POLE IMPACT TEST: STUDY OF THE TWO CURRENT CANDIDATES IN TERMS OF COST AND BENEFITS FOR FRANCE

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Paper number 13-0440

ABSTRACT

Regulatory and consumerism discussions currently take place on the definition of a pole impact that could be representative of car accidents in order to better protect the occupants.
Two main test protocols are in competition: the FMVSS 214 one and the current Euro NCAP one. France, taking part of the discussion in WP29 GRSP, provided accident data as well as cost benefit study.

To supply data for this debate, PSA Peugeot Citroën carried out physical tests on different car platforms with the two types of impact:

- pole test 75° 32 km/h, also called “oblique pole test”
- pole test 90° 29 km/h

With the results of these tests, numerical models were improved to get correlated models.

Then, the correlated models were used to define the optimized technical solutions needed on the 75°/32 km/h test to get back to the same intrusion level as the 90°/29 km/h.
It is therefore possible to quantify the cost of this test if it becomes mandatory for Europe or for another country (eg. China).
In addition, accident data analysis assesses the possible benefits for the European roads.
This paper presents these data as well as the detailed analysis made by PSA Peugeot Citroën to establish the additional cost (in terms of Euros but also of kilograms) if the discussion ends to the selection of the FMVSS214 compared to the selection of the Euro NCAP test protocol.
The overall conclusion is that there is no justification of such a test for Europe when comparing the costs with the benefits.

INTRODUCTION - AIM OF THE STUDY

Pole impact test is not yet mandatory worldwide. USA [1] defined an oblique pole impact test several years ago and it is now required via FMVSS n°214. In Europe, a pole test 90° is applicable in consumer testing [2] but it is not mandatory. The main purpose of Euro NCAP when they introduced this test, in the early 2000’s, was to incite the car manufacturers to fit a head protection on the first row (curtain airbag is usually the protection device used to answer this request). Korea and Australia consumer organisations are also using the same test protocol [3]. But here again, this is not a mandatory / regulatory requirement.
And for the other countries in the world, no requirement exists so far for a pole test.

But things are changing since a couple of years. At the request of USA, an informal working group on Pole Side Impact (PSI) was set up in WP29/GRSP to derive a GTR (Global Technical Regulation) on Pole impact for the coming years [4]. With this informal group creation, started the discussion on test configuration (mainly on angle, impact speed and dummy model).

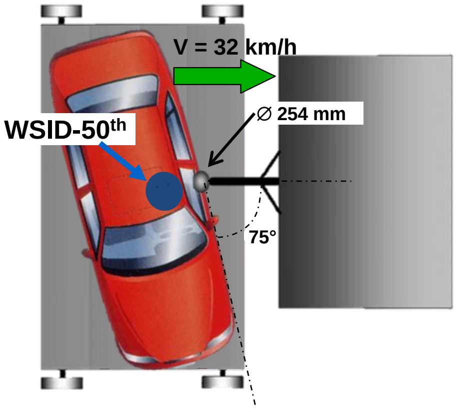
A regulatory test configuration should be pertinent in terms of real world accident statistics and should also be assessed via a cost benefits analysis to check the improvements worth the money.
This is where the debate could start since the oblique pole test would require additional structures (and mass) to control intrusion. And some members questioned if the additional efficiency in terms of occupant protection with respect to a 90° pole impact test was really there. In parallel, the cost for society in terms of CO_2 additional emission is put forward when oblique pole test is compared to the 90° one.

In order to bring some data to this discussion, this paper presents the application of the two pole tests protocols on current cars. This allows the comparison of the protocols and their consequences on the car structures. It allow us to reckon the cost and weight needed to go from a car designed from a 90° pole test to a design for an oblique pole test. This data is then used to assess a cost/benefit study applied to the European roads.

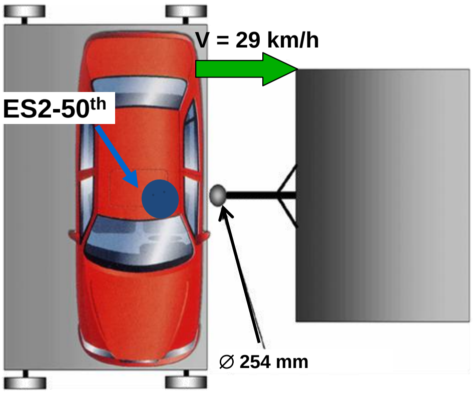
PRESENTATION OF BOTH TYPES OF POLE IMPACT

Two types of pole impacts are applied throughout the world as described in Figure 1:

- 254mm diameter pole impact on a 75° oriented car, travelling at 32 km/h, also called "oblique pole test". The test configuration is defined in FMVSS 214 regulation. But, here we took into account the proposal made to the PSI informal group, i.e. using a WorldSID-50th dummy,
- 254mm diameter pole impact on a 90° oriented car, travelling at 29 km/h. It is applied in Euro NCAP, KNCAP and ANCAP. It uses an ES-2 50th dummy.



(a)



(b)

Figure 1. Illustration of pole tests procedures – (a) 75°-pole test and (b) 90°-pole test

It has to be highlighted that if we consider the Euro NCAP protocol and the current discussion in the PSI informal working group, the crash test dummies are not the same between 75°-pole and 90°-pole (respectively WorldSID 50th and EuroSID-2 50th), as well as their seating position. For this reason and because the pole test is designed to be the worst case and therefore requires impacting the centre of gravity of the dummy, the two impact locations on the car structure may differ.

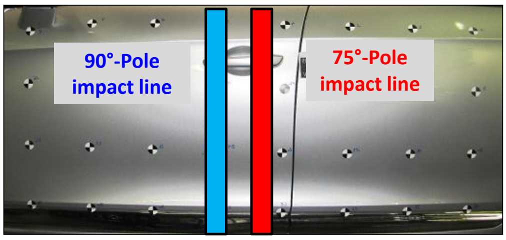


Figure 2. Example of difference in pole impact line between the two tests procedures due to the dummy used

In terms of impact energy, because of the velocity is higher in the oblique pole test, the increase is of 22%. For example, for a 1,500 kg vehicle the crash energy for the 90°-pole test is 63kJ and 77kJ for the 75°-pole test.
Final general remark, the difference in the impact angle (15°) adds an X-component to the force applied to the vehicle, which could destabilize the reinforcements based on Y-direction.

METHOD

This study is based on the analysis of physical and numerical tests performed with the two test protocols on vehicles of different sizes and built on different platforms. We can split the study into three phases:

- The first phase was to make an initial picture of consequences of the two tests on current cars in terms of intrusion and to derive correlated numerical models
- The second phase was to use numerical models to design the reinforcements needed to get the same intrusion level in the 75°-pole impact test as in the initial 90°-pole test.
- The third phase was to assess these reinforcements in physical tests to check if they were effective.

Thanks to this study, we could calculate the cost of reinforcements, in term of mass and price.

In parallel to this analysis, a real world accident data analysis was carried out to identify the relevance of the two test protocols.
A cost/benefit study can be derived from the combination of the two studies to assess the social consequences of adopting one or the other protocol on European roads.

COMPARATIVE TESTS AND STUDIES ON VEHICLES STRUCTURE

Numerical and physical tests were carried out on several platforms:

- small vehicle,
- family vehicle,
- large family vehicle.

Both test protocols were performed on each platform and the differences were identified.

Comparison of the two Pole Test protocols on structural behaviour

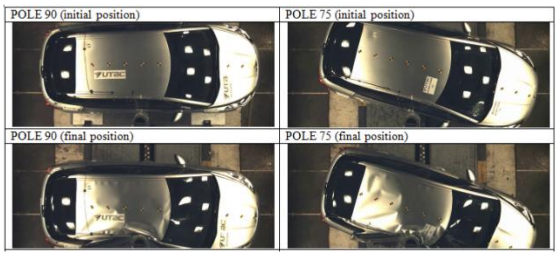


Figure 3. Large Family Car during Pole Tests

Due to dummy availabilities and also because we wanted to have a direct comparison between tests, we decided to use ES2 dummy in all the tests. But in order to be representative of the exact 75°-pole test, we applied the WorldSID seating position in the oblique test even if an ES2 was used. Therefore, the pole impact lines as described in Figure 2 were representative of each of the test protocol.

On the three vehicles, intrusions were measured on the external limit of the underbody and compared.

The first comparison is made on the first phase of the crash. Indeed the beginning-of-crash intrusions are essential to guarantee a good airbag deployment. The results are presented in Figure 4

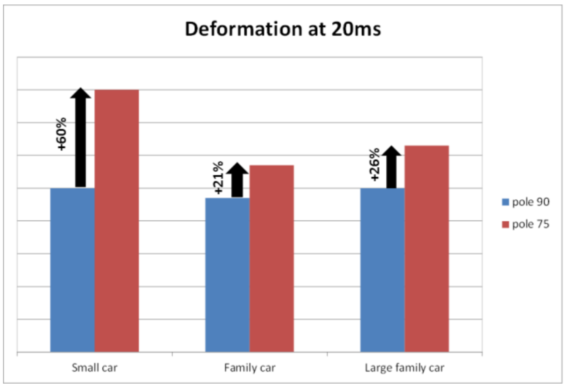


Figure 4. Comparison of the beginning-of-crash deformation between the two pole test protocols and for the three vehicle categories under study.

If the 90°-pole test gives almost the same magnitude of intrusion on the three car families, it is not the case for the 75°-pole test. Intrusions are always higher in the beginning of crash in the oblique test and the increase varies from 21 to 60%.

Concerning the end-of-crash intrusions, which have to be controlled to maintain enough space for the occupant (especially in the pelvis zone when the car is equipped with a high centre console), the results are presented in Figure 5.

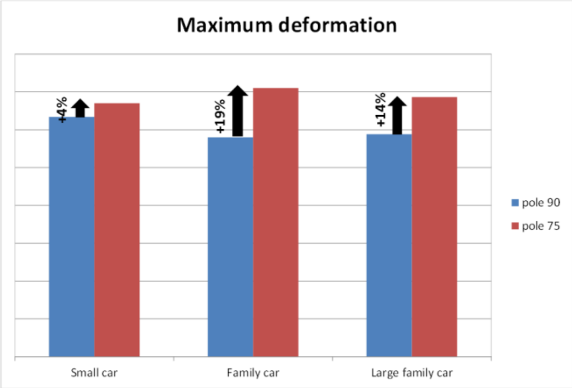


Figure 5. Comparison of the end-of-crash deformation between the two pole test protocols and for the three vehicle categories under study.

Here, the 90°-pole test does not give the same magnitude of maximum intrusion on the three car families. But they are always lower than for the 75°-pole test. In the end-of-crash phase, the oblique test gives an increase of 4 to 19% in intrusion.

We clearly see here that the change of protocol from 90° to 75° has a negative impact on the global behaviour of the structure via an increase of intrusion.

To come back to a level of intrusion equivalent to the 90°-pole test, there is a need to design specific reinforcements for the cars if tested with the oblique pole test.
To design these reinforcements (called structural add-ons), numerical models were used. These models were correlated on the 90° and on the 75°-pole tests.

Design of underbody reinforcements

According to the 75°-pole test scenario, the highest potential for reinforcement is on the underbody. This part of the vehicle presents the most interesting potential stiffness, necessary to guarantee enough vehicle deceleration during the crash and therefore prevent excessive intrusions, even if it will not be the unique part to upgrade.

The principles of such reinforcements are presented in Figure 6.

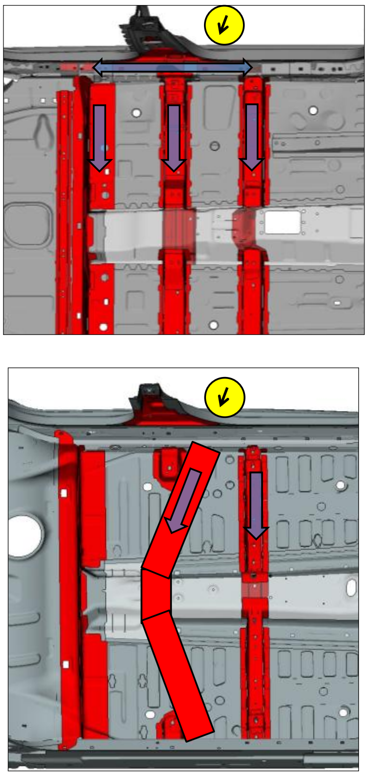


Figure 6. Two examples of underbody reinforcement principles

To give a concrete example, to counterbalance the increase of 19% in the intrusion, the add-ons represent 5 to 10 kg for the family vehicle.

Of course, to maintain a balanced performance between underbody and superstructure, similar reinforcements are necessary on the B-Pillar and in the doors, increasing as well the addition of mass.

Check of performances

For the small vehicle, studies went even further. After having performed the numerical analysis to design the reinforcements, a physical test was carried out with them. Figure 7 presents the reinforcements made on the underbody for the small vehicle.
It is interesting to notice that these simple reinforcements dedicated to the underbody represent, here, 5 kg.

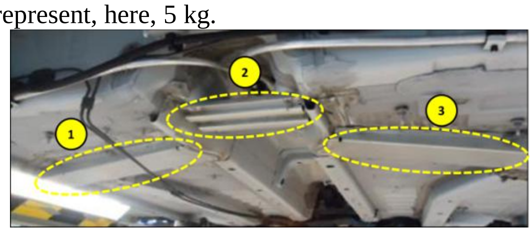


Figure 7. Reinforcements made on the small vehicle to counterbalance the excessive intrusion due to the oblique pole test

To illustrate the improvements made thanks to the add-ons designed for 75°-pole test, Figures 8 and 9 compare the beginning of crash and end of crash deformations for the small car and for the family car. Three configurations are displayed: the initial 90° pole test, the initial 75° pole test and the reinforced 75° pole test.

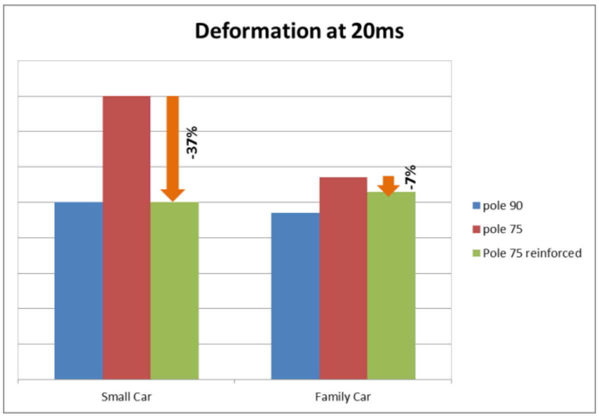


Figure 8. Beginning-of-crash deformation for the three test configurations (initial 90° pole test, initial 75° pole test and reinforced 75° pole test) for small car and family car.

In the first phase, crucial for the airbag deployment, the reinforcements helped to come back at the same level as in the initial 90° test for the small car. But for the family car, the improvement is not sufficient to reach the same level.

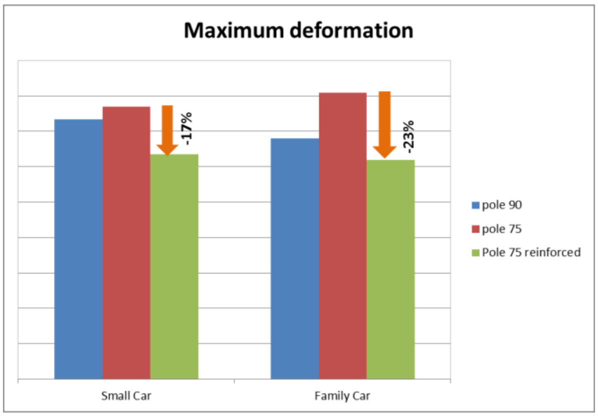


Figure 9. End-of-crash deformation for the three test configurations (initial 90° pole test, initial 75° pole test and reinforced 75° pole test) for small car and family car.

As shown above, for the small car as well as for the family car, there is a substantial gain on the end-of-crash intrusions. The level is even better than in the 90°-pole test.

DISCUSSION ON THE TEST COMPARISON IN TERMS OF STRUCTURAL BEHAVIOUR

As expected when looking at the initial test conditions, the 75°-pole impact test is more severe than the 90° one in terms of intrusion.
This severity is not only present at the end of impact but also in the first phase of deformation, when space is needed to deploy correctly the airbag.
So the first questions to ask are "what would be the consequence on the occupant protection? Will a reinforcement be enough to ensure the same protection? Or should there is a need to change the restraint system and the interaction between the structure, the door and the occupant?"

Therefore, we also investigated the biomechanical criteria between the 90°-pole test and the reinforced 75°-pole test.

Biomechanical criteria comparison

This comparison is presented in Figure 10 in terms of percentage of variation for the small car.
We remind that, for both tests, the measurements were made on the ES2-50[th] dummy so they can be compared without the need of a transfer function.

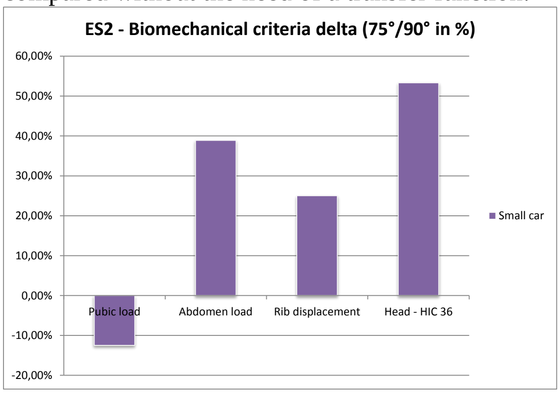


Figure 10. Biomechanical criteria variation when comparing the 75° reinforced test to the 90° one.

In this graph, a positive value means the results on the 75°-pole test is more severe than the 90°-pole test.

So we can conclude that for the small vehicle, the improvement gained with the reinforcements is significant in intrusion. But this is not enough to guarantee same protection as in 90°/29kph without changing the airbag characteristics.

In addition, it is also important to stress that WorldSID 50[th] is larger than ES2 50[th] and therefore, it will be even more difficult to ensure a good airbag deployment. This was not taken into account in our research. This means that our study is optimistic with respect to the modifications needed to fulfil a 75°-pole impact.

Therefore, to ensure a similar level of protection between the two tests configuration, there is no other possibility than adding some structural reinforcements to counterbalance this extra severity.
This will increase the mass, and so the energy to absorb and will also increase the CO_2 emission.

Moreover, a redesign of the airbag is needed to deploy earlier and in a smaller available space. This also increases the cost of vehicle.

This part of the study is somewhat "theoretical" because it just compares objectively two different test protocols. It tells us that if the 75°-pole impact is justified, we will have to take its negative effects on board. It is now time to try to answer to the following questions: is the 75°-pole impact relevant to the real life? And are the additional costs counterbalanced by the benefits that will be provided by an extra protection? And therefore, the final question would be: is the 75°-pole impact justified and needed?

For this reason, we also carried out a costs/benefits study focused on European roads.

COSTS/BENEFITS STUDY

Objectives

The aim of this study is to evaluate the cost/benefit ratio of regulation evolution for passenger cars and light commercial vehicles regarding side impacts. It was carried out to contribute to the WP29 discussion within the Pole Side Informal Working Group.
For this discussion on a regulatory topic, two evolution types have to be considered: the injury reduction in barrier side impact and the injury reduction in pole side impact.

Database used

To realize this work, we used the BAAC (Bulletin d'Analyse d'Accident Corporel) data base which is the French National database coming from the police data collection. Year 2009 was taken into account and we sampled fatalities and serious injuries distribution of passenger cars (M1 vehicles) and light commercial vehicles (N1 vehicles) involved in side impact (see Table 1).

Table 1.
Fatalities and serious injuries distribution regarding side impact types – Year 2009

M1 vehicles	Fatalities: pole side impacts	Fatalities: barrier side impacts	Fatalities: all side impacts
ONISR year 2009	167	307	474

N1 vehicles	Fatalities: pole side impacts	Fatalities: barrier side impacts	Fatalities: all side impacts
ONISR année 2009	11	14	25

M1 vehicles	Serious injuries: pole side impacts	Serious injuries: barrier side impacts	Serious injuries: all side impacts
ONISR year 2009	312	1301	1613

N1 vehicles	Serious injuries: pole side impacts	Serious injuries: barrier side impacts	Serious injuries: all side impacts
ONISR année 2009	6	95	101

French Fleet

To be able to calculate a cost/benefit ratio regarding French vehicle evolution, we need to have some accurate data about fleet. In 2009, the M1 French fleet was about 30.85 Million of vehicles. For the same year, N1 French fleet was about 5.75 Million. Table 2 gives the gravity vs. vehicle fleet ratio for both categories. We find that ratio is much higher for M1 vehicle rather than N1. This is due to different amount and road use between M1 and N1 vehicles.

Table 2.
Ratio (fatalities + severe injuries) versus M1 and N1 French fleet

Gravity (Fatalities + severe injuries) per million vehicle	Pole side impacts	Barrier side impacts	All side impacts
M1	16	52	68
N1	3	19	22

To estimate also this cost/benefit ratio we need to know the time of fleet renewal (progressive increase of new M1 and N1 designed cars into the fleet). For France, it takes about 14 years to renew completely M1 and N1 car fleets.

French social costs

We can estimate some positive and some negative effects on social costs.
For year 2009 in France, the positive effect on fatalities and serious injuries reduction is estimated to 1.2 M€ per fatality and 0.132 M€ per severe injured people. These figures are in the average of European figures.

The negative effect will be on fuel consumption and CO_2 emissions due to vehicle weight increase. Vehicles have to offer the same level of protection for a higher test velocity and a more severe configuration (see EEVC WG13 and WG21 Subgroup, Report: Analysis to estimate likely benefits and costs for the EU of modifying Regulation 95). This last assumption was not taken into account for the cost/benefit calculation due to the difficulties to estimate the CO_2 emission cost.

Technical evolutions - Technical cost and additional weight for M1 and N1 vehicles

The analysis is made with a two-step approach allowing to go from the current initial state to an intermediate state (addition of the 90°-pole test) or to a final state (use of the 75°-pole test instead of 90° one), as shown in Figure 11.
Indeed, the first step is to consider the 90°-pole test impact as the regulatory requirement in addition to the current ECE 95 requirement and in addition to the current fleet performance that could be assessed as scoring at least 13 points in Euro NCAP. We can define the car fleet that would answer this target and its cost and benefits.
And then, the second step would be to go from the car fleet defined in the first step to a car fleet answering to the 75°-pole test as already required in FMVSS 214.

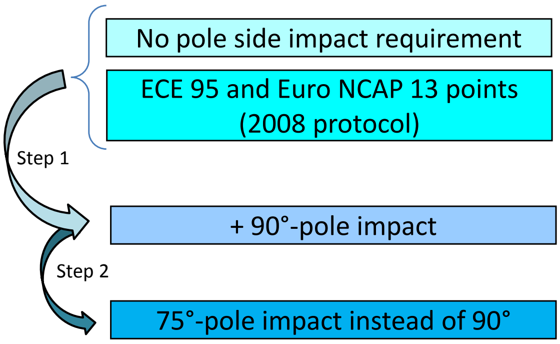


Figure 11. Assessment of side impact technical evolutions as a two-step approach.

To respect the 90°-pole test requirements in regulation, the upgrade of vehicles would require an additional cost of about 290 € to 348 € and an additional weight of about 13 to 20 kg per vehicle (source EEVC studies). This would be the cost for the first step of the approach described above.

To respect the 75°-pole side impact, the vehicle answering to the first step would need an additional update that would cost about 84 € to 223 € (source NHTSA 2004 studies) and about 50 € to 60 €/vehicle (source France) per vehicle.
For this second step of upgrade, the additional weight will represent 7 to 15 kg per vehicle.

To maximize result in our study, the global cost used for calculation is 340 € to 408 €/vehicle and the total weight is 20 to 35 kg/vehicle. It takes into account the two steps presented below.

Potential reduction of Fatalities and Serious injuries

At this stage, it could be good to recall that this study was made to analyse the effect of all the types of side impact; meaning the ones due to large obstacle (eg. other car, heavy vehicle…) combined to the ones due to narrow obstacles (eg. tree, pole). This could be done by requiring what is presented as the first step in Figure 11.

Benefit evaluation of new side impact safety systems on cars (improvement of curtain airbags, and structural changes: car stiffness, side body and doors) contributes to a 34% potential efficiency gain (source: LAB studies).
Evaluation of benefits due to the 75°-pole side impact (optimized airbags, structural changes such as increased reinforcement,…) contributes to a maximum of 20% potential efficiency on fatalities and serious injuries reduction (Figure 12).

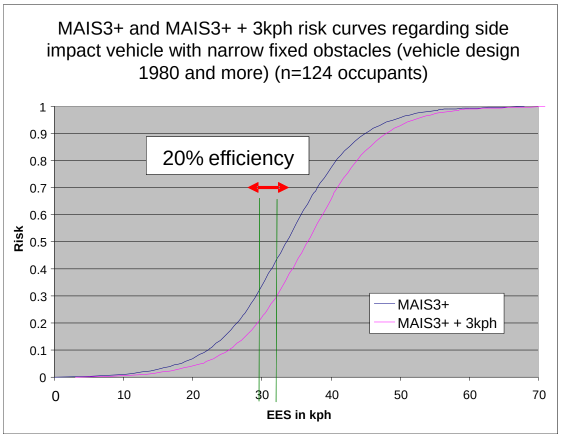


Figure 12. MAIS3+ and MAIS3+ +3kph risk curves regarding side impact vehicle with narrow fixed obstacles.

Cost / benefit ratio results

Regarding M1 vehicle, after 14 years French fleet renewal, stiffness and protection upgrade contributes to a reduction of 4,150 severe injured people and an avoidance of 1,326 fatalities.
Societal benefit is 2,139 M€ and technical cost is between 10,489 M€ and 12,587 M€.
Cost/benefit ratio result is between 4.9 and 5.9.
It may be useful to recall that when result is >1, it means that the cost/benefit ratio is not good.
Therefore, to get something economically interesting the technical cost balance should be at 69€ per vehicle.

Regarding N1 vehicle, after 14 years French fleet renewal, reduction represents 241 severe injured people and 73 fatalities avoidance. Societal benefit is 119 M€ and technical cost is between 1,955 M€ and 2,346 M€. Cost/benefit ratio result is between 16.4 and 19.6 (>1, therefore not good).
Therefore, technical cost balance should be economically interesting at 21€ per vehicle (see Table 3).

Table 3. Cost/benefit ratio for M1 and N1 vehicle – standard fleet.

	Cost / benefit ratio		Balanced cost / benefit ratio
	Min	Max	in Euros
M1 vehicles	4.9	5.9	69.3
N1 vehicles	16.4	19.6	20.8

DISCUSSION ON THE COST BENEFIT ANALYSIS

This cost benefit analysis shows that the ratio is always above 1, for M1 and even more for N1 fleet. The technical cost to be economically interesting would need to be very low – 69€ for M1 and 21€ for N1, which is not realistic.
But, one critic could be to stress that the car fleet will be influenced by a new regulation that came into force not so long ago: the mandatory fitment of ESC.
Therefore, we can carry out a second analysis taking ESC into account.

Potential reduction of Fatalities and Serious injuries with ESC generalisation

Benefit evaluation of ESC (regulation in 2012) regarding pole side impact avoidance gives a 34% potential efficiency (source: EEVC).
Benefit evaluation regarding pole side impact implied by the 75°-pole side impact gives a 20% additional potential efficiency.

<u>Cost / benefit ratio results</u>

Regarding M1 vehicle, after 14 years French fleet renewal, stiffness and protection upgrade contributes to 4,007 severe injured people reduction and 1,249 fatalities avoidance.
Societal benefit is 2,028 M€ and technical cost is between 10 489 M€ and 12,587 M€. Cost/benefit ratio result is between 5.2 and 6.2 (so >1, therefore not good).
Therefore, to get something economically interesting the technical cost balance should be at 66€ per vehicle.

Regarding N1 vehicle, after 14 years French fleet renewal, reduction represents 238 severe injured people and 68 fatalities avoidance.

Societal benefit is 113 M€ and technical cost is between 1,955 M€ and 2,346 M€. Cost/benefit ratio result is between 17.3 and 20.8 (>1, therefore not good).
So, technical cost balance should be economically interesting at 20€ per vehicle (see Table 4).

Table 4. Cost/benefit ratio for M1 and N1 vehicle ESC equipped

	Cost / benefit ratio		Balanced cost / benefit ratio
	Min	Max	in Euros
M1 vehicles - ESC equiped	5.2	6.2	65.7
N1 vehicles - ESC equiped	17.3	20.8	19.6

This is even more stringent to take ESC into account for the cost benefit analysis.

CONCLUSION

Conclusion on the structural reinforcements needed for the 75°-pole test

Comparing the two test configurations, there is no discussion possible: the 75°-pole impact test is more severe than the 90° one in terms of intrusion. It is also important to stress that the severity is not only present at the end of impact but also in the first phase of deformation, when space is needed for a correct airbag deployment.

To counterbalance this additional intrusion severity, structural reinforcements are needed. These add-ons would weigh up to 10 to 15 kg. But this would not be enough to reach the target of getting the same level of occupant protection as the 90°-pole test. The restraint system would also need to be modified.

Moreover, because WorldSID 50th is larger than ES2 50th, it will be even more difficult to ensure a good airbag deployment in this limited space. This was not taken into account in our research. This means that our study is optimistic with respect to the whole set of modifications needed to fulfil a 75°-pole impact.

These modifications would increase the mass of the vehicle, and so the energy to absorb and would also increase the cost of vehicle and the CO_2 emissions.

Conclusion on the cost benefits

As a conclusion, the analysis shows a cost/benefit ratio > 1 for passenger vehicles, and a huge rate for commercial vehicles.
Without ESC, the cost/benefit ratio is estimated > 4 for M1 vehicles and > 16 for N1 vehicles. And for Europe, where ESC is mandatory since January 1st 2012, the cost/benefit ratio is estimated > 5 for M1 vehicles and > 17 for N1 vehicles.

Human benefit versus technical cost balance is then about 66 Euros per M1 vehicle and 20 Euros per N1 vehicle.
Therefore, even if the decrease of fatalities and serious injuries is important, this new possible regulation is not economically interesting for Europe.
We guess that the same conclusion would be derived for China.

ACKNOWLEDGMENTS

The authors wish to thank the different labs (the internal PSA Peugeot Citroën Crash Test Centre, UTAC, Autoliv France and Millbrook Crash Test Centre), and the PSA Peugeot Citroën research teams that were involved in this study.

REFERENCE

[1] FMVSS No. 214, DYNAMIC SIDE IMPACT PROTECTION -Rigid Pole Side Impact Test Requirements - http://www.nhtsa.gov/Vehicle+Safety/Test+Procedures?procedurePage=1

[2] Euro NCAP Pole Impact Testing Protocol - Version 5.2, Feb 2012

[3] Safety Companion, Safety Wissen - Regulation and consumerism tests, 2013 edition

[4] WP29/GRSP – Informal Group on Pole Side Impact - https://www2.unece.org/wiki/pages/viewpage.action?pageId=3178630