2023
26th Presentation Session for Traffic Accident Investigations, Analysis, and Research

Analysis on the influence of road structure on Autonomous Emergency Brake (AEB)

Daisuke Yamaguchi
Researcher, Autonomous Driving Section, Autonomous Driving Group

1. Introduction

1-1. Background and purpose of this research

Since the formulation of "Public Private ITS Initiative/Roadmaps" in 2014, Japanese government strategies for autonomous driving technology have been revised annually in order to realize autonomous driving as quickly as possible through cooperation between relevant government ministries and agencies and private enterprise. In September 2021, the Japanese government established its "Digital Agency", which in August 2022, announced the government strategy "Utilizing Digital Technology for the Future of Transportation Society 2022" which expanded upon and succeeded "Public Private ITS Initiative/Roadmaps". The revised Road Traffic Law also came into effect in April 2023, enabling "Level 4" autonomous driving to be performed on public roads. Although the situation surrounding autonomous driving technology in Japan is constantly changing in manners such as these, in order to realize a digital society that utilizes autonomous driving technology, there is a significant need for research that both supports and promotes advanced safe vehicles and autonomous driving initiatives.

Recent years have seen the popularization of advanced safety vehicles equipped with driving assistance functions, such as autonomous emergency brake (hereinafter, "AEB") and lane departure warning systems (LDWS). AEB is one of the main driving assistance functions of advanced safety vehicles, and since November 2021, has been gradually started to be required for new passenger vehicles. Understanding the effects of AEB, which is expected to become more widespread in the future, is essential not only for future vehicle development, but also for formulating road policies and constructing traffic safety infrastructure.

Although prior research on AEB exists, such as that conducted by Kinoshita[(1)(2)], Kondo,[(3)] and Yoshida[(4)] regarding AEB in different vehicle types, differences in AEB generations, and AEB use on expressways, there are few instances of research analyzing the impact of road structures and traffic characteristics on the effectiveness of AEB, specifically targeting national highways.

Therefore, the purpose of this study is to assess what effects driver assistance functions (including AEB) equipped on advanced safety vehicles have on reducing rear-end collisions under various road traffic environments and conditions on national highways.

1-2. Overview of AEB

AEB uses various sensors such as on-board cameras and millimeter-wave radar to detect vehicles and pedestrians in front of the vehicle. When it senses the risk of a collision, AEB not only alerts the driver to brake, but also activates the brakes automatically in order avoid the collision and reduce damage when the system determines that the collision is unavoidable.

Since November 2021, AEB has become mandatory on new passenger cars, and is also scheduled to become mandatory for current production models of passenger cars from December 2025. According to the Survey on the Status of ASV Technology Adoption[(5)] conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) as part of its General Vehicle Safety Information project, the percentage of new vehicles equipped with AEB has been increasing yearly, reaching 91% in 2020 (Fig. 1).

2. Data used for this research

The analysis performed over the course of this research utilized the Traffic Accident/Vehicle Integrated Database owned by the Institute for Traffic Accident Research and Data Analysis (ITARDA). The Traffic Accident/Vehicle Integrated Database was created by combining traffic accident statistics (e.g., accident-related information such as types of accidents and registration numbers) provided by Japan's National Police Agency, vehicle-related information (e.g., vehicle identification numbers and registration numbers) provided by MLIT, and AEB-related information (e.g., vehicle identification numbers, manufacturer information, and vehicle functions, including AEB) provided in cooperation with the Japan Automobile Manufacturers Association (JAMA).

3. Macro analysis focusing on traffic accidents involving vehicles equipped with AEB and road traffic environments, etc.

3-1. Overview of analysis

This analysis compared AEB-equipped vehicles with non-AEB-equipped vehicles by looking at rear-end accidents that occurred on national highways and in which the primary party was a passenger car. Totals were then calculated using "number of accidents per vehicles owned". The specific method for calculating "number of accidents per vehicles owned" involves dividing the total number of accidents that involving AEB-equipped vehicles and non-AEB-equipped vehicles during the analysis period (2017 to 2021) by the total number of registered and reported vehicles during the same period. Here, "primary party" refers to the party deemed to be the most negligent among the parties involved in the traffic accident.

During each stage of the analysis, a chi-square test was performed to determine whether a significant relationship exists between whether or not a vehicle is equipped with AEB and the number of accidents. In the graphs below, "**" is used when the p-value is less than 0.01 ($P < 0.01$).

3-2. Horizontal alignment

To confirm whether the horizontal alignment of roads affects accident numbers and whether it has any impact on AEB's ability to reduce accidents in AEB-equipped vehicles, horizontal alignments were divided into intersections and non-intersections in order to calculate numbers of rear-end collision accidents involving AEB-equipped vehicles and non-AEB-equipped vehicles per number of vehicles owned, as well as reduction rates for rear-end collision accidents caused by AEB-equipped vehicles (Fig. 2).

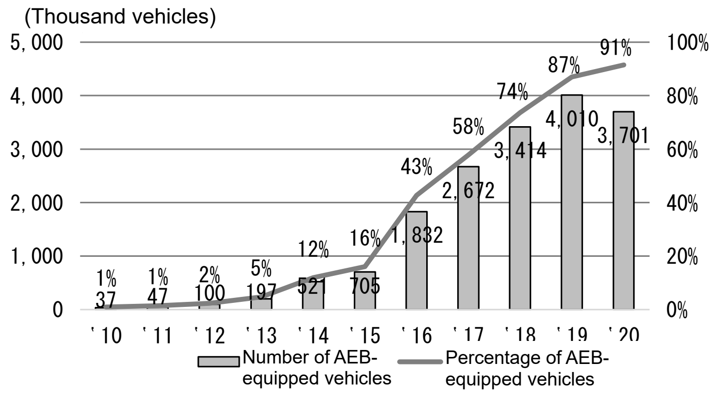

Fig. 1 - Trends in numbers and percentages of new vehicles (passenger cars) equipped with AEB

As shown by the graphs, in the case of both intersections and non-intersections, rear-end collision accident reduction rates were lower for curved and bending sections of roads than for straight sections of roads. In the case of curves, accident reduction effects are thought to be lower due to limitations with the detection range of in-vehicle cameras or due to delays in or failures to detect vehicles ahead when steering, etc.

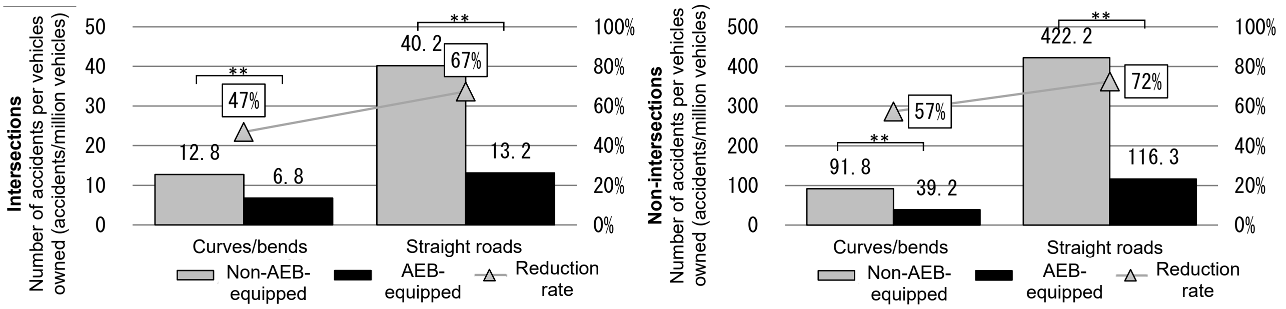

Fig. 2 - Number of rear-end collision accidents involving AEB-equipped and non-AEB-equipped vehicles per vehicles owned / Rear-end collision accident reduction rate in AEB-equipped vehicles (horizontal alignment)

3-3. Vertical gradients

To confirm whether the vertical gradient of roads affects accident numbers and whether it has any impact on AEB's ability to reduce accidents in AEB-equipped vehicles, vertical gradients were divided into intersections and non-intersections in order to calculate numbers of rear-end collision accidents involving AEB-equipped vehicles and non-AEB-equipped vehicles per number of vehicles owned, as well as reduction rates for rear-end collision accidents caused by AEB-equipped vehicles (Fig. 3).

As shown by the graphs, in the case of both intersections and non-intersections, rear-end collision accident reduction rates were lower for uphill and downhill sections of roads than for straight sections of roads. On uphill sections of roads, accident reduction effects are thought to be lower due to drivers often overriding the system by depressing the accelerator pedal, while on downhill sections of roads, accident reduction effects are thought to be lower due gravitational acceleration being applied in the forward direction, which generally causes stopping distances to be extended.

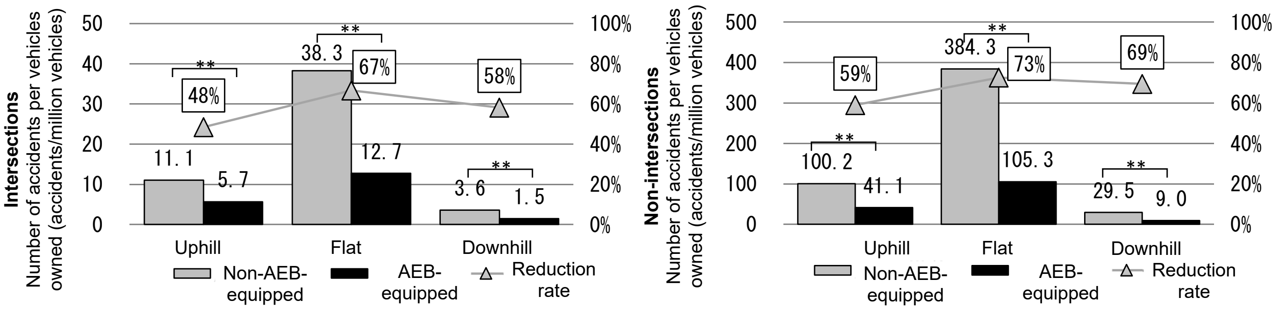

Fig. 3 - Number of rear-end collision accidents involving AEB-equipped and non-AEB-equipped vehicles per vehicles owned / Rear-end collision accident reduction rate in AEB-equipped vehicles (vertical gradients)

3-4. Speed limits

To confirm whether speed limits affect accident numbers and whether it has any impact on AEB's ability to reduce accidents in AEB-equipped vehicles, speed limits were divided into intersections and non-intersections in order to calculate numbers of rear-end collision accidents involving AEB-equipped vehicles and non-AEB-equipped vehicles per number of vehicles owned, as well as reduction rates for rear-end collision accidents caused by AEB-equipped vehicles (Fig. 4).

As shown by the graphs, in the case of both intersections and non-intersections, rear-end collision accident reduction rates were lower for sections of roads in which the speed limit was 30 km/h or less and or more than 60 km/h. When the speed limit is more than 60 km/h, accident reduction effects are thought to be lower due to the relationship between requirements for AEB performance certification systems and AEB safety criteria. Furthermore, it was observed that speed limits of 30 km/h or less are used on special sections of national highways, such as where the road alignment is poor.

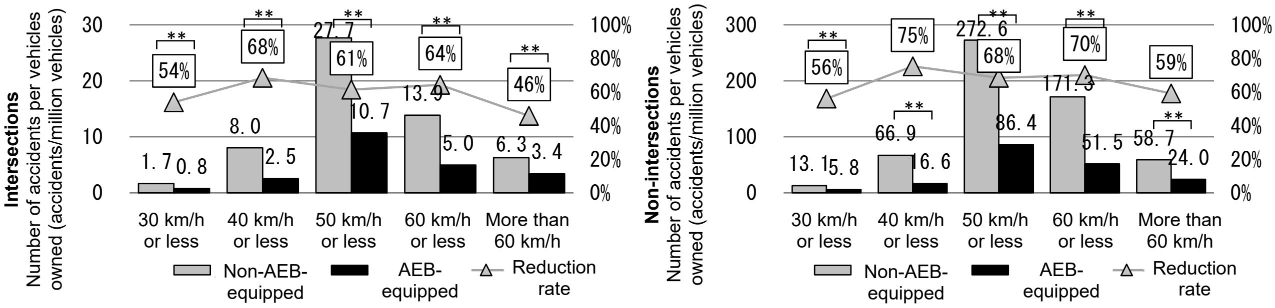

Fig. 4 - Number of rear-end collision accidents involving AEB-equipped and non-AEB-equipped vehicles per vehicles owned / Rear-end collision accident reduction rate in AEB-equipped vehicles (speed limits)

4. Detailed analysis focusing on traffic accidents involving vehicles equipped with AEB and road traffic environments, etc.

4-1. Overview of analysis

Using data from 2017 to 2021, we identified areas (500 m × 500 m) where rear-end collision accidents involving AEB-equipped vehicles frequently occur in Shizuoka Prefecture. Then, by overlaying rear-end collision accidents involving AEB-equipped vehicles with ETC2.0 probe information, we examined road structures and traffic environments where rear-end collision accidents often occur.

The area that was examined was the fourth mesh number, 523833703, located in the Aoi Ward of Shizuoka City in Shizuoka Prefecture. This area was selected due to the large number of rear-end collisions involving AEB-equipped vehicles that occur there. (This area ranked first in the order of difference between rear-end collisions involving AEB-equipped vehicles and rear-end collisions involving non-AEB-equipped vehicles).

4-2. Accident sites

We graphed accident sites in order to understand the characteristics of areas where accidents involving AEB-equipped vehicles often occur (Fig. 5).

This enabled us to see that of the areas analyzed, rear-end collision accidents involving AEB-equipped vehicles were concentrated in the northwest merging section of the Abe-cho intersection. Furthermore, as can be seen from the enlarged view, the distance between the pedestrian crossing and the stop line at this location is extremely large.

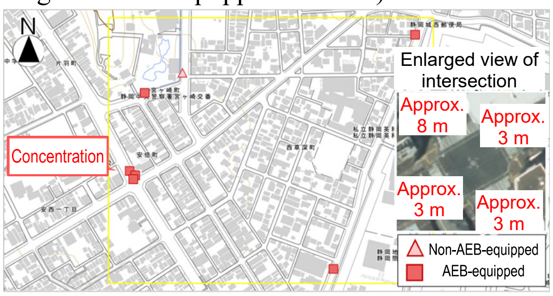

Fig. 5 - Rear-end collision accident sites

4-3. Rapid deceleration conditions

We graphed rapid deceleration sites in order to understand the traffic conditions of areas where accidents

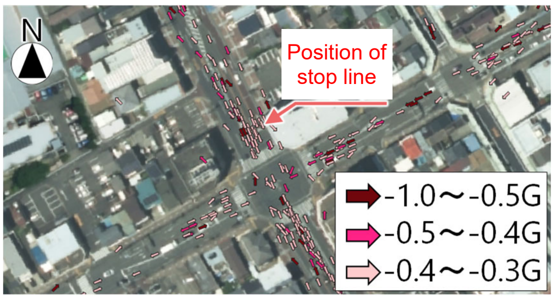

Fig. 6 - Rapid deceleration sites

involving AEB-equipped vehicles are concentrated (Fig. 6).

Rapid deceleration also occurs at the point beyond the stop line at the northwest merging section of the Abe-cho intersection. From this, we can infer that drivers decelerate rapidly when the traffic light changes from green to yellow as they feel it will not be possible to cross the intersection in time.

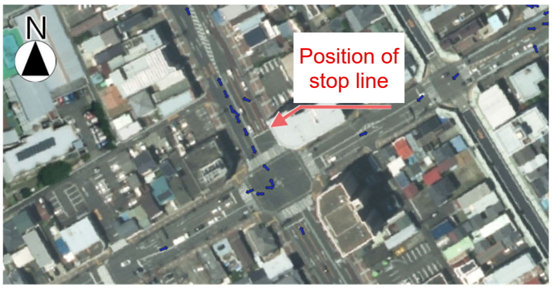

Fig. 7 Acceleration sites

4-4. Acceleration conditions

We graphed acceleration sites in order to understand the traffic conditions of areas where accidents involving AEB-equipped vehicles are concentrated (Fig. 7).

From this, one can see that drivers are often accelerating at the point where rear-end collision accidents are concentrated. This suggests that some drivers accelerate to cross the intersection at the moment the traffic light changes from green to yellow.

5. Conclusion

Over the course of this research, we analyzed how road traffic characteristics such as road structures and traffic environment affect reductions in rear-end collision accidents involving AEB-equipped vehicles. As a result, the following findings were obtained.

- In the case of curves, accident reduction effects are lower due to limitations with the detection range of in-vehicle cameras or due to delays in or failures to detect vehicles ahead when steering, etc.
- On uphill sections of roads, accident reduction effects are lower due to drivers often overriding the system by depressing the accelerator pedal. Also, on downhill sections of roads, accident reduction effects are lower due gravitational acceleration being applied in the forward direction, which generally causes stopping distances to be extended.
- In sections where the speed limit is more than 60 km/h, accident reduction effects are lower due to requirements for AEB performance certification systems and AEB safety criteria not taking such requirements into consideration.
- Rear-end collision accidents involving AEB-equipped vehicles have occurred in sections where vehicles are rapidly decelerating and accelerating simultaneously (such as where stop lines are set a far distance away).

In the future, it should be possible to deepen our analysis by focusing on the damage mitigation effects of AEB by collecting and utilizing information on accidents involving property damage. Furthermore, in anticipation of the future proliferation of autonomous vehicles, we must consider analysis and evaluation methods that focus on driving assistance functions such as Adaptive Cruise Control. However, because such functions can be activated and deactivated, exploring new analysis and evaluation methods remains a challenge.

<Acknowledgment>

This study was supported by the Intelligent Transport System (ITS) Promotion Office of the Road Traffic Management Division of the Road Bureau at the Ministry of Land, Infrastructure, Transport and Tourism (MLIT). For this, we would like to express our sincere gratitude.

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