than or equal to 1.9%).

From Table 10, it appears that there is a trend towards higher scores regarding frontal impact in classic fuel automobiles, since the mean rank is higher for that type of vehicle. It should be noted that since the electric and hybrid vehicle sample is fairly small, it is not advisable to compare the sum of the ranks. Figure 6 presents the comparative boxplot for the results regarding the frontal impact (in %) in classic fuel and in electric and hybrid automobiles.

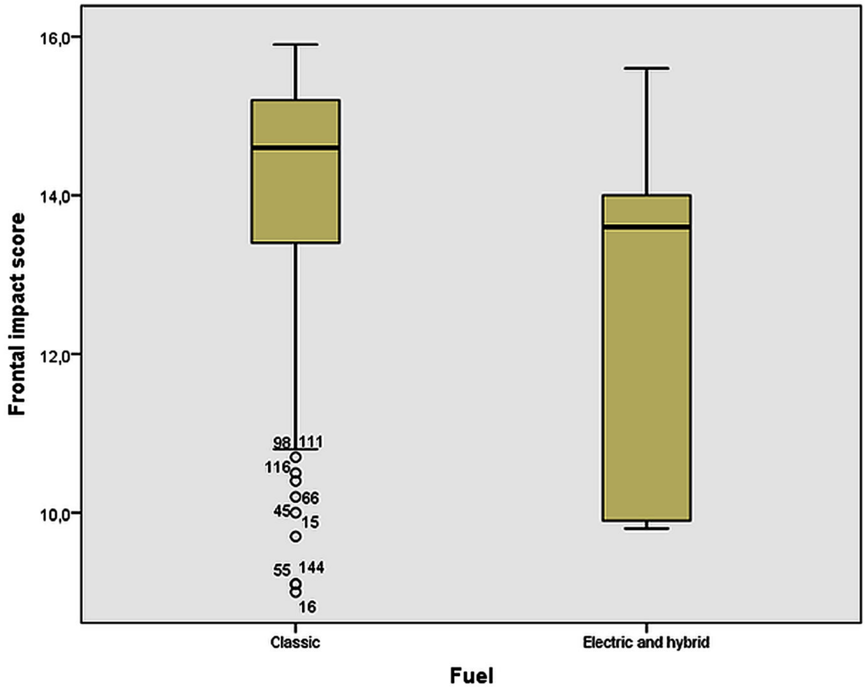
Table 10. Mann-Whitney U test for frontal impact score (mean rank and sum of ranks)

Fuel	N	Mean Rank	Sum of Ranks
Classic	137	78.07	10695.00
Electric and hybrid	13	48.46	630.00
Total	150		

Table 11. Mann-Whitney U test for frontal impact score

	Frontal Impact Score
Mann-Whitney U	539.000
Wilcoxon W	630.000
Z	-2.350
Asymp. Sig. (2-tailed)	0.019

Figure 6. Frontal impact score for different types of fuel
Source: Own preparation.



As Table 10, Figure 6 illustrates the unfavorable scores for electric and hybrid automobiles when compared with the classic fuel cars. For this reason, it would be convenient to test

$$H_0 : \mu_{classic} - \mu_{electric+hybrid} = 0 \ vs. \ H_1 : \mu_{classic} - \mu_{electric+hybrid} > 0$$

Since the samples point towards the alternative hypothesis, the p-value is half of the value obtained in the bilateral test, which, being inferior to the usual levels of significance, leads to the rejection of the null hypothesis, and allows to conclude that there is statistical evidence that the median score concerning frontal impact is higher in the population of classic fuel automobiles.

It should be noted that 137 classic fuel automobiles and only 13 electric and hybrid automobiles were tested, therefore the present conclusions should be taken into consideration with due caution.

After the first question, another relevant question arises: are there statistically significant differences concerning the adult occupants' safety during the six years of study?

Although there have been some updates on this parameter (see the Euro NCAP website for additional details), it is pertinent and relevant to establish a comparison betwen the scores gathered from the models evaluated during the six-year period. This question originates the following hypothesis test:

$$H_0 : \mu_{2010} = \mu_{2011} = \mu_{2012} = \mu_{2013} = \mu_{2014} = \mu_{2015} = \mu \ vs. \ H_1 : \mu_i \neq \mu ,$$

at least for one value of $i\left(i=2010,\ 2011,\ldots,2015\right)$, where μ represents a location parameter for the adult occupants safety scores.

Once more, the process begins by testing the normality of the population from where these samples have been extracted, which allows for the selection of the methodology to employ.

Considering that the size of the sample from 2010 is small (less than 30 observations), one needs to interpret the p-value retrieved from the Shapiro-Wilk test, which leads to the rejection of the null hypothesis for normality for any of the usual levels of significance (Table 12). As for the remaining years, the Kolmogorov-Smirnov's test was deemed as the most appropriate, which also leads to the rejection of the null hypothesis for normality. These assumptions are supported by the histograms with their respective normal distribution curves, and Q-Q Plots, which are not shown here due to space limitations.

As the conditions for the application of parametric tests are not fulfilled since the data strongly contradicts the normality hypothesis, it is necessary to fall back to non-parametric tests as an alternative. The test chosen for this analysis is the Kruskal-Wallis' as there are six years to be compared (six independent samples). Presented in Tables 13 and 14 is the application of Kruskal-Wallis' test, which was used to test if there are statistically significant differences in the population medians for the adult occupant safety score (in the six years of study).

Table 12. Normality tests for adult occupant protection score

Year	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
2010	0.213	27	0.003	0.707	27	0.000
2011	0.155	46	0.007	0.905	46	0.001
2012	0.258	44	0.000	0.764	44	0.000
2013	0.190	33	0.004	0.824	33	0.000
2014	0.189	42	0.001	0.887	42	0.001
2015	0.275	44	0.000	0.727	44	0.000

a. Lilliefors Significance Correction.

Table 13. Kruskal-Wallis test for adult occupant protection score (mean rank)

Years	N	Mean Rank
2010	27	127.28
2011	46	128.61
2012	44	135.02
2013	33	143.33
2014	42	75.11
2015	44	108.82
Total	236	

Table 14. Kruskal-Wallis test for adult occupant protection score

	Adult Occupant Protection Score (%)
Chi-Square	26.320
df	5
Asymp. Sig.	0.000

Based on the analysis of Kruskal-Wallis test one can conclude that the population medians of the adult occupant protection scores, for the car models launched between 2010 and 2015, are considered significantly different, since the asymptotic p-value from the test presented in Table 13 is approximately zero. The reason for this difference may reside in the change of the evaluation criteria of Euro NCAP in the last two years, and not necessarily in real differences in adult safety. For example, it is interesting to note that performing the same test on car models launched in Europe between 2010 and 2013, the score medians retrieved from adult safety are not considered significantly different in those four years, since the asymptotic p-value from the test becomes much greater than the usual levels of significance.

The final research question is: are there statistically significant differences between the most sold automobile classes in what concerns frontal impact protection?

Frontal collision is a frequent scenario in accidents, and it often carries serious consequences. Comparing the scores retrieved from frontal impact protection among different automobile classes is certainly of interest to many drivers. Once there were modifications introduced in the last few years, which make establishing a comparison more difficult, the following analysis only includes the period between 2010 and 2013. However, in these four years of study, there are classes with few tested models, such as the Pick-up class, with only three models tested. Therefore, the option was to develop this study considering the classes in which 20 or more models were tested. For this purpose, the following hypotheses were considered:

$$H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu \ vs. \ H_1 : \mu_i \neq \mu ,$$

for at least one value of $i\left(i = 1, 2, 3, and\ 4\right)$, in which μ represents a location parameter for the score relative to frontal impact, and i identifies the class to be considered, being that 1 is for Supermini, 2 is for Small Family Car, 3 is for Small MPV and 4 is for Small off-road 4×4.

To define the proper methodology to perform the previous hypothesis test, it is required to evaluate the normality of the studied populations by using the usual normality tests (Kolmogorov-Smirnov, with Lilliefors significance correction, and Shapiro-Wilk) and, for example, by inspecting the boxplots, as shown in Table 15 and Figure 7.

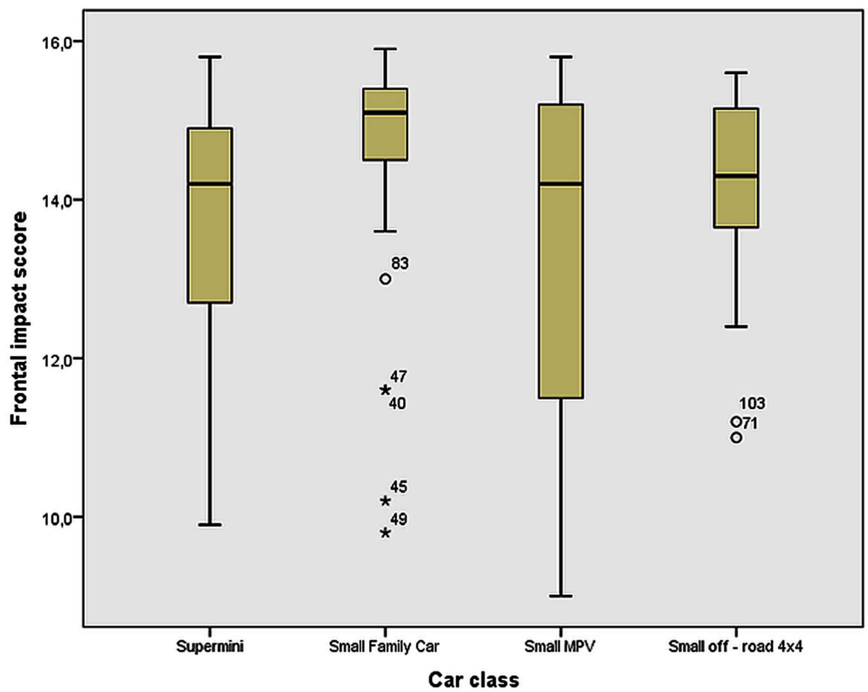
The inexistence of symmetry in the comparative boxplots in Figure 7 suggests the absence of normality in the respective studied populations; however, this conjecture requires a more rigorous statistical analysis through the use of normality tests. Based on the information from Table 15 and the usual levels

Table 15. Normality tests for frontal impact score

Car Class		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Frontal impact score	Supermini	0.202	29	0.004	0.869	29	0.002
	Small Family Car	0.245	41	0.000	0.709	41	0.000
	Small MPV	0.175	21	0.091	0.880	21	0.015
	Small off-road 4x4	0.173	20	0.118	0.860	20	0.008

a. Lilliefors Significance Correction

Figure 7. Frontal impact score by class
Source: Own preparation.



of significance, it is seen that the tests lead to the rejection of the null hypothesis of normality in each of the studied populations (except Small MPV class for $\alpha=1\%$), which supports the initial suspicion.

Since the normality hypothesis is unsupported by the previous analysis, a test is made to compare the central locations in a non-parametric context, choosing the Kruskal-Wallis test for that purpose (Table 16).

Referring to Table 17 and given the asymptotic p-value from Kruskal-Wallis test (0.016), there are two conclusions to be drawn: one for the levels of significance that are greater than or equal to 1.6% (including the usual 5% and 10%), and one for the levels of significance that are inferior to 1.6% (including the usual 1%). In regards to the first case, one rejects the null hypothesis for the equality of the population medians for the frontal impact score in all four classes. In the second case, there is no rejection of the null hypothesis and, therefore, there is no reason to believe in statistically significant differences in the population medians for the frontal impact scores among the different classes. This two-sided conclusion in terms of the accepted level of significance is an indication that there should be precaution regarding the observation of the corresponding conclusion to consider.

CONCLUSION

Despite the fact that hedonic concerns are on the agenda of most of the automotive industry manufacturers, who present hedonic and emotional artefacts in the exploitation of the market needs, there is a clear concern regarding the utility aspects, such as passive or active safety.

Table 16. Kruskal-Wallis test in frontal impact score (mean rank)

Car Brand	N	Mean Rank
Supermini	29	46.43
Small Family Car	41	68.62
Small MPV	21	48.57
Small off-road 4x4	20	51.80
Total	111	

Table 17. Kruskal-Wallis test in frontal impact score

	Frontal Impact Score
Chi-Square	10.349
df	3
Asymp. Sig.	0.016

One of the biggest features of the main automotive industry brands is having on marketing a key success factor underpinning their positioning on the market. Notwithstanding, institutions such as Euro NCAP, by implementing such types of tests, are disclosing information that would be difficult for the general audience to reach. Certainly, this type of institutional marketing is an asset to all those interested in obtaining unbiased information.

One of the main conclusions is that the small family cars and the supermini are the two classes with more models analyzed by Euro NCAP. Another important conclusion to draw is that most of the vehicles (63.6%), in 2015, have reached the five star maximum rating. Moreover, it is also worth noting that in 2013 Mercedes-Benz CITAN Kombi got only three stars, which would not be expected from such a reputable brand that is Mercedes-Benz. This reveals that disclosing the information from Euro NCAP is important for the general public to be aware of the market's realities, which are well beyond the images based on hedonic aspects and emotions provided by most of the main car brands.

In what concerns adult occupant protection, the main conclusion is that brands display a big concern in what regards to their image. However, in 2015 there are six brands whose scores are much lower than the other brands in what concerns adult occupant protection, which means that there is an urgent need to pressure some brands towards the improvement of their safety performance. In regards to adult protection per class, Business and Family Vans present the lowest scores (70.08%), as well as the highest standard deviation (19.95), which indicates a concern for the market, and that it should be more widespread.

Child occupant protection shows a positive evolution, which means that most brands are investing in this type of safety.

It is possible to conclude that classic vehicles are safer than hybrid and electric vehicles in what pertains to frontal impact score in the period between 2010 and 2013. These results should be analyzed cautiously as the sample size was quite different for both. Moreover, although there is a strong concentration on the two upper quartiles in classic vehicles, this type of vehicles shows a larger range than in electric and hybrid vehicles.

It was confirmed that there are statistically significant differences in adult occupant protection for the car models launched between 2010 and 2015, although this difference may be due to changes in the evaluation criteria of Euro NCAP in the last two years and not necessarily in real differences in adult safety. Ultimately, one cannot conclude that there are significant differences among the most important classes (in which 20 or more models were tested between 2010 and 2013) in what concerns the frontal impact protection.

From the marketing point of view, it is possible to state that it is important to disclose information to the general public so that they are aware of the safety intricacies that hardly get revealed to them. On the other hand, disclosing this information is one way of pressuring manufactures to improve the safety innovation trend, so that new car launches are safer for the public.

If electric and hybrid cars are to catch up with new safety market trends, new efforts need to be implemented so that their safety performance may increase. This is an important issue that deserves new studies as the numbers for electric and hybrid cars are expected to grow in the near future.

It is important to realize that using intelligent techniques allows for the understanding of how important safety is for car manufacturers. Moreover, one can witness how brands perform in the market. On the other hand, it is possible to conclude that although the disclosure of information about safety regarding different brands might be important, institutional marketing is not enough to change the customers' awareness about the different brand images and brand equity.

FUTURE RESEARCH DIRECTIONS

In order to complement this study, future research needs to address how the number of stars, for instance, (a) is correlated with child occupant real fatal injuries; (b) is connected with fatal injuries in single-car or two-car crashes. Future studies might also address how brand equity and future repurchase intention are affected when customers are shown how certain brands underperform in safety tests.

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REFERENCES

Fails, A., & Minton, R. (2001). *Comparison of Euro NCAP assessments with injury causation in accidents*. Retrieved September 1, 2014 from http://www-nrd.nhtsa.dot.gov/pdf/esv/esv17/Proceed/00034.pdf

Gronostajski, Z., Bandola, P., & Karbowski, P. (2006). The effect of crashworthiness parameters on the behaviour of car-body elements. *Archives of Civil and Mechanical Engineering*, *6*(1), 31–46. doi:10.1016/S1644-9665(12)60075-2

Huang, H., Hu, S., & Abdel-Aty, M. (2014). Indexing crash worthiness and crash aggressivity by major car brands. *Safety Science*, *62*, 339–347. doi:10.1016/j.ssci.2013.09.002

Huang, H., Li, C., & Zeng, Q. (2016). Crash protectiveness to occupant injury and vehicle damage: An investigation on major car brands. *Accident; Analysis and Prevention*, *86*, 129–136. doi:10.1016/j.aap.2015.10.008 PMID:26551733

Kullgren, A., Lie, A., & Tingvall, C. (2010). Comparison between Euro NCAP test results and real-world crash data. *Traffic Injury Prevention*, *11*(6), 587–593. doi:10.1080/15389588.2010.508804 PMID:21128188

Lie, A., Kullgren, A., & Tingvall, C. (2001). *Comparison of Euro NCAP test results with Folksam car model safety ratings.* Retrieved September 2, 2014 from http://www.euroncap.com/files/ESV_paper_2001---57a2e10b-23a9-4ffb-88e5-a17b21f8923c.pdf

Lie, A., & Tingvall, C. (2002). How do Euro NCAP results correlate with real-life injury risks? A paired comparison study of car-to-car crashes. *Traffic Injury Prevention*, *3*(4), 288–293. doi:10.1080/15389580214632

Martin, J.-L., & Lenguerrand, E. (2008). A population based estimation of the driver protection provided by passenger cars: France 1996–2005. *Accident; Analysis and Prevention*, *40*(6), 1811–1821. doi:10.1016/j.aap.2008.07.001 PMID:19068281

Mittelhammer, R. C. (2013). *Mathematical statistics for economics and business*. New York, NY: Springer. doi:10.1007/978-1-4614-5022-1

Orsi, C., Marchetti, P., Montomoli, C., & Morandi, A. (2013). Car crashes: The effect of passenger presence and other factors on driver outcome. *Safety Science*, *57*, 35–43. doi:10.1016/j.ssci.2013.01.017

Pawlus, W., Karimi, H., & Robbersmyr, K. (2013). Data-based modeling of vehicle collisions by non-linear autoregressive model and feedforward neural network. *Information Sciences*, *235*(20), 65–79. doi:10.1016/j.ins.2012.03.013

Ratingen, M., Ellway, J., Avery, M., Gloyns, P., Sandner, V., & Versmissen, T. (2009). *The Euro NCAP Whiplash test*. Retrieved September 2, 2014 from http://www.euroncap.com/files/Paper_09-0231---0-155567f6-80a9-4d6d-91b6-e1ca2656b132.pdf

Seidel, M., Loch, C., & Chahil, S. (2005). Quo vadis, automotive industry? A vision of possible industry transformations. *European Management Journal*, *23*(4), 439–449. doi:10.1016/j.emj.2005.06.005

Watanabe, Y., Ichikawa, H., Kayama, O., Ono, K., Keneoka, K., & Inami, S. (2000). Influence of seat characteristics on occupant motion in low rear-end impacts. *Accident; Analysis and Prevention*, *32*(2), 243–250. doi:10.1016/S0001-4575(99)00082-2 PMID:10688480

Wilcox, R. R. (2003). *Applying contemporary statistical techniques*. San Diego, CA: Elsevier.

KEY TERMS AND DEFINITIONS

AEB City Test: Autonomous Emergency Braking (AEB) systems are expected to detect when a low-speed, rear-end collision in which the driver of the striking car is distracted and does not notice that the car ahead has stopped. AEB test when such an accident is likely to occur and the AEB system is expected to intervene by applying the brakes to try to avoid the collision. The test vehicle is driven towards the back of a ‘dummy’ target vehicle at speeds between 10 and 50km/h.

Child Occupant Protection Test: It covers the protection offered by the child restraint systems in the frontal and side impact tests, the accommodation of child restraints of various sizes and designs, and the availability of child restraint systems installation checks for safe transport of children in the car.

Frontal Full Width Rigid Barrier Test: Introduced in 2015, it tests cars against a rigid barrier with full overlap at a test speed of 50km/h. It simulates a head-on collision between two oncoming cars at moderately high speeds.

Frontal Impact Score: This test simulates frontal impact between two cars with a speed of about 55km/h. Tests prove that airbags are of added value to support the occupant's head and that seat belts prevent the occupant's chest to be projected against the wheel.

Frontal Offset-Deformable Barrier Test: A test carried out in which two frontal impact dummies, representing the average male and child, are placed in the car compartment. This test replicates a crash between two cars of the same weight, both travelling at a speed of 50km/h. Thus, the vehicle structure is evaluated.

Pedestrian Protection Tests: These tests involve the simulation of accidents involving adult and child pedestrians. They assess the potential risk at injuries to pedestrian head, pelvis, and upper and lower leg. The score is determined from tests to the most important vehicle front-end structures such as the bonnet and windshield, the bonnet leading edge, and the bumper.

Safety Assist Score: It is determined from tests to the most important driver assist technologies that support safe driving, and are meant to avoid accidents and mitigate injuries. The tests involve: electronic stability control, seatbelt reminders, speed assistance, AEB interurban, and lane support systems. The aim is to test the functionality of the system, and the performance during normal driving or in typical accident scenarios.

Side Mobile Barrier Test: In this test a deformable barrier is mounted on a trolley and is driven at 50km/h into the side of the stationary test vehicle at right angles. A side impact dummy representing an average male is put in the driver's seat and child dummies are placed in child restraint systems in the rear seat.

Side Pole Test: A single average male side impact dummy is placed in the driver's seat and a car is propelled sideways at 32km/h against a rigid, narrow pole. This is a very severe test of a car's ability to protect the driver's head.

Whiplash Test: This test is designed to test excessive head movement. It was introduced in 2009 as an integrated neck protection tests on the rear-end collision testing program. The dynamic sled tests indicate how effectively the seat and head restraint operate to provide whiplash protection in typical crash scenarios.