Theoretical and experimental possibilities to set up some sensors systems involved in active safety process

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Abstract. The safety systems present in the construction of modern motor vehicles fully benefit from all development research efforts in the field of autonomous motor vehicles. In this paper, we have analyzed, theoretically and experimentally, for three distinct types of passenger cars, the following active safety systems: 1. Autonomous Emergency Braking system, designed as an automatic braking process of the vehicle, in response to the detection of a probable collision, to reduce the speed of the vehicle; 2. Forward Collision Warning, implemented as an audiovisual warning that is present on board a motor vehicle, to alert the driver; 3. Dynamic Brake support, which further amplifies the braking force to detect the imminent collision to achieve a higher deceleration than in the situation of a normal speed reduction. As a following were study three states such as: Car-to-Car Rear Stationary as a possible collision in which a vehicle travels forwards towards another stationary vehicle and the front structure of the vehicle strikes the rear structure of the other, Car-to-Car Rear Moving as a probable collision in which a vehicle travels forwards towards another vehicle that is travelling at constant speed and the front structure of the vehicle strikes the rear structure of the other and possible collisions named Car-to-Car Rear Braking in which a vehicle travels forwards towards another vehicle that is travelling at constant speed and then decelerates, and the frontal structure of the vehicle strikes the rear structure of the other. The three situations have been examined, experimentally and theoretic, in order to obtain important information about the configurations of sensor systems that compose safety systems. The work allowed to obtain configuration information, experimentally confirmed, with an impact on the improvement of future autonomous vehicles system.

1. Introduction
The development of the safety systems in modern vehicles has benefited fully from the current trend in the evolution of motor vehicles, namely the introduction of various degrees of autonomy, increasingly complex.

On the other hand, it is clear that the construction of a vehicle as less dependent on the human operator makes the movement of that mobile more and more secure. Systems grouped into the concept of 'Active Safety' shall mean all safety systems that act to avoid collisions or to the mitigate of the consequences of collisions between a vehicle and other vehicles, obstacles or pedestrians. The concept of a high-performance vehicle from the point of view of active safety can be considered as having promising potential to develop into a future autonomous vehicle.
Starting with SAE J3016_201806 regulation [1] the EU Commission were adopted the guidelines for safety technology regarding automated vehicles [2], [3] summarized in figure 1 [3], as different levels of automation.

![Figure 1. Different levels of automation. [3].](image)

As is apparent from Figure 1, Autonomous Emergency Braking System, Forward Collision Warning and Dynamic Brake Support systems are already present in many vehicle configurations ensuring partial coverage of levels 1 and 2 of autonomy.

From 2010, Euro NCAP launched Euro NCAP Advanced as a “reward system for advanced safety technologies, complementing Euro NCAP’s existing star rating scheme.” [4]. The evaluation of new cars in terms of the three safety systems mentioned shall be carried out by Euro NCAP according to the protocols described in [4] and [5].

Using Global Vehicle Target (GVT) definition [4] and Car-to-Car Rear stationary (CCRs), Car-to-Car Rear moving (CCRm) and Car-to-Car Rear braking tests protocols fixed in [5], many experiments were performed for old/used vehicle, in real life condition, in order to determine the viability over the time of active safety vehicles systems.

The evolution over time of Autonomous Emergency Braking, Forward Collision Warning and Dynamic Brake Support systems present on older vehicles, their software integration with other asset safety systems, the use of elements for indirect and augmented reality environment, the use of more precise data provided by current GPS systems [6], [7] require verification of active safety systems and in-use cars of a certain age, not only for new vehicles.

The experimental data used in this paper were obtained with the entire research’s expertise and research equipment available in DSD laboratories, Dr. Stefan Datentechnik GmbH - Linz, Austria, during the Easter 2018 PC-Crash Seminar research program.

### 2. Experimental results

Autonomous Emergency Braking System, Forward Collision Warning, and Dynamic Brake Support systems from 2011 – VW Touareg V6 TDI, 2015 – Tesla Model S 85D and 2016 – Mercedes S350 BlueTEC 4MATIC were tested as is summarized in figures 2, 3 and 4.

All experimental scenarios were develop in respect with lateral overlap definition as show in figure 5 [8].
Figure 2. Specific tests scenario for VW Touareg.

Figure 3. Tests scenario for Tesla
In accord with Euro NCAP test protocol [4], [8], for new vehicles “to provide the Euro NCAP Secretariat with colour data (expected impact speeds are not required) detailing the performance of the vehicle in the CCRs and CCRm scenarios for all overlap and impact speed combinations."

To validate a robust evolution of these active safety specific systems were performed tests described in this paper for vehicles manufactured in 2011 (VW), 2015 (Tesla) and 2016 (Mercedes).

Figure 6 shows, as example, the variations of speeds and accelerations of VW and GVT vehicles as time functions, in the CCRm test scenario along with the distance between the two vehicles according to time.
Figure 7 presents velocities and accelerations for some CCRs and CCRm experiments over VW Touareg as Vehicle Under Test (VUT) (“means the vehicle tested according to this protocol with a pre-crash collision mitigation or avoidance system on board.” [8]).

Figure 6. Example of velocities, accelerations and distance of/between VW and GVT in a CCRm test scenarios

Figure 7. Velocities and accelerations of VW as VUT vehicle in some CCRs and CCRm test scenarios
Figure 8. Velocities and accelerations of Tesla as VUT vehicle in some CCRs and CCRm scenarios

Figure 9. Velocities and accelerations of Mercedes as VUT vehicle in some CCRs and CCRm scenarios

Figure 10. TTC for six CCRs, CCRm and CCRb experiments for all three VUT vehicles involved
In figures 8 and 9 are shown velocities and accelerations for some CCRs and CCRm experiments with Tesla and Mercedes as Vehicle Under Test (VUT).

The TTC for six CCRs, CCRm and CCRb experiments for all three VUT vehicles involved are shown in figure 10 (“Time To Collision (TTC) – means the remaining time before the VUT strikes the GVT, assuming that the VUT and GVT would continue to travel with the speed it is travelling.”[8]).

3. Active safety systems simulation

Autonomous Emergency Braking System, Forward Collision Warning, and Dynamic Brake Support systems functionality can be simulate using PC Crash 12.1 software.

Figure 11. VUT (Tesla) and GVT (Ford Fiesta) CCRm scenario vehicles configuration.

Figure 12. Settings for Autonomous Emergency Braking, Forward Collision Warning, and Dynamic Brake Support systems.
Using PC Crash Software we simulated the behaviour of the respective associated systems in the general concept of Active Safety. Thus, for a 2015 Tesla car as the VUT and Ford Fiesta as the GVT vehicle (with configured dimensions) the behaviours of Active Safety systems in the CCRm scenario can be studied.

**Figure 13.** Velocity versus distance for VUT (Tesla) and GVT (Ford Fiesta) vehicles from CCRm simulation.

**Figure 14.** Velocity versus time for both VUT (Tesla) and GVT (Ford Fiesta) vehicles from CCRm simulation.
Figure 11 shows the configuration window for the UVT vehicle and for the GVT vehicle in the CCRm scenario. The configurations for Autonomous Emergency Braking, Forward Collision Warning, and Dynamic Brake Support systems can be seen with the example in figure 12. Figure 12 also shows the configurations specific to the distance sensors (radar sensor) and those for emergency braking.

Figure 13 shows the shapes of velocities versus distance of VUT and GVT vehicles for a common CCRm scenario simulation and figure 14 present the variations of velocities versus time for the same vehicles in the same CCRm scenario.

As can see in figure 12, many sensor are involved in Autonomous Emergency Braking, Forward Collision Warning, and Dynamic Brake Support systems. For the CCRm scenario with the results described in figures 13 and 14, the signals of the sensors that make up these systems, as time functions, are shown in figure 15. By studying the behaviour of the sensors in the composition of the active safety systems, one can estimate very precisely the behaviour of the vehicle blown up in different driving scenarios.

![Figure 15. Specific sensors signal in the previous CCRm simulation.](image)

4. Discussions and conclusions
The Autonomous Emergency Braking System, Forward Collision Warning, and Dynamic Brake Support system appeared in the construction of the vehicles approximately in 2010. They can be considered as basic components of the Active Safety concept and, in a broader perspective, provide basic functions for future autonomous vehicles. Initially, these systems were mounted on more expensive cars and the added safety offered by them began to be quantified in the overall score by Euro NCAP in 2013.

In order to determine the efficiency of these Euro NCAP safety systems, additional data manufacturers for new vehicles need to comply with: “Data shall be provided for each grid point according to the following color scheme for AEB City (CCRs 10-50km/h) and for AEB Inter-Urban (CCRs 30-80km/h & CCRm 30-80km/h):” see figure 16 [8].

Given that the test protocols in [8] appeared in 2017 and that, together with the data example requested in figure 16, refers to new vehicles, it is clear that older vehicles may face problems if they are tested according to CCRs, CCRm and CCRb scenarios. imposing the performances described in figure 12. From the point of view of this scientific paper, the compliance of the active safety systems with the requirements imposed by the test scenarios can be obtained also for older vehicles by
studying the behaviour of the sensor systems, experimentally, and theoretically by simulation with the tools here presented.

\[ \text{Figure 16. Manufacturer required provided data example for the Euro NCAP Secretariat with colour to detailing the performance of the vehicle in the CCRs and CCRm scenarios for all overlap and impact speed combinations [8].} \]

In respect of the cited references, taking into account the theoretical and experienced activities presented in this paper, the following conclusions can be drawn:

1. The Autonomous Emergency Braking System, Forward Collision Warning, and Dynamic Brake Support are modern features that ensure a necessary passage to the autonomous vehicle;
2. Necessary, in the case of vehicles with monitored driving, Forward Collision Warning system will probably disappear or turn into a software warning when it comes to unattended autonomous vehicles;

3. By examining the behaviour of the three Active Safety systems in little aged motor vehicles, you can highlight the influences of age-related wear and tear on the behaviour of cars in CCRs, CCRm and CCRb scenarios;

4. The experimental test of the three vehicles according to the scenarios of CCRs, CCRm and CCRb are not made for the strict validation of a certain norm and standards that do not yet have validity on the production of the respective data of vehicles but to verify a certain level of beneficial use for the occupants of the tested vehicles;

5. The authors, in the tests did not intend to make a comparison between the three vehicles, even the determination regarding the TTC (Time To Collision) being only indicative, with no prerequisites for a rigorous technical comparison between the tested vehicles;

6. The use of software tools to simulate CCRs, CCRm and CCRb scenarios allows for fine-tuning of the various influences on Autonomous Emergency Braking, Forward Collision Warning, and Dynamic Brake Support systems;

7. Using the Active Safety system configuration systems from PC Crash 12.1 [9], very similar to those existing in MATLAB SIMULINK, you can configure the Active Safety characteristic sensors in detail (for example values for distance range, angle range, cycle time as in figure 12);

8. A very useful adjustment of the interactions between the data / signals of the various sensors can be obtained using the menu Diagrams / Sensors Signals available in PC Crash 12.1, as can be seen from figure 15.

5. References

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