

SAFETY EVALUATION OF AUTOMATED VEHICLES THROUGH ACTUAL VEHICLE TESTS IN CUT-IN AND OFFSET CUT-IN SITUATIONS.

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ABSTRACT

This paper describes the safety assessment results of level 2 automated vehicles in cut-in and overlap cut-in collision situations. The test results were compared with typical rear-end and 50% overlap rear-end collisions. From analysis of NASS CDS data, cut-in rear-end accidents occur at a rate of 25% out of rear-end accidents. The cut-in and 50% overlap cut-in situation were tested for the evaluation of level-2 automated vehicles. Main parameters of the cut-in scenario are speed of vehicles, TTC(Time to collision) and TLC(Time to lane changing). The speed of vehicles for scenario composition was selected from NASS CDS data analysis. The speed of the vehicle target was selected at 20km/h. The speed of the VUT(Vehicle Under Test) consisted of 5 types: 30, 40, 50,60 and 70 km/h.

Cut-in scenarios were designed with TTC 4 seconds and the target vehicle changes the lane to the front of the test vehicle at each TTC. The target vehicle's TLC was set to 2 seconds at all scenarios. For comparison, rear-end collision and 50%-offset rear-end collision scenarios suggested by EuroNCAP 2018 were also tested. A low platform robot vehicle target was utilized for all test scenarios. The low platform robot vehicle and a balloon dummy were used to imitating the causative vehicle in the accident and reproduce the accident situation. The robot vehicle target and the VUT were communicated with their position, speed, and acceleration data from GPS INS data. The data were recorded for further analysis.

OVERVIEW

The driver had to take risks such as personal and financial damages while driving the car. Various legal, institutional, and technical measures have been put in place to reduce the risk, and now it is possible to use safe and convenient vehicles based on the development and dissemination of autonomous vehicles.

In particular, the development and emergence of autonomous vehicles and assistive technologies are expected to prevent or reduce the risk of automotive crashes occurring at present. As a result, the demand for the development and distribution of safer autonomous vehicles is getting lighter, and the interest of the users is increasing. In response to this trend, the New Car Assessment Program (NCAP) urged developers of autonomous vehicles to upgrade their safety in accident situations.

However, the current NCAP standards are not a standard for dealing with various accidents that may occur on the current roads. In particular, among the functions of the autonomous vehicle, the evaluation criteria of AEB, which plays the most role in avoiding accidents in sudden accident situations, has a limitation that can be confirmed only for simple rearward collision situations. As the function of the autonomous vehicle increases, it is expected that the users will use the technologies more actively. Therefore, more rigorous safety of the autonomous vehicle is required and safety verification in various accident situations is required.

This paper identifies some of the AEB protocols provided by the NCAP, and develops real-world test scenarios for interrupt situations as a result of classifying dangerous accident situations that often occur on the roads. The AEB performance of the autonomous vehicle is conducted the actual vehicle experiment for the safety evaluation safety.

METHODS

Building of Scenario

Accident data analysing: NASS CDS data was analyzed for five years from 2100 to 2015. 2,633 cases in 2015, 2,896 cases in 2014, 3,385 cases in 2013, 3,581 cases in 2012, and 4,278 cases in 2011. The data were classified and analyzed according to the type of accident. More than 40 types of accidents type was classified by NASS CDS. It was classified into single vehicle accident, rear-end collision, cut-in rear-end collision, frontal collision and side collision..... As a result, shown in the Fig.1, the ratio of single vehicle accident was the highest at 36%, side collision was the second at 31%, rear-end collision and head on collision occupied at the third and fourth, with 5% of ratio.

Especially, when the type of accident was classified as rear-end collision, cut-in collision accounted for about 22% of the total rear collision. As a result of checking the ratio of AIS injuries according to the accident situation, the ratio of injury severity of simple collision accident to intervention collision was similar.

Through the results of the accident DB analysis, it can be seen that the rear-end collision is the most important accident type, which is the type of accident that is already evaluated through the NCAP protocol. However, the NASS CDS DB analysis shows that the rate of interruption in the collision is about 1/4, and the degree of injury in the case of interruption shows a similar tendency to the general collision.

Therefore, it is necessary to confirm the AEB performance not only in a simple rear-end collision situation but also in a cut-in rear-end collision situation. Considering the AEB test Protocol proposed by 2018 Euro NCAP, the cut-in collision scenario and 50% offset cut-in collision scenario were constructed according to the following procedure.

Set parameters for scenario configuration: Main parameters of the cut-in scenario are speed of vehicles, TTC(Time to collision) and TLC(Time to lane change). The parameters were determined by analyzing the results when an accident occurred. The speed of each vehicle was selected by referring to the results of NASS CDS accident database. TTC and TLC were selected by analyzing images acquired from dashboard camera image.

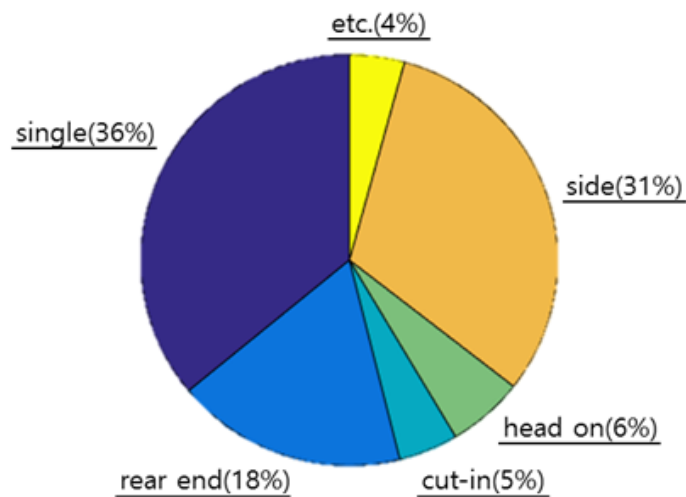


Figure 1. The frequency by accident type.

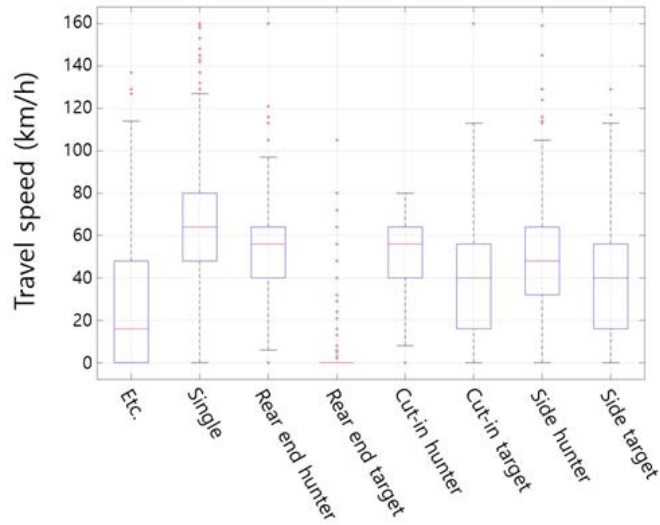


Figure 2. Velocity distribution by accident type (Public roads:Speed limit less than 80 km/h)

In the case of the target vehicle, 50% of the vehicles are present in the range of 20 to 50 km/h and the median value is 40 km / h. The speed of the target vehicles are present in the range of 20 to 40 km/h and the median value is 40km/h. TLC is selected by dashboard camera images in Korean intervention situation. In a total of 63 dashboard camera image data, it was confirmed that the average TLC in an accident situation was 1.85 seconds. It is difficult to determine when to start a cut-in from the black box images or accident DB analysis results. Therefore, the time to start cut-in was arbitrarily selected. Based on the results of the pre-test in one vehicle, the time to start cut-in was selected as TTC 4 seconds. That is, according to the constructed scenario, the time remains 2 seconds for the VUT to collide with the target vehicle when the cut-in complete. Based on these analyzed parameters, the following scenario table is constructed.

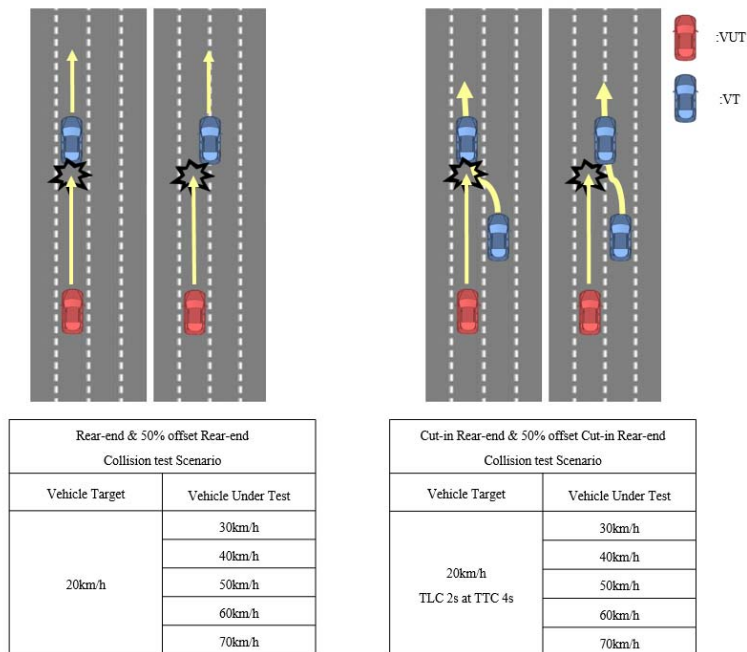


Figure 3. Scenario Table for AEB collision test

Development of Testbed

Low-platform robot vehicle target: In the Euro NCAP protocol, the EVT(Euro NCAP Vehicle Target) used for the AEB test is a pile that shapes the rear-end collision of the vehicle, and serves as a forward vehicle in test such as rear-end collision. In case of EVT, it is not suitable for scenario that requires path following function because it is mounted on a rail or connected with a preceding vehicle. Therefore, a robot vehicle target capable of performing in various scenarios was designed.

In the case of robot vehicle target, it is necessary to be able to perform not only the rear collision test used in the existing NCAP test but also the forementioned cut-in scenario. In addition, in order to be able to repeat the experiment, the robot vehicle was designed so that the equipment, the VUT, and the experimenter would not be damaged or injured in the event of a collision due to the VUT not responding to the accident situation.

RVT (Low-Platform Robot Vehicle Target) was designed as a robot vehicle target. From the developed scenario, the maximum relative speed of VUT and RVT is 50km / h. It should be designed so that the test system is not damaged even if it collides at this speed. The height of the lower part of the vehicle differs by vehicle type, but the legal minimum ground height in Korea is 110mm. As a result, the height of the RVT is limited to 90 mm. In order to carry out the scenario, The RVT equipped with a dummy model is designed to be able to travel at a maximum speed of 40 km/h and change lanes 3.5m within 2 seconds. The RVT and the VUT had configured communication systems to accurately measure each position and transmit data to each other. The type of data to be transmitted is the position, speed, and acceleration information of the vehicle. These data are also the main analytical elements obtained from the experimental results. It is confirmed that the vehicle and RVT were not damaged even when the vehicle stepped over at a speed of 60 km/h, and the RVT travel at a maximum speed of 60 km/h equipped with a dummy model.

3D balloon dummy: The VUT does not recognize the RVT as a vehicle. Therefore, a balloon dummy model should be mounted on the RVT. In the case of such a dummy model, The VUT must be able to recognize the dummy as a real vehicle when sensing the vehicle ahead with a radar or a camera. It should also not damage the VUT in the event of a collision.

As shown in the Figure 4 below, a 3D dummy model was created to have the shape of the actual vehicle using a balloon to minimize the impact quantity when colliding. The 3D balloon dummy was verified using a radar system. The radar used in the verification uses radio waves in the 24 GHz band. The verification method was evaluated by comparing the radar reflectance of the actual vehicle with the radar reflectance of the balloon target pile. Also, we confirmed that the target dummy was recognized as a vehicle by using the vehicle equipped with the actual AEBS.

The AEBS vehicle ran at more than 30 km/h with the balloon target pile up and checked whether there was a warning in the vehicle. The test results confirm that the head-up display gives a vehicle crash warning as shown in the Figure 5. This result shows that AEBS is recognized as a vehicle and can be used for testing.



Figure 4. Shape of Balloon dummy car



Figure 5. AEBS warning test of 3D balloon dummy car

ACTUAL VEHICLE TEST

An actual vehicle test was conducted on the scenarios developed using a real vehicle equipped with an AEB. Each of the scenarios was tested three times and the AEB operation and collision were observed. In case of collision, the velocity at the time of collision was observed. In case that a collision did not occur the minimum approach distance was observed. In addition, the deceleration of the vehicle caused by the AEB was also analyzed.

Scenario Test Results

Test Results: The AEB collision test scenarios shown in Figure 3 was repeated twice for each scenario. The results of the actual vehicle tests are summarized in Table 1. Based on the experimental speed of VT and VUT, it is classified into the items according to the scenario. The classified scenarios are Rear-end, Cut-in, 50% Offset Rear-end, and 50% offset cut-n. If there is no collision, 'no collision' is indicated and the minimum distance is indicated at the bottom. In case of collision, 'collision' is indicated and the speed of collision is indicated at the bottom. In case that a collision did not occur in the actual vehicle experiment, the relative distance when the VUT was closest to the VT was measured. When a collision occurs, the relative velocity of the VUT and VT at the moment of collision is measured.

In the 10 tests with five rear-end collision scenarios, AEB was operating normally and did not crash. VT was very close to the VUT, but it was observed to avoid collision with a maximum of 3.11m margin. Therefore, in the simple rear-end collision situation proposed by the Euro NCAP, the present AEB function shows good performance.

In the 50% offset rear-end collision scenario, one collision occurred when the VUT speed was 70 km/h, but in all cases the AEB was operating normally. As the speed increases, the AEB fails to avoid one collision to the increased difficulty level, but still shows good performance. Also, It has been confirmed that if the AEB of the VUT is operating normally, it will defend the collision situation.

As a result of the general cut-in collision test scenario, five collisions occurred in 10 tests. The AEB response was delayed in all five crashes, which is the main reason for not recognizing the vehicle that changed the lane in the next lane. Likewise, it has been confirmed that the detection performance of the vehicle coming in the next lane is considerably deteriorated in the collision situation in which the AEB must respond.

Table 1. Scenario test results of vehicle test

VT	VUT	Rear-end		Cut-in	
		No Collision (Minimum relative distance) Collision occurred (Relative impact speed)			
20km/h	30km/h	No Collision 2.12	No Collision 2.58m	Collision 11.26km/h	Collision 11.29km/h
	40km/h	No Collision 3.11m	No Collision 2.96m	No Collision 6.02m	No Collision 9.95m
	50km/h	No Collision 1.06m	No Collision 0.58m	No Collision 0.06m	No Collision 12.99m
	60km/h	No Collision 1.44m	No Collision 2.06m	Collision 38.52km/h	Collision 39.20km/h
	70km/h	No Collision 0.15m	No Collision 0.06m	No Collision 0.78m	Collision 42.56km/h
VT	VUT	50% offset rear-end		50% offset Cut-in	
20km/h	30km/h	No Collision 3.14m	No Collision 1.31m	Collision 10.8km/h	Collision 7.19km/h
	40km/h	No Collision 1.58m	No Collision 1.45m	No Collision 0.70m	Collision 8.84km/h
	50km/h	No Collision 1.12m	No Collision 1.41m	Collision 2.49km/h	Collision 8.52km/h
	60km/h	No Collision 1.13m	No Collision 1.44m	Collision 18.3km/h	Collision 17.8km/h
	70km/h	Collision 9.83km/h	No Collision 1.14m	Collision 21.1km/h	Collision 19.7km/h

CONCLUSIONS

Experimental results show that level 2 automated vehicles have a lack of ability to avoid a crash in cut-in collision situations. 2018 Euro NCAP's proposed AEB test protocol scenarios did not have good response capabilities in a barrage situation, even for vehicles with good performance.

In some cases, the VUT did not detect the vehicle target so it strikes target without any deceleration. The sensor seems to detect only the same lane of the vehicle not for its side lanes.

In view of the injury analysis results, the current AEB performance alone does not seem to prevent any serious injury to the driver in the event of interruption.

The cut-in and 50% offset cut-in experimental scenarios were constructed from the actual accident. Four types of vehicle tests were conducted and test results were analyzed. In each scenario, relative speed and deceleration were analyzed. The safety performance for an automotive vehicle in cut-in rear collision situations was evaluated. Further studies on safety assessments in various test scenarios are needed in order to validate the safety performance of automated vehicles.

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