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Analysis of the test criteria for vehicle containment systems in the Standard EN 1317 regarding the number of vehicles in use

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Abstract

In 1999, the harmonized standards EN 1317 relating to vehicle restraint systems came into force in Europe, in order to establish specific requirements based on safety features. For this reason, these systems have to overcome successfully the full-scale crash tests defined in these standards. However, some defined criteria are not in correspondence with the reality of Spanish roads.

Almost a decade ago, in the United States, the evaluation criteria for crash tests were updated based on the new characteristics of the vehicles that circulated on their roads.

Considering the registrations and fleet of light vehicles in Spain, a statistical analysis of the evolution that both parameters have undergone over the years is carried out in this paper. The outcome of this study shows, in a clear way, the change produced in the market in relation to the type of light vehicles that currently circulate in Spain.

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Keywords: crash test; registration of vehicles; vehicle fleet; road restraint system; traffic accidents, severity of impact

Nomenclature

m	mass of the vehicle.
v	speed of the vehicle.
θ	impact angle.

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1. Introduction

Road transport is a key aspect of today's society, to which two other factors of great importance should be added: a) the mobility of people and goods; and b) traffic accidents derived from that mobility. In Spain, this situation implies a loss of more than 1.000 lives each year due to traffic accidents [DGT (2016)]. Therefore, the improvement of road safety is a priority issue in today's society. Considering that, of the total of deadly traffic accidents, around 40% of them are due to the departure of vehicles from the roads [DGT (2016)], special attention should be given to the protection of both sides of the roadways. First, and very important, they should be protected and, if so, the protection given should be the appropriate one.

The uncontrolled departure of a vehicle from the roadway can cause it crashes against an obstacle on the lateral margin of the road, to fall over a nearby slope or rollover, or the invasion of the vehicle from an adjacent track to another, among others. One of the main measures that should be adopted to protect the lateral margins of the road, is the installation of vehicle restraint systems, but these systems themselves, however are obstacles for road departuring vehicles. For this reason, the installation of these systems has to be in correspondence with the needs of the road, as well as meet the safety requirements so that the severity of the impact is the minimum possible. In other words, that they adequately absorb the energy during the impact that occurs.

By a vehicle restraint system is understood any device installed in the median or/and lateral margin of the roadway. It is intended to reduce the severity of incidents caused by the uncontrolled departure of vehicles from the roadway. Among vehicle restraint systems are the following: a) safety barriers; b) crash cushions; c) terminals; d) removable barriers; and e) transitions. This study focuses on the safety barriers because they represent the majority of the vehicle restraint systems installed on Spanish roads to protect their margins and medians. The safety barriers are systems installed longitudinally on the sides of the roads. Depending on their position, they can be classified as follows: a) barriers in lateral margins; b) barriers in median, and c) parapets. The latter are the system installed on bridges, viaducts or similar constructions.

2. Analysis of the current standard

Currently, the safety barriers to be installed on roads in the European Union must have the CE marking. The CE Marking of a vehicle restraint system ensures that its behaviour against vehicle impact, manufacture and installation are in accordance with the European Standard EN 1317 Part 5 (2008+2012). This marking is an essential requirement for a restraint system to be marketed in the European Union. The CE marking of a vehicle restraint system necessarily requires the overcoming of crash tests with full-scale vehicle. These European standards establish the methods of performance assessment of vehicle restraint systems against a vehicle impact (full-scale crash tests) as well as their technical classes and acceptance criteria. Security barriers, specifically the acceptance criteria and test methods contained in Part 2 of the EN 1317 Standard (2011) are described in detailed later. The efficacy criteria that identify and define the behaviour of any vehicle restraint system are:

- **Containment Level**: Retention capacity of the vehicle restraint system in terms of the kinetic energy involved in the vehicle impact. The level of containment will be greater if the system is capable of absorbing the kinetic energy, thus preventing any vehicle at any speed from exceeding the system;
- **Impact Severity**: Criteria that measure the risk of injury to the occupants, mainly based on the ASI parameter (Severity Index Acceleration);
- **Deformation**: Deformation of the vehicle restraint system. Its value must be such that it allows the absorption of the energy involved in the impact, reducing its severity, but keeping the vehicle from leaving the road or hitting an obstacle;
- **Redirection Capacity**: Capacity of the vehicle restraint system to, once the impact has occurred, incorporate the vehicle back into the road again with a trajectory whose angle with respect to the axis of the road being the minimum possible, thus ensuring that no additional impacts with other vehicles will occur.

Specifically, for the Containment Level, the EN 1317-2 Standard (2011) specifies the full-scale crash tests that are necessary to be performed and overcome for each level (Fig. 1).

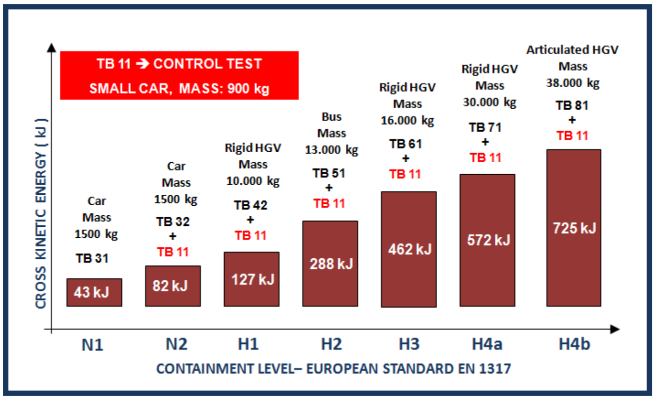

Figure 1. Containment levels for security barriers [EN 1317-2 (2011)].

According to Fig. 1, from the level of containment N2 (level of containment of installation more usual on Spanish roads), it is necessary to overcome two crash tests. These tests are: (a) the test with the heaviest vehicle defines the containment level of the system; and (b) the test with the lightest vehicle defines the severity of the impact.

As previously mentioned, from the level of containment N2 on, the severity of the impact will be defined by the overcoming of the impact test with the lightest vehicle (900 kg) [EN 1317-2 (2011)]. Given the relevance of this test, it is defined as "Control Test." Through it, we can verify that a certain safety barrier does not pose a serious risk to the passengers of the light vehicle, even if its level of containment is high or very high. The characteristics defined for this crash test are summarized in Table 1.

Table 1. Characteristics defined for TB11 crash test indicated in Table 1 of the EN 1317 Standard

Test	Impact speed (km/h)	Impact angle (°)	Total mass (kg)	Type of vehicle
TB 11	100	20	900	Car

The set of harmonized standards EN 1317, which entered into force in Europe in 1999, become mandatory on January 1, 2011. These standards were developed by the European Committee for Standardization (CEN), with the purpose of establishing specific requirements based on security features. Since the entry into force of these regulations in 1999, they have been subjected to several revisions and updates. The application of the above standards marked a before and after in the safety of the roads, since the vehicle restraint systems began to be safer than their predecessors. However, currently, some of the criteria defined in these standards are no longer consistent with the reality of Spanish roads. An example of this are the characteristics of the vehicle used for the "Control Test" (TB11-vehicle of 900 kg of mass).

This situation has been the main motivation to carry out this study on the light vehicle that currently circulates on Spanish roads, as well as their repercussion on the severity of an impact of a vehicle against a restraint system, since the difference of the characteristics of the vehicles and some of their circulation parameters (mass, speed, and road exit angle) suppose a significant increase in the severity of the impact for the occupants of this type of vehicles.

Taking as reference the regulations applied to the vehicle restraint systems in the United States, it can be seen that these regulations have suffered different changes over the years:

- In 1962, the TRB (Transportation Research Board) published the first crash tests for safety barriers;
- In later years, new studies were carried out through the research program “National Cooperative Highway Research Program (NCHRP)”, studies that supposed improvements in the application criteria to crash tests;
- Considering the studies carried out so far, the document “NCHRP 350” was published in 1993. This document established criteria that were considered valid until 2009;
- In 2009, the Manual for Assessing Safety Hardware (MASH) was presented by the AASHTO Technical Committee on Roadside Safety (TCRS).

MASH manual (2008/2016) contemplates important changes in the crash test criteria with respect to its predecessor

(NCHRP 350 document). One of the most significant changes is related to the light vehicle mass, specified in the document "NCHRP 350" (1993), which is 895 kg for this type of vehicle. The MASH manual (2008/2016) specifies 1.100 kg for light vehicles, representing an increase of 23% in the weight of this type of vehicle. This important modification was introduced after conducting a study on the sales of vehicles in the United States market, being aware the TCRS Technical Committee that there had been a change in that sector, so continue to consider a mass lower than the real mass for light vehicle in the crash tests, did not makes any sense.

In Europe, this change has not yet ocurred in the current regulations (February 2011). The weight of the light vehicle for the Control Test continues to be 900 kg, as indicated in Table 1.

3. Statistical study of the evolution of registered cars and car fleet in Spain

Aware of the change undergone today in the European vehicle fleet, this study made a detailed statistical analysis of:

- The evolution of the light vehicle registration in Spain
- The evolution of the light vehicle fleet in Spain

3.1 Evolution of the light vehicle registration in Spain.

The evolution of vehicle registration in Spain from 2013 to 2017 have been analysed in this paper. Of the total number of vehicles registered, those weighing between 800 kg and 1.200 kg has been identified and selected (Vehicle registrations-ANIACAM). A maximum weight of 1.200 kg has been established taking into account that the weight of the vehicle that defines the normal level of containment (N2) is 1.500 kg. Therefore, a greater weight than 1.200 kg for the light vehicle, would be far from the objective that it is pursued with the Control Test, which mainly verifies the severity of the impact on this type of vehicles in case of a traffic accident. The number of light vehicles that correspond to the defined weight range represents around 38% of the total number of registered vehicles.

In order to make a comparison between the number of light vehicle registered depending on their weight, the selected weight range has been divided into two main groups: Group 1 vehicles weighing 1.000 kg or less; and Group 2 vehicles with a weight greater than 1.000 kg but less than or equal to 1.200 kg. Table 2 summarizes the number of light vehicles that correspond to each group.

Table 2. Statistics of light vehicle registered in Spain (2013-2017)

Group 1 Weighing vehicles < 1.000 kg			Group 2 1.000 kg < Weighing vehicles ≤ 1.200 kg		
Year	Registered vehicles	%	Year	Registered vehicles	%
2013	20.360	8	2013	255.700	92
2014	27.688	9	2014	309.129	91
2015	43.513	12	2015	356.415	88
2016	40.672	11	2016	379.037	89
2017	39.599	10	2017	391.784	90

When analysing the number of registered vehicles for each group included in the above table, it is easy to identify also the percentage that each group represents with respect to the total:

- Vehicles weighing less than 1.000 kg (Group 1) represent around 10% of the total;
- Higher weight vehicles (Group 2) represent around 90%.

This means that only 1 in 10 light vehicle registered in Spain is in correspondence with the specifications established in the regulation EN 1317 in relation to the type of vehicle used for the Control Test.

3.2 Evolution of the light vehicle fleet in Spain.

It is important to stress that the vehicle registrations per year represent only a part of the total of vehicles that circulate on the roads. For this reason, a statistical analysis of the evolution that has taken place in the fleet of light vehicles in Spain is made in this section (EUROSTAT data).

In relation to the current vehicle fleet in Spain, it should be noted that passenger vehicles account for around 70% of the total number of vehicles, which means that around 22.200.000 are passenger vehicles [DGT (2016)]. Consequently, it is important to study the safety and behavior impact of this type of vehicles in case of a traffic accident. Due to the fact that this study focuses on light vehicles (weighing less than 1.200 kg), those that meet this condition have been selected applying the same criteria as for the analysis carried out with the vehicles registration. The small difference with respect to the upper limit weight of group 2 has not been considered, because it will not be affect the outcome of this study.

On the other hand, for the study of the vehicle fleet, the period analysed is increased up to 10 years, since in a shorter period, the decrease suffered in the number of vehicles weighing less than 1.000 kg is not appreciated.

Table 3. Statistics of the vehicle fleet in Spain (2007-2016)

Group 1 Weighing vehicles < 1.000 kg			Group 2 1.000 kg < Weighing vehicles ≤ 1.249 kg			Percentage difference
Year	Cars fleet	%	Year	Cars fleet	%	
2007	6.190.000	44	2007	7.735.000	56	11%
2008	5.896.000	43	2008	7.786.000	57	14%
2009	5.478.000	42	2009	7.648.000	58	17%
2010	5.215.000	41	2010	7.631.000	59	19%
2011	5.036.000	40	2011	7.601.000	60	20%
2012	4.890.000	39	2012	7.497.000	61	21%
2013	4.726.000	39	2013	7.337.000	61	22%
2014	4.376.810	37	2014	7.370.780	63	25%
2015	4.285.954	37	2015	7.429.153	63	27%
2016	4.231.900	36	2016	7.556.135	64	28%

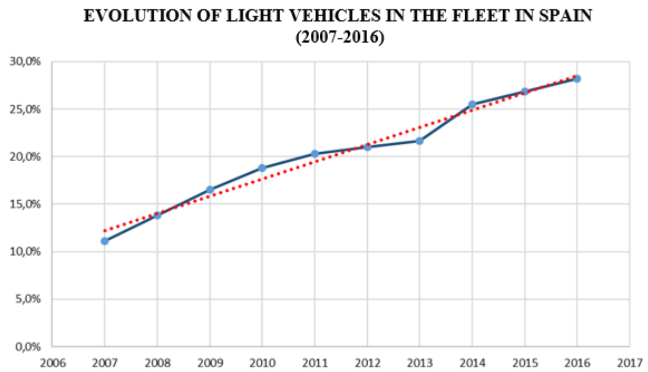

Figure 2. Evolution of light vehicles in the fleet in Spain (2007-2016)

As a result of the analysis made about the evolution of the light vehicle fleet in Spain, the following conclusions can be considered:

- Table 3 shows the passenger car fleet weighing less than 1.000 kg has decreased by 32% in the last decade from 6.190.000 vehicles in 2007 to 4.231.900 vehicles in 2016;
- When comparing the two groups of the vehicle fleet of Table 3, you can see the evolution between the quantities of both groups throughout the decade studied. In 2007 this difference only represented 11%, while in 2016 this difference reached 28%;
- According to Table 3, two out of three vehicles currently traveling on Spanish roads exceeds the weight of 1.000 kg, so today vehicles weighing less than 1.000 kg are no longer the most common vehicles in Spain.

Taking into account the evolution between both groups of vehicles over a decade (Fig.2), it is possible to estimate that the difference will reach 45% in the year 2025. This means in that year the fleet of vehicles weighing less than 1.000 kg moving through the Spanish roads will be about 30% of the total vehicles, while the fleet of vehicles weighing between 1.000 and 1.250 kg will be about 70%.

In view of the analysis made above the following can be stated: the weight of the vehicle considered in the Control

Test, specified in the EN 1317 standard (2011), does not correspond with the type of vehicles that are now circulating on the roads of Spain or that will circulate in the future.

4. Analysis of the severity of the impact due to the weight of the vehicle

For the analysis of the impact of a vehicle against a restraint system, it must be taken into account that the weight of the vehicle is directly related to the kinetic energy (1) that the road restraint system must be able to absorb due to the impact. Therefore, an increase in the vehicle weight implies a proportional increase in the kinetic energy to be absorbed by the restraint system installed. It is known that kinetic energy is expressed as:

$$Ec = \frac{1}{2} \cdot m \cdot (v \cdot sen\theta)^2 \tag{1}$$

Considering the above expression, it is possible to estimate the increase in kinetic energy as a result of an increase in the vehicle mass.

In this case, the comparison was made between the type of vehicle currently used in the Control Test (mass: 900 kg) and the vehicle mass of 1.100 kg. The vehicle mass of 1.100 kg has been considered as a reference to the same vehicle adopted by the United States in the modification made in 2009 (Manual MASH), in relation to this vehicle characteristic, for the Control Test defined in its regulations. In this case, an increase in vehicle mass from 900 kg to 1.100 kg implies an increase in kinetic energy of more than 20%

Analysing other changes incorporated in the US regulations [MASH (2009/2016)], in addition to the one mentioned in relation to the mass of the light vehicle, there was also an increase in the impact angle previously considered. This parameter was increased from 20º to 25º, in this case the kinetic energy reaches a difference of 85%.

This increase in kinetic energy translates into a greater severity of impact for the occupants of the vehicle since, as we know, the kinetic energy of the impact has to be absorbed by all the elements involved in it, that is, though: (a) the deformation of the road restraint system (if any); (b) the deformation of the impacting vehicle; and (c) the way in which it is transmitted to the occupants of the vehicle. Obviously, each of the factors mentioned above is involved in a different way during the process of absorbing the kinetic energy in the impact of a vehicle.

In the case of deformation of the restraint system, the more deformable it is the less aggressive the impact of the light vehicle against it will be. Although there are many situations in which it is impossible to install restraint systems with a large deformation, mainly when there is not enough space behind the barrier, and when a high or very high level of containment is required for the barrier to be installed, due to the characteristics of the road or obstacles to be protected.

A safety barrier with a high or very high level of containment requires the restraint of heavy vehicles, whether trucks or coaches. For this reason, restraints systems with a high rigidity are necessary to ensure the containment of a heavy vehicle, and adequate redirection thereof; however, this situation is not favourable for the light vehicle that impacts against the restraints system.

Facing a safety barrier with reduced deformation for light vehicles, an increase in the vehicle mass will mean a greater severity of the impact that occurs, and in that case, factors such as the deformation of the vehicle and the severity that the occupants receive must be considered.

In relation to this situation, in the Contractor's Final Report for NCHRP Project 22-14 (3) (2010), different tests carried out in the United States are summarized and analysed by applying both the test criteria defined in the NCHRP 350 (1993) document, and in the MASH manual (2009/2016), for different types of barriers. In the case of a rigid concrete barrier, this report makes the following comparison:

"…As previously discussed, MASH test 3-10 has been revised to include a heavier 2425-lb passenger car (denoted 1100C) and a higher 25 degree impact angle. This is compared to NCHRP Report 350 test 3-10, which involves an 1800-lb vehicle impacting the barrier at an angle of 20 degrees. Considering both the increase in weight and impact angle, the impact severity of the revised small car redirection test (MASH Test 3-10) has increased by 206 percent…"

However, in the case of crash tests performed on less rigid barriers, it is impossible to make a comparison between the severities that can occur with the vehicles of both regulations.

After having analysed different European studies on road safety, it can be confirmed that these studies differentiate between the impacts produced by different types of vehicles: cars, coaches, trucks, etc., but in the specific case of cars they do not differentiate in relation to the weight of the them , so it is impossible to make a comparison in that sense.

As it has been shown in Section 3, it is evident that the type of light vehicle that currently circulates on the Spanish roads exceeds the weight of 1.000 kg and, for this reason, it does not make any sense that under the test conditions of the regulation EN 1317, a vehicle of 900 kg is still maintained for the Control Test. Now, it would be of great interest to carry out crash tests for different vehicle weights and different types of barriers, comparing in them the severity of the impact occurred.

The factors mentioned are related to the moment of impact in itself, but previously, there are a series of situations that contribute to the uncontrolled departure of the vehicle from the road. These situations are linked to: (a) human factor; (b) vehicle factor; and (c) road factors.

In most cases, the human factor is the main responsible for the majority of the accidents. This indicates that they can be avoided to a large extent if a responsible driving is carried out. Factors such as speed, fatigue, illness, medication, distractions, alcohol, and drugs are among the main causes of traffic accidents.

In the case of the vehicle factor, elements such as active safety (Anti-lock Braking System (ABS), stability control, tyres, and car lighting control) and passive safety (seatbelt, headrest, and airbag), together with the correct maintenance of the vehicle, represent the most important elements to avoid or reduce traffic accidents.

When referring to the road factors it should be noted that factors such as the layout, paving, width, friction, slope, number of lanes, maintenance, the location of signals, and vehicle restraints systems, are some of the situations that influence the traffic accidents.

Taking the necessary measures to prevent these accidents from occurring is everyone's responsibility. However, in many cases, it is inevitable that traffic accident occurs and, for this reason, the consequences of these accidents must be reduced to the minimum.

In the specific case of traffic accidents, the improvement of road roadside safety is one of the measures adopted to reduce the accidents caused by this factor. A study carried out by Mapfre Foundation and Spanish Road Association (2015), estimated that the improvement of roadside would reduce the number of traffic accidents with victims by 30-35%, and with mortal victims by 15%.

In the treatment of roadside, actions included in the following points must be carried out:

1- Measures to prevent the exit of the roadway: reflex reflectors, anti-slip pavements, road markings, and improvement of geometry in curves, etc;

2- Measures to reduce the probability that a departure of the vehicle from the roadway will collide with an obstacle: security zone, and redesign of the culvert end, etc;

3- Measures to reduce the consequences of traffics accidents due to the departure of the vehicle from the roadway, in the event that they occur: fusible structures, reduce the gradient of slopes, arrester beds, and vehicle restraint systems, etc.

In the same study an estimation in the reduction in the traffic accident rate by the installation of vehicle restraint systems, as a measure to reduce traffics accidents with victims, has been included. For this reason, different international studies carried out on the subject in different countries have been considered, because the information obtained in Spain related to traffic accidents, does not allow to quantify or estimate to what extent the actions carried out on the lateral margin and in the median of the roads, reduced traffic accidents in the country (see Table 4).

Table 4. Estimation of the reduction in the traffic accident rate due to the departure of vehicles from the roads according to different international studies

Measure	Estimation for the reduction of traffic accidents with victims	Source
Installation of restraint systems on the lateral margins of the roads	Fatal accidents: -44% Accidents with victims: -47%	Short and Robertson, 1998 Ljungblad, 2000
Installation of restraint systems in the medians of highways or motorways.	Fatal accidents: -43% Accidents with victims: -30%	Hancock and Ray, 2000 Nilsson and Ljungblad, 1999 Hunter et al., 2001

Source: The Road Safety Measures Manual. Elvik R. 2013.

As can be seen in Table 4, the installation of vehicle restraint systems on lateral margins or/and in the medians of the roads produce a significant reduction, both in traffic accidents with victims and in fatal traffic accidents, so their effectiveness during the impact will depend to a large extent on the proper selection of it, and on its correct installation. In addition, a restraint system will be effective, if the system satisfactorily exceeds the different crash tests required by the EN 1317 Standard. For this purpose, crash tests must be in correspondence with the actual situation of the vehicles that circulate through the country roads.

The vehicle restraint systems, besides being a measure that contributes to saving lives, it reduces significantly the cost derived from traffic accidents.

To demonstrate the above, the ERF (2012) was based on an analysis carried out by the German Land of Hesse in two black spots identified in its road network. In these two areas, safety barriers were installed in the lateral margins and in the medians of the roads, resulting in a reduction of traffic accidents with victims of 65% and 91%, respectively. This meant a reduction in the annual traffic accident cost of 70% and 88%, respectively. The global annual saving is approximately 1.214.000 €.

5. Conclusions and Recommendations

As it has been included in the summary of this paper, a statistical study was carried out on the evolution of the registrations and the fleet of light vehicles in Spain, obtaining the following conclusions:

- Regarding the evolution of light vehicles registered per year in Spain:
  - Those weighing less than 1.000 kg only represent around 10% of the total;
  - Vehicles weighing between 1.000 and 1.200 kg represent around 90% of the total.
- Regarding the evolution of the fleet of light vehicles in Spain:
  - The fleet of vehicles weighing less than 1.000 kg has suffered a decrease of 32% in the last decade;
  - The evolution between the quantities of vehicles in the two groups analysed (vehicles weighing less than 1.000 kg and vehicles weighing more than 1.000 kg) represents an increase of almost 20% in 10 years (2007-2016);
  - According to Table 3, two out of three light vehicles currently traveling on Spanish roads exceed the weight of 1.000 kg, so today vehicles weighing less than 1.000 kg are no longer the most common vehicles in Spain.

Based on our statistic study, our main conclusion it is that is necessary to modify and update the EN 1317 regulation "Road restraint systems," respect to the characteristics specified therein in relation to the light vehicles used in the crash test called "Control Test", where its weight of 900 kg is approximately 20% lower than the weight of the current average vehicle travelling on Spanish roads.

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