Objective Testing of Autonomous Emergency Braking Systems for the EuroNCAP AEB Rating
Agenda

- Autonomous Emergency Braking Systems
- Test Scenarios
- Robots for AEB Tests
- Impressions and Results
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Autonomous Emergency Braking -
Typical Sensor Technologies

- Radar
- Video
- Laser/Lidar
- Ultrasonic
- Infrared

Pictures from: Comparative test of advanced emergency braking systems, ADAC
Autonomous Emergency Braking -
Basic Principle

► The control unit calculates the object’s position, the relative speed and the relative acceleration in relation to the own vehicle.

► Sensor fusion and plausibility check by comparing the input data of all sensors.

► By integrating the steering angle sensor, the vehicle’s desired path of movement can be estimated. This helps AEBS identify the objects which the vehicle is likely to collide with.

► Analysing the data transmitted from the acceleration sensor and the indicator, AEBS knows whether or not the driver has seen the object and responds to it by stepping on the brakes or swerving.
Autonomous Emergency Braking -
Three Stages of Safety Measures

Stage 1: Collision Warning
► visual and acoustic warnings
► haptic warnings like brake jerk or accelerator force feedback

Stage 2: Assisted Braking
► brake linings get shifted to get in contact with the discs
► tripping threshold of the hydraulic brake assist is lowered
► support braking of driver with necessary deceleration to avoid a collision

Stage 3: Automatic Braking
► automatic braking by absence of driver reaction

up to 100ms gain of time
Autonomous Emergency Braking -
 Typical Time-to-Collision Sequence

Source: www.daimler.com
AEB Alert Cascade -

Example Audi A7

Audi A7

From 100kph to 60kph

Visual/ acoustic warning
TTC 2.1sec

Brake
TTC 1.9sec

Partial braking
3.6m/s²
TTC 1.7sec

Partial braking 2
5.3m/s²
TTC 1.1sec

Full deceleration
TTC 0.1sec

Source: Comparative test of advanced emergency braking systems, ADAC
AEB Alert Cascade - Example Volvo V60

Volvo V60
From 100kph to 60kph

Visual/aural warning
TTC 2.3sec

Full braking
TTC 0.9sec

Speed reduction: 20kph

Source: Comparative test of advanced emergency braking systems, ADAC
**AEB Alert Cascade - Example Ford Focus**

Ford Focus
100 km/h auf 60 km/h

- **optische/akustische**
  - Warnung
  - TTC 2,5 sec

- **Teilbremsung**
  - -2,9 m/s²
  - TTC 0,7 sec

Source: Reduzierung von Unfällen durch Notbremssysteme bei PKW, ADAC Technik Zentrum

*Teilbremsung nur, wenn nach der Warnung der Fuß vom Gaspedal genommen wird.*
### EuroNCAP Rating Scheme - AEB Relevant Changes 2013 - 2016

<table>
<thead>
<tr>
<th>Adult Occupant Protection</th>
<th>Child Occupant Protection</th>
<th>Pedestrian Protection</th>
<th>Safety Assist</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>20%</td>
<td>20%</td>
<td>10%</td>
</tr>
</tbody>
</table>

- Front ODB
- Dynamic
- Head form
- SBR

- Side barrier
- CRS fitment
- Upper leg form
- SAS

- Side pole
- Vehicle based
- Lower leg form
- ESC

- Whiplash front

---

2013
### EuroNCAP Rating Scheme - AEB Relevant Changes 2013 - 2016

<table>
<thead>
<tr>
<th>Category</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult Occupant Protection</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>Child Occupant Protection</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Pedestrian Protection</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Safety Assist</td>
<td>10%</td>
<td>20%</td>
</tr>
</tbody>
</table>

- **AEB City**:
  - Front ODB
  - Dynamic CRS fitment
  - Vehicle based
- **AEB Inter-Urban**:
  - Side barrier
  - Head form
  - Upper leg form
  - Side pole
  - Lower leg form
  - Whiplash front
  - SBR
  - SAS
  - ESC
  - Whiplash rear
  - LDW/LKD
  - AEB City
# EuroNCAP Rating Scheme - AEB Relevant Changes 2013 - 2016

<table>
<thead>
<tr>
<th>Adult Occupant Protection</th>
<th>Child Occupant Protection</th>
<th>Pedestrian Protection</th>
<th>Safety Assist</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% → 40%</td>
<td>20%</td>
<td>20%</td>
<td>10% → 20%</td>
</tr>
</tbody>
</table>

- **Front ODB**
- **Front FW**
- **Side barrier**
- **Side pole**
- **Whiplash front**
- **Whiplash rear**

**AEB City**

**Dynamic**
**CRS fitment**
**Vehicle based**

**Head form**
**Upper leg form**
**Lower leg form**

**AEB Pedestrian**
**SBR**
**SAS**
**ESC**

**LDW/LKD**

**AEB Inter-Urban**
### EuroNCAP Rating Scheme - AEB Relevant Changes 2013 - 2016

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<th>Safety Assist</th>
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<tbody>
<tr>
<td>Side barrier</td>
<td>Vehicle based</td>
<td>Lower leg form</td>
<td>ESC</td>
</tr>
<tr>
<td>Side pole</td>
<td></td>
<td>AEB Pedestrian</td>
<td>LDW/LKD</td>
</tr>
<tr>
<td>Whiplash front</td>
<td></td>
<td></td>
<td>AEB Inter-Urban</td>
</tr>
<tr>
<td>Whiplash rear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AEB City</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5-star rating practically impossible without AEB from 2014 on
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**Test Scenario CCRs -**

**Car-to-Car Rear Stationary**

<table>
<thead>
<tr>
<th></th>
<th>CCRs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AEB + FCW combined</td>
</tr>
<tr>
<td></td>
<td>AEB only</td>
</tr>
<tr>
<td></td>
<td>FCW only</td>
</tr>
<tr>
<td><strong>AEB City</strong></td>
<td>10-50 km/h</td>
</tr>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10-50 km/h</td>
</tr>
<tr>
<td><strong>AEB Inter-Urban</strong></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>30-80 km/h</td>
</tr>
<tr>
<td></td>
<td>30-80 km/h</td>
</tr>
</tbody>
</table>

Source: EuroNCAP AEB Test Protocol V1.0, April 2013
Test Scenario CCRm - Car-to-Car Rear Moving

<table>
<thead>
<tr>
<th>CCRm</th>
<th>AEB + FCW combined</th>
<th>AEB only</th>
<th>FCW only</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AEB Inter-Urban</strong></td>
<td>30-70 km/h</td>
<td>30-80 km/h</td>
<td>50-80 km/h</td>
</tr>
<tr>
<td></td>
<td>50-80 km/h</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: EuroNCAP AEB Test Protocol V1.0, April 2013
**Test Scenario CCRb - Car-to-Car Rear Braking**

![Diagram of car-to-car rear braking scenario]

<table>
<thead>
<tr>
<th>CCRb</th>
<th>AEB+FCW combined, AEB only &amp; FCW only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 m/s²</td>
</tr>
<tr>
<td>AEB Inter-Urban</td>
<td></td>
</tr>
<tr>
<td>12m</td>
<td>50 km/h</td>
</tr>
<tr>
<td>40m</td>
<td>50 km/h</td>
</tr>
</tbody>
</table>

Source: EuroNCAP AEB Test Protocol V1.0, April 2013
Test Scenario -

Required Precision

According to EuroNCAP Test Protocol V1.0, April 2013 following precision is required for a valid test:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of VUT (GPS-speed)</td>
<td>Test speed + 1.0 km/h</td>
</tr>
<tr>
<td>Speed of EVT (GPS-speed)</td>
<td>Test speed +/- 1.0 km/h</td>
</tr>
<tr>
<td>Lateral deviation from test path</td>
<td>0 +/- 0.1 m</td>
</tr>
<tr>
<td>Relative distance VUT and EVT (CCRb)</td>
<td>0 +/- 0.5 m</td>
</tr>
<tr>
<td>Yaw velocity</td>
<td>0 +/- 1.0 °/s</td>
</tr>
<tr>
<td>Steering wheel velocity</td>
<td>0 +/- 15.0 °/s</td>
</tr>
</tbody>
</table>
VUT Brake Application Profile -
According to EuroNCAP AEB Test Protocol

According to EuroNCAP AEB Test Protocol

VUT speed control

Accelerator displacement control

Accelerator displacement

Brake displacement control

Brake force control

Brake force

Switch to Brake force control, when D4 or F4 is exceeded, whichever is reached first

max. exceeding of 200ms allowed during AEB interventions

T_{FCW} + 1.2s

T_{FCW} + 1.4s

T_{Switch}

T_{Switch} + 0.2s

D4

F4

F4 +/- 25%
Robots are required to meet the specifications
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Equipment for AEB Tests - Overview

Target

Driving Robots

DGPS
Steering Robot –

**FMVSS 126 compliant with universal mounting**

**Characteristic features:**

► no special steering wheel necessary
► regular airbag control remains unaffected
► quick and easy installation
► adaptable to virtually all standard steering wheels
► driver's seat remains free
► vacuum cup mounting enables the rapid adaptation to different vehicles
► record and replay steering maneuver

**Technical data:**

► nominal steering torque up to **70 Nm**
► steering angle velocity at nominal torque: **1200 °/s**
► max. steering angle velocity: **3500 °/s**
► typical current consumption: **20 A**
► supply voltage: **12 V**
► weight of robot drive: **4.9 kg**
Gas Pedal Robot CG300 – lightweight and fast designed for the accelerator pedal

Characteristic features:

- flexible due to wire rope principle
- actuator mounted on top of pedal
- mounting point in the floor area required
- driver can always override pedals
- automatic adaptation to different pedal travels
- control of pedal position, vehicle velocity or distance
- easy to use via Web interface

Technical data:

- max. operation speed: 110 cm/s
- typ. operation force: 300 N
- typ. duration for gas operation: < 0,15 s
- typ. current consumption for gas operation: 5 A
- power supply voltage: 12 V
- dimensions incl. mounting: 11,5 x 7,5 x 7 cm
- weight: 0,6 kg
Braking Robot CB2100 –

*highest strength and performance*

Characteristic features:

- control of pedal *position*, *force*, *hydraulic brake pressure* or *vehicle deceleration*
- any *braking profiles* with simple script commands
- *synchronous operation* with steering machine
- *easy to use* via Web interface
- non-destructive and *quick to install*
- pedal can be *overridden by drivers*
- *physical relief* for emergency braking

Technical data:

- max. operation speed: **125 cm/s**
- max. operation force: **2,000 N**
- nominal operation speed: **100 cm/s**
- nominal operation force: **900 N**
- resolution of position measurement: **0,03 mm**
- power supply voltage: **12 V**
Automatic Track Control –
reproducible smooth and robust high g driving

- capable of lateral acceleration up to 1g
- stabilizes car even after drifting
- smooth but high performant steering (steering rates up to 2000 °/sec)
- independent of vehicle velocity
- usable also for offroad tracks
- compatible with all commonly used GPS sensors

- easy course programming with scripting language
- arbitrary combinations of open- and closed-loop manouevers possible
- easy to use via Web interface
- software extension to Steering Robot
- fast adaption to different cars
Video Automatic Track Control CO.TRACK – Handling Course

Automatic Track Control

- Handling Course -

VEHICO GmbH
Video Automatic Track Control CO.TRACK – Double Lane Change

VEHICO GmbH
Equipment for AEB Tests - Overview

Target

Driving Robots

DGPS
ADAC Target – Standard for all EuroNCAP AEB Tests

Characteristic features:

- realistic reflexion characteristics
- for pulling speeds up to 80 km/h
- for differential speeds up to 50 km/h
- deceleration up to 6 m/s^2 possible
ADAC Target –

Outer Cover with Realistic Appearance

Source: Reduzierung von Unfällen durch Notbremssysteme bei PKW, ADAC Technik Zentrum
ADAC Target –
Radar Absorption Mat, Radar Reflector and Reflective Film

Source: ADAC AEBS (Advanced Emergency Braking System) Testsystem, ADAC Technik Zentrum
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EuroNCAP AEB tests –
both vehicles equipped with VEHICO Gas, Brake and Steering Robot

Control algorithms used:
► automatic track guidance
► velocity control
► deceleration control

Control algorithms used:
► automatic track guidance
► velocity control
► distance control
► brake pedal position and force control
EuroNCAP AEB tests –

sudden braking after driving with constant distance
EuroNCAP AEB tests – driving with constant velocity on standing target
ADAC Test Autonomous Emergency Braking Systems 2012 – Driven with VEHICO Robots

Reported in... ADAC Motorwelt 9/2012

complete test report online

www.adac.de > Info, Test und Rat > Assistenzen > Notbremsassistenten 2012

ADAC uses VEHICO robots for AEB testing
Summary

Objective vehicle testing for autonomous braking systems:

► development of AEBS is rapidly pushed by EuroNCAP rating
► high precision requirements for objective comparison
► test scenarios for pedestrian tests will be defined
► VEHICO robots are perfectly suitable for EuroNCAP AEB tests