

Legal Versus Consumer Requirements for Secondary Safety of Passenger Vehicles in Europe and the U.S.

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ABSTRACT

In 1978, the U.S. National Highway Traffic Safety Administration (NHTSA) established the New Car Assessment Program (NCAP) and began rating vehicles for frontal impact safety for MY1979 with the purpose of providing information to the public so consumers could make better-informed decisions about their purchases. Manufacturers responded to the ratings by voluntarily improving the safety of their vehicles beyond the minimum Federal safety standards. In 1996, NHTSA added testing for side impact protection and more recently to assess the vehicle's rollover propensity.

After NHTSA's NCAP, other organizations have followed testing the passive safety performance of the vehicles and publishing the results to the customers with the intention of improving the protection given by the vehicles. The Insurance Institute for Highway Safety (IIHS) started in 1995 with an offset frontal impact test and in 2002 with a side impact test using a mobile barrier that represents the typical SUV frontend. Also in 1995, IIHS started publishing results from a head-restraint geometry assessment that was complemented with a dynamic test in 2004. In 2009 the IIHS introduced the roof strength test protocol for rollover protection and in 2012 they introduced the small overlap crash test protocol.

In Europe, Euro NCAP started its testing program in 1997 with: a frontal offset test, a side impact test and pedestrian protection testing; these were complemented with a pole test in 2000. In 2008, Euro NCAP introduced whiplash testing and in 2009 a new rating system.

In this paper, the current European and U.S. legal requirements are presented and compared with the major consumer testing programs: Euro NCAP, NCAP and IIHS.

CITATION: Huguet, J., Garcia Gutierrez, C. and Del Pozo, E., "Legal Versus Consumer Requirements for Secondary Safety of Passenger Vehicles in Europe and the U.S.," *SAE Int. J. Trans. Safety* 1(1):2013, doi:10.4271/2013-01-0121.

INTRODUCTION

The New Car Assessment Program (NCAP) has been providing U.S. consumers for more than 3 decades with reliable and independent information on the crashworthiness of passenger vehicles to aid consumers in their vehicle purchase decisions. The NCAP program has turned out to be a great success both in terms of the dissemination of the information among the public and motivation of manufacturers to enhance the safety performance of successive vehicle models.

In 1995 the Insurance Institute of Highway Safety (IIHS) established, their crash test programme in the U.S. Currently, vehicles are evaluated in two frontal offset crashes (moderate overlap and small overlap) and a lateral crash test against a light-truck-like moveable deformable barrier (MDB). The rear crash protection of the vehicle is also evaluated by means of dynamic testing and geometric assessment of head restraints and the rollover protection through the evaluation of the roof strength.

Taking advantage of the American initiative a similar programme was established in Europe in 1997, known as the European New Car Assessment Programme (Euro NCAP), providing consumers with information on vehicle safety performance. Euro NCAP was the first programme that adopted a pedestrian protection assessment of the vehicles, much earlier than any other programme had ever considered. In February 2009 Euro NCAP implemented a new rating scheme with the double aim of providing consumers with clearer information on the safety of the vehicles in the market and encouraging the car manufacturers to enhance the safety performance of their products to higher levels.

The existing differences between legal and consumer requirements programmes make necessary for the manufacturers to adapt their development programmes for each specific market. In many cases, also differences in the vehicles are introduced to obtain the best performance in each regulatory and consumer testing programme.

LEGAL REQUIREMENTS

EC Type Approval

To ensure that the European vehicles, their systems and their components meet the appropriate safety requirements, they are submitted to a type approval process, generally called homologation. In this process, a number of tests are performed by a recognized third party, the Technical Service and approved by a Type Approval Body, the approval authority certifying that a type of vehicle, system or component satisfies the relevant administrative provisions and technical requirements of the Regulations. These tests are performed to confirm that the production samples of a design meet the requirements specified in the different regulations. The Type Approval also includes a Conformity of Production (COP), a means of evidencing the ability to produce a series of vehicles that exactly match the specification and performance requirements outlined in the Type Approval documentation.

The current European Community Whole Vehicle Type Approval (ECWVTA) activities related with complete vehicle secondary safety are:

- Protection of occupants of motor vehicles in the event of a frontal impact: Directive 96/79/EC (European Commission) and UNECE (United Nations Economic Commission for Europe) Regulation 94/02 since 1st of November 2012
- Protection of occupants of motor vehicles in the event of a side impact : Directive 96/27/EC and UNECE Regulation 95/03 since 1st of November 2012
- Protection of pedestrians and other vulnerable road users before and in the event of a collision with a motor vehicle: Regulation 78/2009
- ECE (European Commission for Europe) Regulation 17: Uniform provisions concerning the Approval of Vehicles with regard to the Seats, their Anchorages and any Head Restraints

There are other directives related to passive safety also included in the Type Approval process but limited to vehicle components such as those for the seat belts (77/541/EC), seat belt anchorages (76/115/EC), and interior fittings (74/60/EC) among others. These directives will not be considered in this paper for the purpose of comparing legal versus consumer requirements.

Frontal Impact

The Directive 96/79/EC specifies the protection that passenger vehicles not exceeding a mass of 2.5 tonnes shall offer to their front occupants in case of a frontal impact with an overlap of 40% of the width of the vehicle at 56 km/h into a deformable barrier. This Directive establishes that 2 belted Hybrid III 50% dummies will be placed in the front seats of the vehicle, and the performance criteria recorded in the dummies are specified in [Table 1](#) and [Table 2](#).

Table 1. Dummy performance in Directive 96/79/EC

Criteria	Limit
Head Performance Criterion (HPC)	≤ 1000
Head Resultant Acceleration (cumulative)	$\leq 80g$ for 3ms
Neck Injury Criteria (NIC)	$\leq$ curve limit
Neck Bending Moment (in extension)	≤ 57 Nm
Thorax Compression Criterion (ThCC)	≤ 50 mm
Thorax Viscous Criterion (V*C)	≤ 1.0 m/s
Femur Force Criterion (FFC)	$\leq$ curve limit
Tibia Compression Force Criterion (TCFC)	≤ 8 kN

Table 2. Other requirements in Directive 96/79/EC

Criteria	Limit
Residual steering wheel upward vertical	≤ 80 mm
Residual steering wheel rearward horizontal displacement	≤ 100 mm
Restraint system release force	≤ 60 N
Continuous Fuel leakage	$\leq 5 \cdot 10^{-4}$ kg/s
No door opening during the test	Verify
No door locking during the test	Verify
Possibility to open a door per row of seats or to tilt the backrest to allow evacuation of all the occupants	Verify
Occupant removal without adjustment of the	Verify

The European Union is intended to simplify and harmonize the regulations and the Directive 96/79/EC will be withdrawn with date November 1st 2014. Starting in 1st of November 2012, UNECE Regulation 94/02 is applicable for vehicle homologation in Europe.

Side Impact

For side impact protection, Directive 96/27/EC specifies the protection that passenger vehicles not exceeding a mass of 2.5 tonnes and with an 'R' point of the lowest seat below 700 mm from the ground level shall offer to an occupant seated in the front row on the impact side when the vehicle is impacted by a 950 kg mobile deformable barrier (MDB) travelling at 50 km/h and centred on the vehicle's 'R' point. The deformable barrier used in this test corresponds to the specifications defined by the European Enhanced Vehicle-Safety Committee Working Group 13 (EEVC WG 13).

The Directive 96/27/EC will be withdrawn on 1st November 2014 and starting on 1st November 2012, UNECE Regulation 95/03 will be applicable for vehicle homologation in Europe. The dummy performance criteria for Directive 96/27/EC are specified in Table 3 and Table 4.

Table 3. Dummy performance in Directive 96/27/EC

Criteria	Limit
Head Performance Criterion (HPC)	≤ 1000
Rib deflection Criterion (RDC)	≤ 42 mm
Soft Tissue Criterion (V*C)	≤ 1.0 m/s
Abdomen Peak Force (APF)	≤ 2.5 kN
Pubic Symphysis Peak Force (PSPF)	≤ 6 kN

Table 4. Other requirements in Directive 96/27/EC

Criteria	Limit
No door opening during the test	Verify
No door locking during the test	Verify
Possibility to open a sufficient number of doors provided for normal entry and exit of passenger and if necessary tilt the seat backs to allow evacuation of all passengers	Verify
Release from the protection system	Verify
Occupant removal	Verify
No interior device or component must become detached in such a way as to increase considerably the risk of injury from sharp projections or jagged edges	Verify
Ruptures resulting from permanent deformation are acceptable provided that these do not increase the risk of injury	Verify
Continuous Fuel leakage	$\leq 5 \cdot 10^{-4}$ kg/s

Pedestrian Protection

Currently, the active and safety measures used to improve pedestrian safety are combined in the Regulation 78/2009/EC. In terms of active safety, the only requirement consists of a "brake assist" system, and leaves the door open to other collision avoidance systems that could be developed in the future.

Regarding the passive safety performance of the vehicle, the impactors used are defined by EEVC WG17 (Legform, Upper Legform and Adult Headform, until 24th February 2013) and JAMA-JARI (Child/small adult Headform, Adult Headform, after 24th February 2013). These anthropomorphic test devices are impacted on different parts of the vehicle as shown in Table 5 in order to validate the passive safety performance of the vehicle:

Table 5. Impactor used in Regulation 78/2009/EC

Impactor	Part of the vehicle
Lower legform / upper legform	Bumper
Upper legform	Bonnet leading edge
Child/small adult headform	Bonnet top
Adult headform	Bonnet top

Until 24th February 2013 passenger vehicles shall comply with the performance criteria shown in Table 6.

Table 6. Pedestrian protection criteria applicable until 24th February 2013

LOWER LEGFORM TO BUMPER	
Criteria	Limit
Dynamic Knee Bending Angles	$\leq 21.0^\circ$
Dynamic Knee Shearing Displacement	≤ 6.0 mm
Tibia Acceleration	≤ 200 g
UPPER LEGFORM TO BUMPER Alternative test to Lower legform to bumper	
Criteria	Limit
Sum of Impact Forces	≤ 7.5 kN
Bending Moment	≤ 510 Nm
CHILD/SMALL ADULT HEADFORM TO BONNET TOP (JAMA-JARI - 3,5 kg)	
Criteria	Limit
Head Performance Criterion (HPC) over 2/3 of the bonnet area	≤ 1000
Head Performance Criterion (HPC) over the remaining 1/3 of the bonnet area	≤ 2000

In addition to the previously mentioned tests, the following additional tests are performed for monitoring purposes only:

- Upper legform to bonnet leading edge
- Adult headform (EEVC WG17 - 4,8 kg) to windscreen

After 24th February 2013, passenger vehicles will have to comply with the performance criteria shown in Table 7.

**Table 7. Pedestrian protection criteria applicable after
24th February 2013**

LOWER LEGFORM TO BUMPER	
Criteria	Limit
Dynamic Knee Bending Angles	$\leq 19,0^\circ$
Dynamic Knee Shearing Displacement	≤ 6.0 mm
Tibia Acceleration	≤ 170 g
UPPER LEGFORM TO BUMPER	
Alternative test to Lower legform to bumper	
Criteria	Limit
Sum of Impact Forces	≤ 7.5 kN
Bending Moment	≤ 510 Nm
UPPER LEGFORM TO BONNET LEADING EDGE	
Criteria	Limit
Sum of Impact Forces	≤ 5.0 kN
Bending Moment	≤ 300 Nm
CHILD/SMALL ADULT HEADFORM AND ADULT HEADFORM TO BONNET TOP	
Criteria	Limit
Head Performance Criterion (HPC) over 1/2 of the child headform test area	≤ 1000
Head Performance Criterion (HPC) over 2/3 of the combined child and adult Headform test areas	≤ 1000
Head Performance Criterion (HPC) over the remaining areas for both headforms	≤ 1700

The Antropomorphic Test Devices used in the pedestrian tests after 24th February 2013 are the JAMA-JARI - 3,5 kg child/small adult headform and the JAMA-JARI - 4,5 kg adult headform.

Head Restraints

The current Regulation 17/08 does not include dynamic dummy testing to verify the head restraints performance in case of rear impact and only geometric and strength requirements are considered.

Table 8 compiles the most significant requirements applying to Head Restraint Systems in Regulation 17.

Table 8. Head restraint systems requirements in R 17/08

Criteria	Limit
Head rest height from H-point (non-adjustable head rest)	≥ 800 mm
Head rest height from H-point (adjustable head rest)	≥ 750 mm
Gaps within Head restraint	≤ 60 mm
Gaps between Head restraint and Seat	≤ 25 mm
Head rest width	≥ 170 mm
Backset retention	≤ 102 mm

U.S. Self-Certification

In the United States, the legal approach is different than in Europe and is based on the manufacturers' certification of compliance of its vehicle to all the applicable Federal Motor Vehicle Safety Standards (FMVSS). For this reason, this process is called 'self-certification'.

According to Title 49, Part 567 of the Code of Federal Regulations, vehicle manufacturers shall affix a permanent certification label stating that '*this vehicle conforms to all applicable Federal motor vehicle safety, bumper, and theft prevention standards in effect on the date of manufacture shown above*'. This label implies that the certification is done on the single vehicle manufactured and not the 'Vehicle Type' as in Europe and for this reason the manufacturer shall demonstrate that the vehicle design meets the crash protection requirements specified by the different standards including the possible result variation due to test repeatability and production dispersion. This means that crash tests are just one of the elements necessary to demonstrate vehicle conformity, that have to be supported by other activities such as CAE simulation, sled testing, quality assurance and others.

For the purpose of this paper, the following occupant protection requirements in FMVSS will be described:

- 49 CFR 571.202a: Head Restraints.
- 49 CFR 571.208: Occupant Crash Protection
- 49 CFR 571.214: Side Impact Protection

The Federal Motor Vehicle Safety Standards determine other requirements that are not considered in this paper for the purpose of comparing the legal versus consumer requirements, such as occupant protection in interior impact (49 CFR 571.201), seat belt assembly anchorages (49 CFR 571.210), door locks and door retention components (49 CFR 571.206), fuel system integrity (49 CFR 571.301) and others.

Frontal Impact

The Standard FMVSS 208 defines the impact conditions with the ranges of velocities and impact angles in which the passenger cars shall offer adequate protection to the front occupants. Car manufacturers shall demonstrate the compliance of their vehicles in any of these conditions. To show the compliance, they usually test the vehicles in a limited number of conditions that they consider the most severe and representative of the others. Table 9 shows a common set of tests and Table 10 the dummy requirements. Depending on the vehicle and its restraint system performance, other tests could be considered necessary to show the compliance with the standard.

Table 9. Common tests for frontal U.S. self-certification

Velocity	Barrier	Angle	Dummy
56 km/h	Rigid	0°	2 Hybrid III 50 th %ile belted
56 km/h	Rigid	0°	2 Hybrid III 5 th %ile belted
40 km/h	Rigid	0°	2 Hybrid III 50 th %ile unbelted
40 km/h	Rigid	+30°	2 Hybrid III 50 th %ile unbelted
40 km/h	Rigid	-30°	2 Hybrid III 50 th %ile unbelted
40 km/h	Rigid	0°	2 Hybrid III 5 th %ile unbelted
40 km/h	40% offset Deformable	0°	2 Hybrid III 5 th %ile belted

Table 10. Performance requirements for the Hybrid III 50th and 5th percentile belted dummies in frontal impact tests

HYBRID III 50 th PERCENTILE BELTED DUMMY	
Criteria	Limit
Head Injury Criterion (HIC15)	≤ 700
Neck Injury Nij	≤ 1
Neck Tension	≤ 4.170 N
Neck Compression	≤ 4.000 N
Thorax Resultant Acceleration (cumulative)	≤ 60g for 3ms
Chest Compression	≤ 63 mm
Femur Axial Force	≤ 10.008 N
HYBRID III 5 th PERCENTILE BELTED DUMMY	
Criteria	Limit
Head Injury Criterion (HIC15)	≤ 700
Neck Injury Nij	≤ 1
Neck Tension	≤ 2.620 N
Neck Compression	≤ 2.520 N
Thorax Resultant Acceleration (cumulative)	≤ 60g for 3ms
Chest Compression	≤ 52 mm
Femur Axial Force	≤ 6.805 N

The FMVSS 208 also determines other requirements that are not considered in this paper for the purpose of comparing the legal versus consumer requirements:

- Labeling and owner's manual information
- (Airbag) Readiness indicator
- Rear seat belt requirements

- Seat belt assembly requirements
- Pressure vessels and explosive devices
- Airbag deployment risk

Side Impact

The Standard FMVSS 214 establishes the side impact protection requirements for passenger cars. These requirements are a combination of a static door crush test, a mobile deformable barrier test and two vehicle-to-pole impacts using 50th and 5th percentile dummies. In this paper, for the purpose of legal versus consumer testing requirements comparison, only the mobile deformable barrier and the pole tests will be discussed.

In the same way that the FMVSS 208, the FMVSS 214 defines a range of velocities where the vehicles shall offer adequate protection in case of side impact. For this impact configuration, the dynamic tests usually performed to demonstrate the compliance with the requirements of this Standard are:

- A Mobile Deformable Barrier (MDB) side impact into a stationary vehicle with a ES-2re 50th percentile dummy in the front seat and a SID-II's 5th percentile dummy in the rear seat.
- 75° Vehicle-to-pole impact from 0 to 32 km/h with a ES-2re 50th percentile dummy in the front seat.
- 75° Vehicle-to-pole impact from 0 to 32 km/h with a SID-II's 5th percentile dummy in the front seat.

The MDB used for the side impact weighs 1.367 kg and its line of forward motion forms a 63° angle with the centreline of the test vehicle. The longitudinal centreline of the MDB is perpendicular to the longitudinal centreline of the vehicle and is aligned with the vehicle's 'Impact Reference Line'. In the case of passenger cars, this line is located 940 mm forward of the centre of the vehicle's wheelbase if the wheelbase is 2.896 mm or less, or 508 mm rearward of the centreline of the vehicle's front axle if the wheelbase is greater than 2.896 mm. The deformable element used in these tests corresponds to NHTSA's specifications.

The performance criteria requirements for the dummies used in the side impact protection tests are shown in [Table 11](#):

Additional requirements also included in the FMVSS 214 are:

- Any side door that is struck by the pole shall not separate totally from the vehicle.
- Any door that is not struck by the pole shall not disengage from the latched position.
- The latch and the hinge components of any door that is not struck by the pole shall not separate from each other or from their attachment to the vehicle.