Simulation of AEBS Applicability by Changing Radar Detection Angle

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Abstract: As smart cities become a global topic, interest in smart mobility, the core of smart cities, is also growing. The technology that comes closest to general users is “autonomous driving”. In particular, the successful market entry and establishment of some private companies proved that “autonomous driving” is not technology of the future but imminent reality. However, safety in autonomous vehicles that rely on sensors instead of the driver’s five senses has been the focus of attention from the beginning and continues to be so. In this study, we attempted to counter this interest. Based on the actual data of thirty traffic accidents, assuming the AEBS (Autonomous Emergency Braking System) was installed to assist the driver in safe driving, it was reinterpreted through simulation to see what changes occurred in the accident. In the computer program, PC-Crash, the results were first analyzed through simulation using Euro NCAP (New Car Assessment Program)’s AEBS test standards. Subsequently, the other variables in the AEBS were controlled and the accident was reinterpreted by changing only the angle of the radar detection sensor. As a result, it was confirmed that a total of 27 accidents out of thirty accidents could have been prevented with the AEBS. In addition, it proved that the crash avoidance rate of vehicles gradually increased as the radar angle increased.

Keywords: traffic accident; ADAS; AEBS; PC-Crash; simulation

1. Introduction

Many traffic accidents occur every day in Korea. According to the TAAS (Traffic Accident Analysis System), the national traffic accident statistics system in South Korea, of the types of accidents in 2019, rear end or side crashes accounted for 20% of all accidents, and accidents at pedestrian crossings accounted for 39% of all fatalities [1]. Technology development in the field of the AEBS (Autonomous Emergency Braking System) has been actively conducted to cope with such accidents. Looking at the technology’s global trend, the Euro NCAP (New Car Assessment Program) added the AEBS to the NCAP evaluation items in 2014, and to receive the “Best Rating”, it is necessary to receive a “GOOD” rating in all collision safety evaluation criteria, and a collision avoidance device should also be mounted. In addition, since 2015, the European Union has decided to equip AEBS for commercial vehicles operating long distances [2]. According to the Euro NCAP and the NHTSA (National Highway Traffic Safety Administration), AEBS-equipped vehicles have reduced traffic accidents by about 38% when operated on low-speed highways, and traffic accident insurance claims have also decreased by about 35%, making AEBS an effective system for reducing traffic accidents [3,4]. A study has been carried out suggesting the importance of safety device development through an in-depth analysis of more than 2000 traffic accidents acquired from Germany’s GIDAS (Germany In-Depth Accident Study) database [5].
For reference, the international effort for standardization related to the database for in-depth analysis of traffic accidents is IGLAD (Initiative for the Global Harmonization of Accident Data), and in 2010, FISITA (The International Federation of Automotive Engineering Societies) also began building a traffic accident database. ACEA (European Automobile Manufacturers Association) is conducting cooperative research with the International Automobile Federation. Currently, countries such as Germany, the United States, Spain, India, Austria, and Poland are actively participating in R&D, putting forth effort to build a traffic accident database system that will help in developing safety devices that prevent traffic accidents [6].

Regarding the development of safety devices based on traffic accident analysis, Kim et al. [7] applied a Korean traffic accident database to a European traffic accident database system, and then proposed a method to utilize the traffic accident database in developing safety devices through in-depth analysis.

Jang et al. [8] established a system for evaluating the AEBS and conducted the evaluation using real vehicles. By using the evaluation system in accordance with international standards, the situation that occurred on the road was organized into a systematic scenario to establish the performance and safety evaluation method of the AEBS. After comparing the results obtained by applying the AEBS to the PC-Crash program using the pedestrian traffic accident data and the actual experimental results using the pedestrian dummy, the collision avoidance or collision mitigation performance of AEBS, Vertal and Steffan verified the safety of AEBS [9].

The purpose of this study was to analyze the effect of the AEBS and radar angle on collision avoidance by using a PC-Crash simulation based on the traffic accident database (ACCC). This kind of simulation approach to evaluate sensor-based safety systems based on a national traffic accident database has been the current practice for many years [15].

Complementing the PC-Crash simulation results, the data used include the date, type, and location of the accident. Additional data used include a photo of the vehicle damage, the specifications of the vehicle, speed, braking, tire size, injury to the occupant and pedestrian, accident description (if any), and so forth. This data set was named ACCC (Automotive Collision Case Catalog).

2. Preparation of Simulation

In this study, the following system was used to apply AEBS to the PC-Crash program based on the traffic accident database (ACCC).

2.1. AEBS Configurations

AEBS is one of the safety devices of the ADAS (Advanced Driver Assistance System) that is expected to effectively reduce traffic accidents. As shown in Figure 1, after monitoring the road conditions, AEBS ① measures the distance to the front object, ② informs the driver of a collision when the distance to the front object approaches, and ③ when the driver does not brake despite the warning, it automatically brakes to avoid collision or mitigate impact. For this, AEBS is equipped with a camera sensor and a 77 GHz radar sensor, as shown in Figure 2.

The camera detects whether the front object is a vehicle, a pedestrian, or a structure; the radar measures the distance to the front object, and the ECU determines if control is necessary and brakes using an actuator. Figure 3 shows the algorithm for AEBS operation [10].
Here, TTC (Time to Collision) represents the collision time as the ratio of the relative speed and the relative distance between the target vehicle and the front vehicle, and \( \text{TTC}_{\text{min}} \) represents the minimum time at which collision avoidance is possible as the ratio of the relative speed and the braking distance between the two vehicles (see Equations (1) and (2)). The core of the algorithm is that the brake is activated when \( \text{TTC} \) is less than \( \text{TTC}_{\text{min}} \) when comparing them.

\[
\text{TTC (sec)} = \frac{\text{Relative Distance}}{\text{Relative Speed}} \tag{1}
\]

\[
\text{TTC}_{\text{min}} \text{ (sec)} = \frac{\text{Braking Distance}}{\text{Relative Speed}} \tag{2}
\]
Table 1 summarizes the specifications of radar sensors used as conditions for simulation in this study. Since the maximum detectable distance of radars varies from 100 m to 200 m, for this study, we fixed the detectable distance as 100 m, and increased the detection angle by ±2° from a minimum ±4° to a maximum ±10°.

| Maker          | Fujitsu | ADC  | Delphi | Bosch | Honda Elesys | Denso | Hitachi | Mando |
|----------------|---------|------|--------|-------|--------------|-------|---------|-------|
| Image          | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) | ![Image](image4.png) | ![Image](image5.png) | ![Image](image6.png) | ![Image](image7.png) | ![Image](image8.png) |
| Detectable Distance (m) | ≤120 | ≤150 | ≤150 | ≤120 | ≤100 | ≤150 | ≤150 | ≤200 |
| Detectable Angle (°) | ±8 | ±5 | ±5 | ±4 | ±8 | ±10 | ±8 | ±10 |

2.2. Application of AEBS

The program used for simulation with AEBS is PC Crash Version 11.0. This is a rigid body collision analysis program that is widely used to describe the situation before and after a vehicle collision in a traffic accident analysis process. It is possible to implement various vehicle data and road environments, and therefore, it can construct many traffic accident scenarios. The basic collision model in PC-Crash is a two- and three-dimensional model of momentum and is based on Newton’s Law of Conservation of Momentum [11].

In this study, the active safety function of PC-Crash was activated as shown in Figure 4 for the AEBS application. Each block of this function is formed in visual basic, so it can be easily modified through coding. It can be used as an algorithm for the AEBS by modifying the detection distance and detection angle in the Distance Sensor Block and passing it to the EmBrake Block.

![Figure 4. Active safety function of PC-Crash.](image9.png)
2.3. AEBS Simulation Scenario

Before applying the actual traffic accident database and AEBS, a pre-simulation was performed to check the suitability of PC-Crash’s Active Safety function. Specifically, as shown in Figures 5–7, simulations were conducted using a total of three situations to meet Euro NCAP’s AEBS scenario conditions [12,13]. Figure 5 was a low-speed test scenario, named as an AEBS city scenario, in which the test vehicle approached the speed of $V_0$ to the black target vehicle stopped on the right side.

![Euro NCAP Test Method for AEB City](image)

**Figure 5.** AEBS City Scenario of Euro NCAP Test Method.

![Euro NCAP Test Method for AEB Inter-Urban](image)

**Figure 6.** AEBS inter-urban scenario of Euro NCAP (New Car Assessment Program) test method.

![Euro NCAP Test Method for AEB VRU-Pe](image)

**Figure 7.** AEBS VRU-Pe scenario of Euro NCAP test method.
Figure 6 shows the AEBS Inter-urban scenario, which is further classified into three categories. First, CCRs (Car to Car Real stationary) is the same as the AEBS City test, where the target vehicle is stationary, and the test vehicle’s speed runs at medium and high speeds. Second, CCRm (Car to Car Real moving) is a condition where the target vehicle proceeds at a constant speed of 20 km/h. Third, in the case of CCRb (Car to Car Rear braking), the distance between the test vehicle and the target vehicle is fixed at 12 m and 40 m, and the two vehicles proceed at the same speed of 50 km/h, and the target vehicle decelerates at \(2 \text{ m/s}^2\) and \(6 \text{ m/s}^2\). It is a condition for braking on the road.

Figure 7 is a summary of the pedestrian test scenario (VRU-Pe; VRU stands for Vulnerable Road User) and is further classified into three categories. First, the CVFA (Car to VRU Far side Adult) is a scenario in which an adult pedestrian dummy collides with the center of a test vehicle at 50% of the width while approaching at a speed of 8 km/h from the opposite lane. Second, CVNA (Car to VRU Nearside Adult) 25% and 75% are scenarios in which an adult pedestrian dummy approaches 5 km/h in the direction of the test vehicle and crashes at 25% and 75% of the vehicle width. Third, CVNC (Car to VRU Nearside Child) is a scenario where a child’s pedestrian dummy approaches the vehicle at a speed of 5 km/h and collides with the center of the vehicle width by 50% after suddenly appearing from around two vehicles stopped in front of the test vehicle.

The dimensions of the adult dummy and the child dummy are shown in Figures 8 and 9. Here, the specification of the pedestrian dummy was based on the Euro NCAP standard [13], and the test vehicle was simulated with the specifications of Hyundai Motor Co.’s Sonata, the most sold vehicle in Korea in 2016.

**Figure 8.** Euro NCAP adult pedestrian target.

**Figure 9.** Euro NCAP child pedestrian target.
3. Results and Discussion

Figures 10–12 show the simulation method of PC-Crash for the three AEBS scenarios (City, Inter-Urban, VRU-Pe). For reference, a test vehicle is located on the left side of the picture, while a target vehicle and target pedestrian pile are located on the right. In this study, 71 scenarios were created by increasing the speed of the test vehicle in 5 km/h increments according to the Euro NCAP AEBS test standards [12,13]. A total of 284 total scenarios were constructed by changing to 4 km/h increments, meaning that the number 284 came about by multiplying 71 times 4. However, not all of them can be shown here. Only the three AEBS scenarios (City, Inter-Urban, VRU-Pe) are shown. Tables 2–4 show the simulation results.

**Figure 10.** Euro NCAP city scenario.

**Figure 11.** Euro NCAP inter-urban scenario.

**Figure 12.** Euro NCAP VRU-Pe scenario.
Table 2. AEBS city scenario results.

| Speed (Km/h) | Radar Angle (°) | 4 | 6 | 8 | 10 |
|--------------|----------------|---|---|---|----|
| 10           | ○              | ○  | ○ | ○ | ○  |
| 15           | ○              | ○  | ○ | ○ | ○  |
| 20           | ○              | ○  | ○ | ○ | ○  |
| 25           | ○              | ○  | ○ | ○ | ○  |
| 30           | ○              | ○  | ○ | ○ | ○  |
| 35           | ○              | ○  | ○ | ○ | ○  |
| 40           | ○              | ○  | ○ | ○ | ○  |
| 45           | ○              | ○  | ○ | ○ | ○  |
| 50           | ○              | ○  | ○ | ○ | ○  |

First, Table 2 shows the simulation results of the AEBS City Scenario by increasing the speed of the test vehicle from 10 km/h to 50 km/h in 5 km/h increments. Here, the ○ mark indicates that the test vehicle has stopped without colliding with the stationary target vehicle and thus has avoided collision, regardless of the radar angle and the speed of the test vehicle.

Table 3 shows the AEBS Inter-Urban scenario simulation results, and the notation of N/A (Not Applicable) means that it is irrelevant to the scenario. Most of the simulations for the three scenarios (CCRs, CCRm, and CCRb) were avoided, but in the case of CCRb, a collision occurred when the distance between the test vehicle and the target vehicle was 12 m and the deceleration of the target vehicle was 6 m/s². Table 3 also lists the test vehicle’s speed at the time of the crash. All four cases showed the collision speed of the test vehicle at 14 km/h when colliding with the target vehicle regardless of the radar angle but, considering the initial speed of the test vehicle (50 km/h), the speed was reduced by 72%. Therefore, it can be estimated that the shock has been alleviated.

Table 4 shows the pedestrian collision scenario (AEBS VRU-Pe) results and the different results, depending on the radar angle. In the CVFA scenario, the radar angles of 4° and 6° did not avoid pedestrian collision. In the simulation result for the CVNA 25% scenario, the notation X is indicated when the radar angle is 4°, which signifies that the test vehicle collided with the pedestrian, and the collision speed of the test vehicle was the same as the initial speed, indicating that the pedestrian was not recognized. Simulation results for the CVNA 75% scenario show that pedestrian collisions do not occur in all cases.

On the other hand, simulation for the CVNC scenario showed that a pedestrian collision occurs when the initial speed of the test vehicle is 50 km/h or less when the radar angle is 4°. Based on the simulation results, it was checked whether the traffic accident could have been prevented if the AEBS was applied at the time using the actual traffic accident database (ACCC).
### Table 3. AEBS scenario inter-urban results.

| Radar Angle (°) | Speed (Km/h) | CCRs | CCRm | CCRb |
|-----------------|--------------|------|------|------|
|                 | 4 6 8 10      | 4 6 8 10 | 4 6 8 10 | 4 6 8 10 |
| 30              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 35              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 40              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 45              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 50              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 55              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 60              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 65              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 70              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 75              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |
| 80              |              | N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A N/A | |

### Table 4. AEBS scenario VRU-Pe results.

| Radar Angle (°) | Speed (Km/h) | CVFA | CVNA | CVNC |
|-----------------|--------------|------|------|------|
|                 | 4 6 8 10      | 4 6 8 10 | 25%  | 75%  |
| 20              |              | 14 12 10 | x    | x    | 17   | 6    |
| 25              |              | 18 17 14 | x    | 23   | 21   | 11   |
| 30              |              | 24 21 17 | x    | 28   | 21   | 15   |
| 35              |              | 28 25 19 | x    | 33   | 19   | 15   |
| 40              |              | 33 29 18 | x    | 36   | 21   | 21   |
| 45              |              | 38 33   | x    | 34   | 22   | 22   |
| 50              |              | 42 35   | x    | 35   | 20   | 20   |
| 55              |              | 46 36   | x    | 36   | 20   | 20   |
| 60              |              | 51 34   | x    | 34   | 20   | 20   |
4. Applications of the AEBS to Actual Cases

Applications to Actual Cases

Figure 13 shows the result of applying the AEBS to an actual traffic accident case. Here, the upper figure shows the traffic accident that occurred without the AEBS, and the lower figure is the result predicted by simulation of how the outcome would have changed if the AEBS were applied to the actual accident.

Figure 13. Real Case 1 application of the AEBS.

The accident outline identified through the ACCC is one where a collision occurred when a southeast-bound vehicle did not see a pedestrian walking from a pedestrian crossing during the night until it was too late, and the pedestrian was struck by a vehicle. The driving speed of the vehicle was 46.5 km/h, and the collision speed was 28.9 km/h. A grid pattern circled in the top figure indicated the collision point. If the AEBS was applied to this accident, as shown in the figure below, with the detection distance of 100 m and the detection angle of 4°, the vehicle would have stopped completely before the collision point, so collision with the pedestrian would not occur.

The accident outline depicted in Figure 14 is an example of an eastbound vehicle crashing at a signal intersection while speeding (driving speed of 91 km/h), and a vehicle with a westbound left turn due to a signal violation (collision speed of 37.8 km/h). In this case, as shown in the figure below, after applying the AEBS with a detection distance of 100 m and a detection angle of 4°, it could be seen that the eastbound vehicle stopped safely before the collision point.

Figure 14. Real Case 2 application of the AEBS.
The outline of the accident in Figure 15 is one where a vehicle waiting in a left-turn lane suddenly changes lanes and collides with a vehicle driving in a through lane. The driving speed of the vehicle was 55 km/h and a collision speed of 44.3 km/h. In this case, it was also found that no accident occurred when the AEBS, with a detection distance of 100 m and a detection angle of 10°, was applied to the through vehicle.

![Figure 15. Real Case 3 application of the AEBS.](image1)

Figure 15 is an accident that occurred while the vehicle driving in the first lane turned into a left-turning pocket, and the vehicle driving in the second lane suddenly crossed both lanes into the left-turning pocket.

First, the vehicle’s driving speed was 30 km/h, and the collision speed was 29.7 km/h. In this case, even if the AEBS with a detection distance of 100 m and a detection angle of 10°, which prevented accidents, were applied, the collision speed was only reduced by 0.1 km/h. In the end, it shows that the AEBS considered in this study is not effective in accidents caused by lane changes. In a sense, this is intuitive as the vehicle is equipped with forward collision avoidance sensors and not with blind spot detection sensors. However, even in this case, considering the positions of the front and rear vehicles over time, if the angle is large enough, it is a condition that can involve the AEBS. Therefore, this case was simulated and resulted in a near-avoidance of the radar detection range.

![Figure 16. Real Case 4 application of the AEBS.](image2)
Table 5 shows the total of 144 simulation results applying the AEBS to 30 actual accident cases considered in this study. First, traffic accident types were divided into four categories: intersection collision, pedestrian collision, rear-end collision, and lane change. After applying the AEBS to both accident vehicles in one traffic accident case, the simulation was performed by changing the radar angle to 4°, 6°, 8°, and 10°. In Table 5, “N/A” indicates that it is meaningless to apply the AEBS to a vehicle or pedestrian in front of a collision in a rear-end collision or pedestrian collision. In addition, “SN” is the serial number of the traffic accident case, and “Vw/o” is the speed at the time of the collision estimated in the actual accident without AEBS. SN 12 is an interesting example of the fact that radar detection angles should not be ignored as a countermeasure to preventing traffic accidents. Looking at the results of SN 12 in Table 5, the collision speed gradually decreases as the radar angle increases, but an accident does not occur when the radar angle reaches 10°.

Table 5. AEBS results applied in real cases.

| Type            | SN | Vw/o (km/h) | Variable_1 | Vw/o (km/h) | Variable_2 |
|-----------------|----|-------------|-------------|-------------|-------------|
|                 |    |             | 4           | 6           | 8           | 10          |
| Intersection    | 1  | 48          | 47          | 46          | 46          | 45          |
|                 | 2  | N/A         | N/A         | N/A         | N/A         | 48          |
|                 | 3  | N/A         | N/A         | N/A         | N/A         | 91          |
|                 | 4  | N/A         | N/A         | N/A         | N/A         | 16          |
|                 | 5  | 47          | N/A         | N/A         | N/A         | 30          |
|                 | 6  | 20          | 13          | 14          | 14          | 10          |
|                 | 7  | 50          | 48          | 47          | 45          | 45          |
|                 | 8  | 18          | N/A         | N/A         | N/A         | 30          |
|                 | 9  | 22          | N/A         | N/A         | N/A         | 66          |
|                 | 10 | 35          | 27          | 27          | 26          | 26          |
|                 | 11 | 17          | N/A         | N/A         | N/A         | 43          |
|                 | 12 | 15          | N/A         | N/A         | N/A         | 60          |
|                 | 13 | 37          | N/A         | N/A         | N/A         | 40          |
|                 | 14 | 53          | N/A         | N/A         | N/A         | 67          |
|                 | 15 | 36          | 22          | 22          | 22          | 20          |
| Pedestrian      | 16 | 87          | N/A         | N/A         | N/A         | 6           |
|                 | 17 | 46          | N/A         | N/A         | N/A         | 5           |
|                 | 18 | 36          | N/A         | N/A         | N/A         | 6           |
|                 | 19 | 80          | N/A         | N/A         | N/A         | 8           |
| Rear-End        | 20 | 70          | N/A         | N/A         | N/A         | 15          |
|                 | 21 | 76          | N/A         | N/A         | N/A         | 0           |
|                 | 22 | 60          | N/A         | N/A         | N/A         | 0           |
|                 | 23 | 23          | N/A         | N/A         | N/A         | 67          |
|                 | 24 | 36          | N/A         | N/A         | N/A         | 22          |
|                 | 25 | 46          | N/A         | N/A         | N/A         | 40          |
| Lane Change     | 26 | 30          | N/A         | N/A         | N/A         | 30          |
|                 | 27 | 42          | N/A         | N/A         | N/A         | 25          |
|                 | 28 | 55          | N/A         | N/A         | N/A         | 44          |
|                 | 29 | 34          | 34          | 34          | 34          | 43          |
|                 | 30 | 27          | 27          | 27          | 26          | 26          |

Figure 17 shows the collision avoidance derived through the simulation when the AEBS is applied to the four types of traffic accidents summarized in Table 5.

In the simulation, in the case of pedestrian collision or rear collision, 100% of the accidents could be prevented by applying the AEBS. However, in the case of traffic accidents caused at intersections or by lane changes, it was found that it is difficult to obtain significant traffic accident prevention by applying the AEBS.

Based on these results, additional simulations were performed while increasing the radar angle by 1° up to 50° for traffic accidents that occurred at intersections since intersections record high accident rates in daily life. The results are summarized in Table 6 where the radar angle represents the detection angle that could prevent collisions through the simulation. In particular, Table 6 is the result of a separate simulation of only the intersection part of Table 5. If Table 5 shows the simulation results in the case of a radar angle of 4 to 10 degrees as this is a practical range for car makers, Table 6 shows the simulation results to see what extent the radar angle should be raised to actuate the AEBS, using 15 cases of
intersections presented in Table 5. In the case of 3, 12, 14, and 15, both 1st and 2nd vehicles showed the activation of the AEBS indifferent to other cases.

![Collision avoidance rate in a real case.](image)

**Figure 17.** Collision avoidance rate in a real case.

| Type          | Case No. | Radar Angle (°) |
|---------------|----------|-----------------|
| Intersection  | 1        | 12              |
|               | 2        | 18              |
|               | 3_Veh 1  | 4               |
|               | 3_Veh 2  | 4               |
|               | 4        | 4               |
|               | 5        | 13              |
|               | 6        | 25              |
|               | 7        | 24              |
|               | 8        | 25              |
|               | 9        | 23              |
|               | 10       | 29              |
|               | 11       | 25              |
|               | 12_Veh 1 | 29              |
|               | 12_Veh 2 | 50              |
|               | 13       | 39              |
|               | 14_Veh 1 | 18              |
|               | 14_Veh 2 | 10              |
|               | 15_Veh 1 | 50              |
|               | 15_Veh 2 | 12              |

In addition, Figure 18 shows the collision avoidance rate for each radar angle (class interval), which is summarized as a result of additional simulations. As expected, as the radar detection angle of the AEBS increases, the probability of preventing an accident also increases. For reference, when the radar detection angle is 50°, an intersection collision accident can be prevented 100% of the time.
using 15 cases of intersections presented in Table 5. In the case of 3, 12, 14, and 15, both 1st and 2nd vehicles showed the activation of the AEBS indifferent to other cases.

Table 6. Additional simulation results for intersections.

| Type       | Case No. | Radar Angle (°) |
|------------|----------|-----------------|
| Intersection | 12      | 20              |
| 3_Veh 1    | 4       | 20              |
| 3_Veh 2    | 4       | 20              |
| 4          | 4       | 20              |
| 5          | 13      | 20              |
| 6          | 25      | 20              |
| 7          | 24      | 20              |
| 8          | 25      | 20              |
| 9          | 23      | 20              |
| 10         | 29      | 20              |
| 11         | 25      | 20              |
| 12_Veh 1   | 29      | 20              |
| 12_Veh 2   | 50      | 20              |
| 13         | 39      | 20              |
| 14_Veh 1   | 18      | 20              |
| 14_Veh 2   | 10      | 20              |
| 15_Veh 1   | 50      | 20              |
| 15_Veh 2   | 12      | 20              |

In addition, Figure 18 shows the collision avoidance rate for each radar angle (class interval), which is summarized as a result of additional simulations. As expected, as the radar detection angle of the AEBS increases, the probability of preventing an accident also increases. For reference, when the radar detection angle is 50°, an intersection collision accident can be prevented 100% of the time.

Figure 18. Collision avoidance rates from additional simulations.

5. Conclusions

In this study, traffic accidents occurring on real roads were reinterpreted using the traffic accident analysis simulation program PC-Crash. In this process, we examined the changes that occur when the AEBS is applied while changing the radar detection angle to a traffic accident that has already occurred.

(1) First, to evaluate the significance of PC-Crash simulation, pre-simulation was performed based on the Euro NCAP AEBS test standard. As a result, in the case of “City” and “Inter-urban” simulation scenarios, collision avoidance or collision mitigation was shown regardless of the radar angle and the speed of the test vehicle. In the case of the pedestrian scenario (AEB VRU-Pe), different results were obtained depending on the radar angle, and in the case of the radar detection angle of 4°, the pedestrian dummy could not be detected.

(2) After confirming the validity of the PC-Crash program during pre-simulation, individual accidents were reinterpreted by applying AEBS using actual traffic accident data (ACCC). As a result, pedestrian collision and rear collision cases showed 100% collision avoidance, but in the instance of intersection and lane change accidents, collision avoidance was not satisfactory.

(3) In addition, further simulations focusing on intersection accidents showed the highest rate of collision avoidance when the radar detection angle was increased from 20° to 30°.

Through this study, we showed that application of the AEBS can reduce the possibility of traffic accidents by using the simulation tool PC-Crash. In the future, the AEBS evaluation items used in this study and the Euro NCAP need to be reviewed to see if they meet the national traffic conditions and safety evaluation standards. Additionally, it is necessary to improve the reliability of potentially reducing traffic accidents with the AEBS by applying the actual traffic accident database (ACCC) to various applications of AEBS and sensor types, as well as radar detection angles.

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