Study regarding the influence of passive safety systems on the occupant in the case of Automatic Emergency Braking System activation

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Abstract. The aim of this paper was to analyze the injury level of the occupants of a vehicle in the case using the AEB system to reduce the velocity of a front-back collision by utilizing virtual simulations in PC-Crash software. This was achieved by conducting simulation at different velocities and 3 passive safety systems configurations. The velocities tested were 70, 75 and 80 km/h to observe the speed reduction of the vehicle in a collision by the AEB system. Also, the occupant was configured in 3 types of scenarios, when the occupant does not have the seatbelt or airbag, when only the seatbelt is used and when both seatbelt and airbag are activated. The results revealed a great speed reduction by the AEB system, reducing the impact velocity and also the occupant presented a reduced injury risk when both passive safety systems are active.

1. Introduction

The AEB (Autonomous Emergency Braking) is a system introduced in 2011 by Volvo that utilises an array of sensors, radars and cameras in order to avoid a collision by braking the vehicle automatically [1]. After the system was introduced, more and more automakers install these type of systems on their vehicles in order to actively assist drivers in avoiding hazardous traffic situations [2]. The first 2 generations of the system introduced by Volvo were able to detect pedestrians and partially brake the vehicle with a deceleration of 5 m/s2 [3]. Studies show that the AEB system can reduce the speed before impact with 10% and 30% the risk of fatal injuries [4]. The AEB system is very useful and will be used in future fully autonomous vehicles where there will not be needed a human driver [5]. A statistic study shows that front-back collisions count as 63% of the total accidents on the road [6]. The AEB can be inserted into the ACC (Adaptive Cruise Control system). This system is also successful in assisting the driver in avoiding collisions on the highway by maintaining a reasonable distance between the vehicle and the vehicle in front at velocity [7]. The main core of a system designed of mitigating a collision is a situational awareness and risk assessment in case of an obstacle and predict a minimal distance necessary for stopping/or avoiding the collision [8, 9, 10]. This paper wants to analyze the functionality of the AEB system using the PC-Crash module software by simulating a vehicle to vehicle collision and also a MADYMO occupant model to simulate the movement inside the vehicle compartment.

In order to assess the injury level of the occupant, the head injury criteria were used. This is calculated using the following formula [11]:

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t1}^{t2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} \tag{1}$$

Where a is the head acceleration, measured in m/s2 and t1 and t¬2 , measured in seconds, represent the interval time in between the HIC formula is calculated and has the maximum value. Also it is to mention that HIC is dimensionless.
HIC values can be correlated with the AIS (Abbreviated Injury Scale) in order to assess the injury level of the occupant. The AIS scale is a system of assessing the injury potential of the occupant or pedestrian in the form of category level of injury, ranging from 1 to 6, where 1 represents minor injury and 6 represents death. The scale is represented in figure 1 [12].

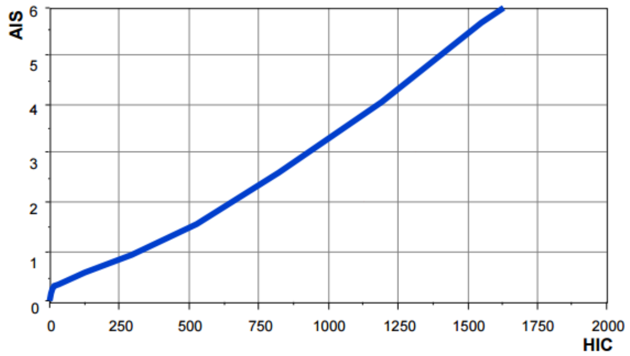

Figure 1. Correlation between HIC and the AIS scale.

2. Methods

The aim of the study was to analyze the active and passive systems of the vehicle to determine their influence on the injury level of the occupant by simulating a front-rear collision scenario at different speeds in which the autonomous braking system is activated using the PC Crash program and the MADYMO module. The study speeds were 70 km/h, 75 km/h and 80 km/h respectively. The chosen speeds are in line with the EuroNCAP for AEB tests, where the maximum speed is 80 km/h [13].
The test scenario consisted of the positioning of 2 vehicles at a distance of 20 m, one is stationary, and the second being imposed speed of movement. The scenario is shown in figure 2.

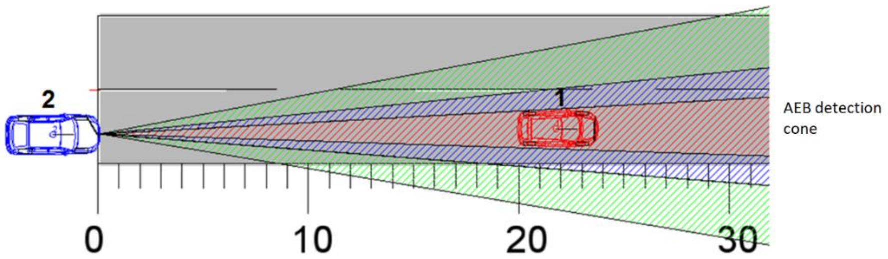

Figure 2. AEB simulation scenario in PC Crash.

In the simulation, vehicle 1 was stationary, positioned 20 m from the vehicle 2 which was in motion. The green detection cone, which is the basis for the operation of the AEB braking system, has been determined. The green cone is the hazard identification radar to inform the driver of imminent threats. The blue cone is the hazard detection and initial braking, and the red cone is secondary braking to avoid a collision. The AEB program uses a logical system scheme` to configure the braking system autonomy. Various parameters for modifying AEB system behavior can be configured in the operational schematic. The primary element of the system is the distance sensor based on simulation data (vehicle speed and distance from the front obstacle). Thus, using said data, the system decides the degree of braking of the vehicle by issuing the signal to the braking system. At the same time, it issues the audible warning signal to the driver to warn him of the imminent danger. In figure 4 the variation of the study speeds of the vehicle is presented under the conditions in which the AEB system is active.

3. Results

The initial result is the velocity variation for the tested scenarios as presented in the next figure.

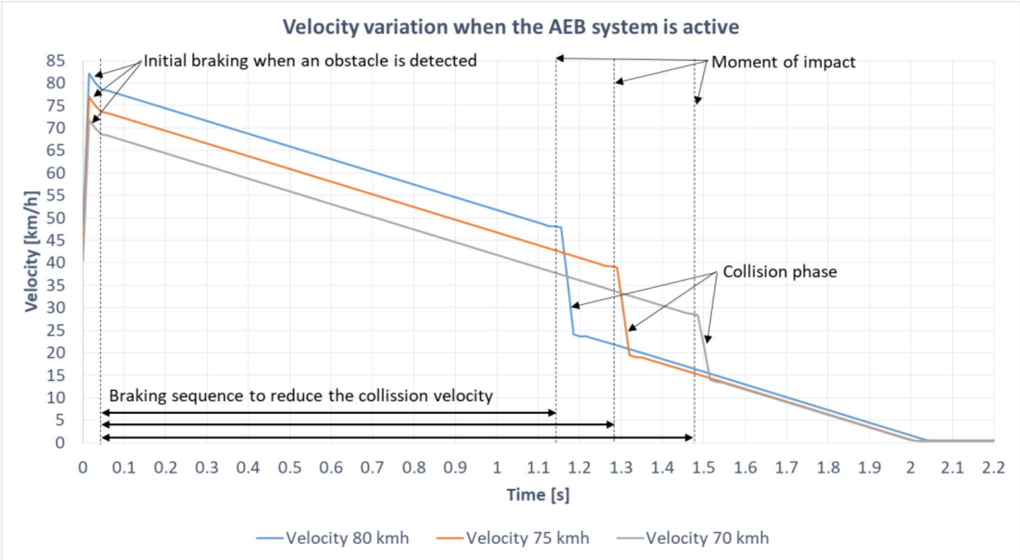

Figure 3. Variation of vehicle speed with active AEB system.

In the first phase, due to the small distance between the vehicles, the AEB system initiates a slight brake due to the detection of the first vehicle, followed by secondary braking to reduce the collision speed.

In table 1 the study rates and the percentage reduction of the collision velocities for the respective cases are presented

Table 1. Percentage reduction of collision rate depending on the speed of study.

Initial velocity [km/h]	Braking time [s]	Collision velocity [km/h]	Speed reduction [%]
70	0.5 – 1.48	28	60
75	0.5 – 1.3	40	47
80	0.5 – 1.15	50	38

The data obtained showed that the AEB system reduced the collision speed by up to 60%, from an initial speed of 70 km/h to 28 km/h. Following the trend in the operation of the AEB system, it was noted that the possibility of reducing the impact speed decreases with the increase in the initial speed of the vehicle. After obtaining the front-end impact data with the active AEB system, it was desired to determine the occupant's injury level by running the MADYMO program and performing 3 simulations for each study speed. In figure 5 the collision phases with an occupant without passive safety systems is presented.

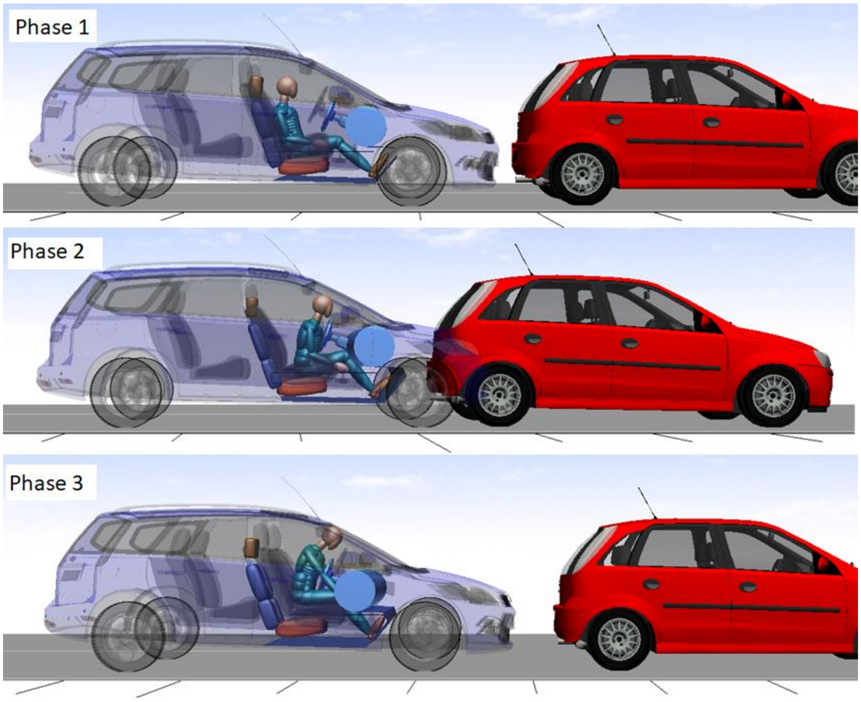

Figure 4. Phase collisions of vehicles with MADYMO occupant without passive systems.

Phase 1 represents the time before the collision, where the occupant was in the normal seat position. Phase 2 is the collision phase where the occupant came in contact with the vehicle dashboard. In Phase 3, the vehicles were detached with the occupant's body rebound towards the seat.
In the next phase simulations were performed using the MADYMO module in which three situations were analyzed:

- The occupant is not retained in the seat;
- The occupant is retained by the seat belt with the pre-tensioning system;
- The occupant is retained by the seat belt and the airbag.

Data from the comparative analysis served to determine the degree of injury by calculating the head injury (HIC) criterion. Thus, in figure 6 the HIC36 diagram for the established situations is presented. In table 3 the maximum HIC criteria for the studied cases are presented.

Table 2. HIC for the tested velocities.

Velocity [km/h]	Passive safety systems (airbag and seatbelt)	Maximum HIC value
70		110
75	NO	150
80		215
70		9
75	YES	3
80		19

Based on the calculated maximum values of the HIC criterion, they correlated with the AIS injury scale. Since the HIC values are relatively small (less than 200), on the AIS scale it is considered minor injury (AIS-1). In figure 7 the probability of minor injury (AIS-1) was calculated.
From the diagram analysis we can see that the probability of injury increases with the speed of the vehicle in the absence of passive safety systems. In table 3 the probability injury is presented.

Table 3. Likelihood of occurrence of injury depending on the value of the HIC criterion.

Velocity [km/h]	Passive safety systems	Probability of minor injury (AIS -1) [%]	Reduction of the injury level by using passive safety systems [%]
70		37	0
75	NU	50	0
80		72	0
70		3	34
75	DA	1	49
80		6	66

The results of the study highlighted the effectiveness of safety systems in reducing head injury by up to 66% at 80 km/h.

4. Conclusions

The study of the influence of the autonomous braking system (AEB) has been concluded with positive results, so there was a significant reduction by up to 60% of the collision speed in the case of the front-and-rear impact. A tendency to increase the likelihood of injury of the AIS-1 occupant was observed, in the absence of passive safety systems, with increasing travel speed, from 37% to 72%. If passive safety systems (belt and airbag) are present, the probability of injury falls below 7%.

5. References

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