PERFORMANCE COMPARISON BETWEEN A CAMERA ONLY AEB-FCW AND A CAMERA-RADAR FUSION AEB-FCW

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ABSTRACT

Autonomous Emergency Braking Systems and Forward Collision Warnings (AEB-FCW) are progressively entering European market. Due to cost constraints, the more efficient (expensive) systems are first implemented in Premium brands' vehicles where the impact of the cost of the system on the overall cost of the vehicle is smaller than for Standard brands' vehicles. For those models less expensive systems are implemented but they usually cover less scenarios. It induces a largely smaller benefit for the road safety even if they have higher market share.
To increase the benefit on road safety, it is needed to develop less expensive AEB-FCW aimed to cover the same scenarios as the more expensive systems. The objective of this study is to demonstrate our ability to design a more affordable FCW-AEB with high efficiency and comparable to the one equipping Premium brands' vehicles using two sensors (camera and radar)
To compare the performances achieved by these two AEB, evaluations have been performed on the same car model by UTAC following the Euro NCAP 2016 protocols (AEB City, AEB Inter Urban, AEB Vulnerable Road Users). These protocols are the existing ones in use at the moment which covers the largest amount of accident scenarios.
They include following scenarios:
- Car to car rear stationary,
- car to car rear moving,
- car to car braking,
- car to adult pedestrian crossing walking,
- car to adult pedestrian crossing running,
- and car to initially obscured child crossing walking.

Both systems have been developed following the same functional safety rules and aiming to have the same level of safety. The braking profile has been adapted to do so.
At the end, PSA defined a logic that provides a similar performance for pedestrian targets, and a slightly different one for car target but with a high cost difference.

This comparison has been done using the existing test protocols for AEB-FCW systems. But we have to know that it doesn't cover 100% of the field scenarios. Night scenarios for example have not been evaluated. But we can assume that if the low beam is on, the pedestrian will still be detected. Longitudinal scenarios for pedestrian have also not been performed but also there, the performance difference should be low.

This study has showed that it is possible to develop a relatively cheaper AEB-FCW with the same functional safety level, a mostly similar performance and with a much higher market share. This will increase the global level of road safety.

INTRODUCTION

New technologies' capabilities induce the apparition of Autonomous Emergency Braking Systems and Forward Collision Warnings (AEB-FCW). Consumer organizations on the other hand push OEMs to develop such systems. As a consequence, they are progressively entering European market. Due to cost constraints, the more efficient (expensive) systems are first implemented in Premium brands' vehicles where the impact of the cost of the system on the overall cost of the vehicle is smaller than for Standard brands' vehicles. For those models less expensive systems are implemented but they usually cover less scenarios. It induces a largely smaller benefit for the road safety even if they have higher market share.
To increase the benefit on road safety, it is needed to develop less expensive AEB-FCW aimed to cover the same scenarios as the more expensive systems. The objective of this study is to demonstrate that mainstream cars' manufacturers are able to design a more affordable FCW-AEB with high efficiency and comparable to the one equipping Premium brands' vehicles using two sensors (camera and
radar) or more.

FEATURES COMPARISON

Active Safety Brake description

This function, sold to the consumer includes three combined features:

- an Autonomous Emergency Braking system (AEB)
- a Forward Collision Warning (FCW)
- a Driver Brake support (DBS).

Autonomous Emergency Braking PSA Groupe developed two variants of the AEB. One is based on a camera-radar 24GHz fusion and is called "AEBS2". And the other one is based on a camera only. It is called "V-AEB".

The architecture of both AEBs is described in Figure 1 and 2.

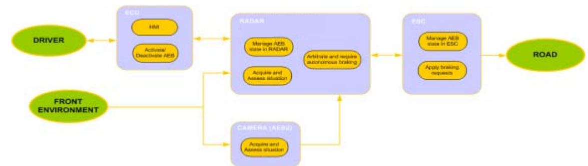


Figure 1. Basic Functional architecture of AEBS2

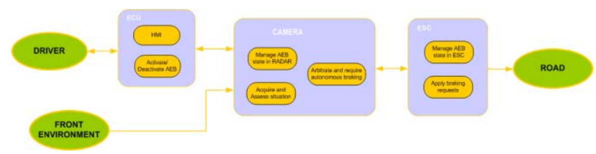


Figure 2. Basic Functional architecture of V-AEB

Forward Collision Warning There is no variant of this feature. This feature will warn the driver when there is a risk of crash.

Dynamic Brake Support. There is no variant of this feature. If the sensor(s) detects a risk of an imminent crash, and if the driver is braking, then, the DBS will apply full braking. It will help the driver to avoid the crash or highly reduce the impact speed, even if he doesn't apply a high pressure on the brake pedal.

Active Safety Brake comparison

In Table 1, there is a summary of the differences for the two variants of Active Safety Brake.

Features	AEBS2	V-AEB
AEB	Behaviour A	Behaviour B
FCW	Same behaviour	
DBS	Same behaviour	

Table 1.
Summary of feature differences

It shows that a variation of performance will only be noticeable when the driver does not react at all to the imminent crash threat.

In table 2, is a summary on sensors capabilities.

Sensor	Radar 24GHz	Camera
Horizontal Field of view	+/-11°	+/-18°
Light conditions	No influence	Reduced performance
Bad weather	Minor influence	Reduced performance
Moving obstacle	Detected	Detected
Fixed obstacle	Detected but often filtered (if out of the trajectory)	Detected
Pedestrian	Weakly detected	Detected
Cyclist	Detected	Detected

Table 2.
Sensors capability comparison

This table shows that no sensor is perfect. On the one hand the radar has limited field of view, detection capability on non-moving obstacles and is not always able to detect pedestrians. On the other hand, the camera detection is influenced by the light or weather conditions.

AEB behaviours description for AEBS2

AEBS2 works until 140kph and is automatically activated above 5 kph (except if driver deactivation). It works with mobile and fixed targets on the whole range, and pedestrians up to 60 kph.

If no driver reaction to the FCW, the system brakes the vehicle automatically:

- From 0 to 30 kph : up to 1.0g (depending on grip conditions) to complete stop
- From 30 kph to full speed : up to 1.0g (depending on grip conditions) and 50 kph speed decrease, (depending on radar and camera confirmation)
- The emergency brake can be overridden by the driver at any time by accelerating over a threshold.

AEB behaviours description for V-AEB

The function works until 85kph and is automatically activated above 5 kph (except if driver deactivation). It works with mobile and fixed targets on the whole range, and pedestrians up to 60 kph.

If no driver reaction to the FCW the system brakes the vehicle automatically:

- From 0 to 30 kph : up to 1.0g (depending on grip conditions) to complete stop
- From 30 kph to full speed : up to 1.0g (depending on grip conditions) and 23 kph speed decrease, (depending on radar and camera confirmation)
- The emergency brake can be overridden by the driver at any time by accelerating over a threshold.

Cost comparison

V-AEB is using one sensor less than AEBS2. So in global, V-AEB costs 40% less than AEBS2.

It should also be noted that V-FCW and V-AEB functions are carried by a camera which is also used for many other functions (traffic sign recognition, lane departure warning, Lane keeping assist, High/low beam auto-switching). And then it makes it possible to limit the real additional cost of these functions.

FUNCTIONAL SAFETY COMPARISON

We followed a usual safe design approach, in compliance with ISO 26262 [1]:

a. Definition of driver functionality
b. Identification of the risks of failure and misunderstanding of situations
c. Risk assessment and definition of objectives. Since the zero risk does not exist, we set ourselves admissible limits.
d. Safety design of the function
e. Verification of the respect of the objectives (by means of simulations, tests on tracks and finally of endurance driving). If necessary, adjust the design (return to step a.)

Below the different steps which allowed us to define the safety profiles of AEBS2 and V-AEB are presented.

a. Definition of driver functionality

We have identified that the main levers affecting the risks of these AEB functions are:

- Operating range
- Braking profile
- Speed reduction allowed

Then our goal was to adjust these parameters to make manageable and verifiable the safety level while providing the maximum performance and efficiency.

Our iterative studies have thus made it possible to fix the behaviour of the functions as described previously.

b. Identification of the risks of failure and misunderstanding of situations

Preliminary Risk Analysis identified two types of risk:

- Failures of parts and systems leading to unwanted behavior (excessive braking, loss of trajectory, unavailability, ...)
- Untimely braking due to misunderstanding of scenes (False positive braking)

The safe design to cover a risk of failure consists of:

- identify all contributors, interfaces and decision chains (functional architecture and organic architecture)
- decompose and distribute the overall risk among the different contributors by redefining the decision chains and taking into account the capacity of the parts to keep the allocated objective (eg, organ X will be able to limit the generation of failure Y to a Value less than 10E-8/hour of operation)

c. Risk assessment and definition of goals.

Each identified risk by PRA is assessed according to ASIL scale (Automotive Safety Integrity Level). We evaluate:

- occurrence of the unwanted event
- possible controllability by the driver or other users if the unwanted event occurs
- severity if the unwanted event occurs (death, serious injury, minor,…)

We simulated automatic brake at each time step of a driving database of hundreds of thousands of kilometers.

The successive iterations allowed us to adjust the following profiles giving an equivalent safety level:

AEBS2 :

➔ 1G + 50kph of speed decrease

V-AEB

➔ 1G + 22kph of speed decrease

PERFORMANCE COMPARISON

Perfomance Evaluation Method

Vehicles used The vehicles tested are two pre-serial Peugeot 3008, having the same engine, same trim level and same definition besides their AEB systems.

Test Method Test series have been done in 2016 by UTAC, using Euro NCAP AEB City , AEB InterUrban [2] and AEB VRU [3] protocols. Other protocols are available worldwide but these protocols were the one covering more accident scenario when the study has been done.

Both AEB City and AEB InterUrban, are including front-rear accident scenarios.

AEB City has only one type of scenario with a stationary target (CCRs) and the AEB feature is tested.

AEB InterUrban has three kind of scenario. The first is done with a stationary vehicle target. In this scenario, only the FCW feature is tested with a robot reacting to the warning and braking. The second one with a moving vehicle target is avaluating both AEB and FCW performances.

And the last one is a scenario, where the tested vehicle is following a moving vehicle target, both driving at 50kph. At a certain time, the target will brake. 4 configurations are tested with FCW and AEB.

Table 4 describes the scenarios.

	CCRs			
	AEB + FCW combined		AEB only	FCW only
	AEB	FCW		
AEB City	10-50 km/h	-	10-50 km/h	-
AEB Inter-Urban	-	30-80 km/h	30-80 km/h	30-80 km/h

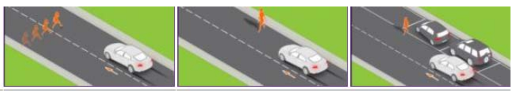
	CCRm			
	AEB + FCW combined		AEB only	FCW only
	AEB	FCW		
AEB Inter-Urban	30-70 km/h	50-80 km/h	30-80 km/h	50-80 km/h

		CCRb	
		AEB+FCW combined, AEB only & FCW only	
		2 m/s²	6 m/s²
AEB Inter-Urban	12m	50 km/h	50 km/h
	40m	50 km/h	50 km/h

Table 4.
Euro NCAP Car to Car scenarios description

In AEB VRU protocol in 2016, the different scenarios used represent a pedestrian crossing the road in front of the tested vehicle. Only AEB performance is evaluated in the protocol.

Test configurations are described in **table 5**.



	Farside	Nearside	
PEDESTRIAN	Adult	Adult	Child
	8 km/h	5 km/h	5 km/h
	50%	25% & 75%	50%
VUT	20-60 km/h	20-60 km/h	20-60 km/h

Table 5.
Euro NCAP VRU scenarios description

All tests have been done using articulated dummy.

Assessment Method
The weight of each test for each scenario and weight of each scenario taken into account are the one used described in the Euro NCAP Assessment Protocols [4], [5] and [6].

It is important to notice that the weight of each speed and each scenario is not evenly distributed. It has been defined taken into account the accident data and weights of different accident scenarios in the field.
Taking Euro NCAP methods is a good way to measure and compare performance of AEBS2 and V-AEB.

Results

AEB City
In this scenario, AEBS2 passes all tests.

AEB City		AEB	
TESTNUMBER		Impact speed	Points
CCRs			
	10 km/h	0	1,000
	15 km/h	0	2,000
	20 km/h	0	2,000
	25 km/h	0	2,000
	30 km/h	0	2,000
	35 km/h	0	2,000
	40 km/h	0	1,000
	45 km/h	0	1,000
	50 km/h	0	1,000
CCRs RESULT		14,000	
SUMMARY			
	CCRs	100%	

Table 6.
AEB City performance of AEBS2

As V-AEB has a limited speed reduction in higher speeds, the performance is reduced above 30kph.

AEB City		AEB	
		Impact speed	Points
CCRs			
	10 km/h	0	1,000
	15 km/h	0	2,000
	20 km/h	0	2,000
	25 km/h	0	2,000
	30 km/h	0	2,000
	35 km/h	12,82	1,267
	40 km/h	19,21	0,520
	45 km/h	19,99	0,556
	50 km/h	25,51	0,490
CCRs RESULT		11,833	
SUMMARY			
	CCRs	85%	

Table 7.
AEB City performance of V-AEB

In this scenario, the performance is reduced by 15% for V-AEB.

AEB InterUrban results for AEB feature

AEBS2 passes almost all the test without impact for the Car to Car Moving scenario (**Table 8**), where V-AEB has a reduced performance in higher speeds due to its safety barriers (**Table 9**).

SUMMARY		
	CCRs	-
	CCRm	99,7%
	CCRb	77,9%

Table 8.
AEB InterUrban performance of AEBS2

SUMMARY		
	CCRs	-
	CCRm	73.5%
	CCRb	50.1%

Table 9.
AEB InterUrban performance of V-AEB

So, on AEB InterUrban, for ist AEB feature, AEBS2 has an overall performance of 88,8% where V-AEB has a performance of 61,8%. It makes a reduction of 30,4%.

AEB InterUrban results for FCW feature

For these scenarios, a 0,4g braking is applied to the brake pedal by a robot reacting with a 1,2s delay to the FCW. As the AEB is not deactivated during the test, even if the FCW has the same characteristics for fusion and camera only systems, there is a slight difference in the performance for V-AEB (table 11) and AEBS2 (table 10).

SUMMARY	
CCRs	84,6%
CCRm	100,0%
CCRb	87,3%

Table 10.
AEB InterUrban performance of AEBS2

SUMMARY	
CCRs	77.7%
CCRm	81.5%
CCRb	86.5%

Table 11.
AEB InterUrban performance of V-AEB

AEBS2 gets a performance of 90,6% when V-AEB gets 81,9%.

AEB VRU results

As radar is not able to detect the pedestrian, performance is almost equal for both systems. AEBS2 has a performance of 75% and V-AEB has 74,4%. So there is no significant difference of performance.

SUMMARY	
Adult Running, farside, 50%	73%
Adult Walking, nearside, 25%	87%
Adult Walking, nearside, 75%	100%
Child Running, nearside obscured, 50%	41%

Table 12.
AEBS2 results in AEB VRU protocol

SUMMARY	
Adult Running, farside, 50%	78%
Adult Walking, nearside, 25%	83%
Adult Walking, nearside, 75%	94%
Child Running, nearside obscured, 50%	43%

Table 13.
V-AEB results in AEB VRU protocol

Results	AEBS2	VAEB	Variation of perf.
AEB City	100%	85%	-15%
AEB InterUrban-AEB	88,8%	61,8%	-30,4%
AEB InterUrban-FCW	90,6%	81,9%	-9,6%
AEB VRU	75%	74,4%	~0%

Table 14.
Performance comparison for AEBS2 and V-AEB

Table 14 shows that in the different Euro NCAP evaluation protocols, the performance reduction of V-AEB is very limited.
V-AEB has the same performance in case of pedestrian crossing scenario and low speed car to car rear scenarios too. For higher speeds the reduction of performance is more noticeable but, the effect on the % of performance is low as the weight of these scenarios is less, in correlation to real life accidentology.

Cost/benefit ratio

As Car to car rear or car to pedestrian accidents don't have the same occurrence, so we calculate separated cost/benefice ratios.

If we suppose that the benefit for society is directly correlated to the Euro NCAP performance evaluation, then it is easily possible to compare the benefit / cost ratio between AEBS2 and VAEB.

Table 15 presents the calculation assuming Euro NCAP performance of the system is proportional to the benefit for society.

The calculation formula of the increase of benefit/cost ratio is as follows:

$$IR = \frac{R_{VAEB} - R_{AEBS2}}{R_{AEBS2}}$$

Where:
IR means the increase of benefit/cost ratio of VAEB compared to AEBS2,
R_{VAEB} means Benefit/cost ratio of V-AEB and R_{AEBS2} means benefit/cost ratio of AEBS2.

As $$R_{VAEB} = \frac{A * P_{VAEB}}{0,6 * C_{AEBS2}}$$

And $R_{AEBS2} = \frac{A*P_{AEBS2}}{C_{AEBS2}}$

Where:
A means the factor relating society benefit to the Euro NCAP performance,
P_{VAEB} means performance of VAEB,
P_{AEBS2} performance of AEBS2,
C_{VAEB} means cost of VAEB and
C_{AEBS2} means cost of AEBS2.

We already mentioned that V-AEB is 40% less expensive than an AEBS2, so C_{VAEB}=0,6*C_{AEBS2}.

Then,

$$IR = \frac{\frac{A*P_{VAEB}}{0{,}6*C_{AEBS2}} - \frac{A*P_{AEBS2}}{C_{AEBS2}}}{\frac{A*P_{AEBS2}}{C_{AEBS2}}} = \frac{\frac{P_{VAEB}}{0{,}6} - P_{AEBS2}}{P_{AEBS2}}$$

Results	AEBS2 perf.	VAEB perf.	Variation of benefice/cost ration ratio for VAEB
Cost	*X*	*0,6*X*	
AEB City	100%	85%	**+42%**
AEB IU AEB	88,8%	61,8%	**+16%**
AEB IU FCW	90,6%	81,9%	**+51%**
AEB VRU	75%	74,4%	**+65%**

Table 15.
Comparison of the VAEB benefice/cost ratio to the AEBS2 one

This calculation shows that the benefice/cost ratio is much better for the camera only. Using this sensor only decreases the performance of AEB but it decreases even more the cost of the AEB-FCW.

LIMITATIONS OF THE STUDY

The evaluation of the performance has been carried out using Euro NCAP protocols existing in 2016. It is known that they do not cover all accident scenarios in the field.

Euro NCAP is aware of that is developing addition test protocols aiming to increase their coverage. From 2018, they will include robustness scenarios for car to car AEB tests with different target/tested vehicle overlaps. Pedestrian longitudinal scenarios will also be added. Night tests will be also done for pedestrian scenario.
New bicycle scenarios will also part of Euro NCAP 2018 protocols. This may change slightly the results, but conclusions will not be affected, as camera is not still working as long as headlamps are on by night and that a 24GHz radar is already almost "blind" toward a pedestrian by day.
Another parameter can affect the conclusion of this study. It is the constant increase of sensors' performances and the availability of new sensors on the market. For example, new 77GHz radars are now available. They are now able to robustly detect pedestrians. Their cost is almost equivalent to 24GHz radars. This will bring a better performance on AEB VRU protocols for camera-radar fusion AEB-FCW. But will it be sufficient to make them more cost efficient? Not sure, if we look at the better benefit/cost ratio we already have for a camera only system on AEB Car to Car scenarios.
Last point is that we did the study based on perfect, repeatable test protocol, with ideal weather condition. Extreme bad weather or light conditions may affect performance.

CONCLUSIONS

Within this study, demonstration has been made that the cost benefit ratio is more interesting for a camera only AEB than for radar 24GHz in fusion with a camera. With this good ratio, it allows to OEMs to provide it for consumer standard or as option at a lower price compared to a fusion AEB. In consequence it will more easily spread through vehicle fleet.
Radar 24GHz only AEB has not been evaluated, but will be less interesting because it will highly reduce AEB VRU performance.
New radars with pedestrian detection capabilities will bring new opportunities, but there is no interest to use them without a camera. As a matter of fact, a camera also supports lots of other safety features (speed limit recognition, line detection for Lane Departure Warning or Lane Keeping Assistance for example).

REFERENCES

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