SAFETY ASSESSMENT PROCEDURE FOR ADVANCED EMERGENCY BRAKING SYSTEM

Taewoo Kim
Taeyoung Lee
Kyongsu Yi
School of Mechanical and Aerospace Engineering, Seoul National University
Korea

Jaewan Lee
Korea Automobile Testing & Research Institute, Korea Transportation Safety Authority
Korea

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ABSTRACT

This paper suggests a safety assessment procedure for evaluation of enhanced longitudinal safety by Advanced Emergency Braking (AEB) system in Korea. The objective of project is to suggest safety evaluation procedure of the AEB system with the consideration of Korean road condition and physically meaningful situation.
To develop the impact assessment procedure of the AEB system, the AEB test vehicle as well as the test scenario should be designed. Before the development of the test procedure, this paper reviews the international regulation of AEB system and traffic accident statistics, and develops domestic safety standards and evaluation requirements. Test scenario has been developed to assess the safety performance of AEB systems for the reductions in collision frequency and severity by using the Korea's traffic accident statistics. Also, the test scenario is designed to represent the real driving condition and to evaluate the safety performance of AEB system in various situations. The AEB test vehicle comprises of a millimeter wave radar sensor, CCD camera and pre-developed AEB algorithm of which are processed to judge the collision risk. To evaluate the collision avoidance performance of the AEB test vehicle, pre-performance test was conducted by using the NCAP-AEBS draft test procedure and proposed test scenario.
From the traffic accident statistics and the field test result, it is shown that proposed AEBS test scenario represents not only the frequently occurred collision case but also physically meaningful situation in terms of expected control performance of the AEB system. Also, it has been shown that AEB system of prior study can reduce the collision velocity and provide the greatest real world benefits. Because of the limitation of test equipment and safety, test scenario about Cut-in vehicle could not be included in the test results of the proposed test procedure. However, by using the analysis methods and simulation test, the safety effect for enhanced longitudinal safety of the AEBS with respect to Cut-in case has been assessed scientifically.
In this paper, the safety assessment procedure for AEB system has been described to evaluate the safety performance of the AEB system. The test procedure according to AEB system provides objective safety performance level of each AEB system. Also, these tests are expected to be a strong driver of improved safety in the real world.

INTRODUCTION

Since the passive safety systems, such as seat belts, airbags or active head-rest, etc., became part of almost every vehicle, the demands of vehicle active safety system had been also getting larger. Therefore, many automakers are trying to help drivers to avoid or mitigate collision using active safety system. Several systems are already commercialized including Adaptive Cruise Control (ACC), Traffic Jam Assist (TJA), Lane Keeping Support (LKS), Lane Change Assist (LCA), Blind Spot Detection (BSD), Automated Parking Assist (APA) and Forward Collision Warning System (FCWS). [1]~[6] Especially, Advanced Emergency Braking (AEB) system is one of the active safety system which is supposed to be able to significantly contribute to reduce the number of road fatalities.
After AEB system was developed and commercialized, the number of vehicles with AEB system have been increased and is predicted to be increased more. Also, as AEB system became one of the most interesting topic for researchers and automakers, there have been many studies to improve the performance of AEB system. Therefore, each of AEB systems developed in different ways which means it is difficult to compare the performance between

each AEB systems. Hence, the studies to evaluate the performance of these AEB systems are required. Governments and research centers of many countries such as Euro NCAP and International Organization for Standardization (ISO) have been studied about the regulation of AEB system and some of them already announce a standard regulation. The regulation of ISO is already using as a standard of safety performance for the commercialization of AEB system. Euro NCAP provides objective standards about the safety performance of AEB system. [7] However, these regulations are still not perfect to guarantee the safety by AEB system in various situation.

In the case of Korea, there is no specific regulation about the performance of AEB system. According to the National Policy statistics in Korea, the total number of deaths in 2010 caused by traffic accidents in Korea was 5,505 which means about 2.6 per 10,000 cars experianced the fatal accident. It was the twice the OECD average of 1.3. [8] In 2009, Traffic Accident Analysis Center of Korea reports that almost 60 percent of traffic accident was longitudinal accident. Hence, the regulation which is based on the Korean road condition is required to reduce the collision frequency and severity.

In this paper, the international regulation of AEB system and the traffic accident statistics are reviewed. The typical factors which should be considered for the development of AEB test scenario are summarized.Then, we present the AEB test scenario which contains the characteristics of traffic accident of Korea and represents not only the frequently occurred collision case but also physically meaningful situation. Last of all, the proposed test scenario is verified via computer simulation and vehicle test.

TRAFFIC ACCIDENT STATISTICS AND THE STATUS OF REGULATION OF AEB

In this chapter, traffic accident statistics and the international regulations of AEB are reviewed.

Traffic Accident Statistics

To develop the test scenario for the evaluation of the performance of AEB systems which is appropriate to the case of Korea, traffic accident statistics of Korea should be studied. In this section, the type of traffic accident of Korea is reviewed based on the reports of Traffic Accident Analysis Center of Korea. Also, to determine the specific ratio of each type of collision which was not exists in the case of Korea, international traffic accident statistics is also reviewed.

Korea Lee analyzed the traffic accident of Korea from 2005 to 2009 based on the reports of Traffic Accident Analysis Center of Korea. [9], [10] He analyzes and classifies the traffic accident statistics based on the two topics: violation of law and human factor. Based on the case of violation of law, almost 50 percent of all traffic accident was caused by the violation of the duty to drive safely. Signal violation and safe distance violation was followed. Safe distance violation which is closely related with the longitudinal safety was 13.7 percent of traffic accident. According to the classification based on the human factors, almost 60 percent of traffic accident was caused by the negligence in forward-looking which is also closely related with the longitudinal safety.

International NHTSA reports about the situation and driving condition of traffic accident. [11] According to the report of NHTSA, traffic accident which occurred in America can be classified into 7 categories, and 39 percent of total traffic accidents were longitudinal collision. Also, in order to analyze the situation of traffic accident, NHTSA classify the traffic accident into 45 kinds of typical scenarios. Five of them were closely related with the longitudinal safety, which are about 28.9 percent of total traffic accidents.

Regulation of AEB system

Research centers of many countries have been studied about AEB system for the announcement of regulation of AEB system. In this section, the regulation of Euro NCAP and ISO are introduced.

Euro NCAP Euro NCAP classifies the AEB test procedure into 2 cases: City and Inter-Urban test procedure. [12] For AEB City test scenario, they evaluate the performance of AEB in low speed region while the preceding vehicle is at standstill. For AEB Inter-Urban test scenario, they evaluate the performance of AEB in low and high speed region for the cases of which the preceding vehicle is stationary, slowly moving and braking with constant deceleration. The scoring of each test procedure was developed based on the statistical data about the frequency and severity of traffic accident at each speed region. However, they only regulate the performance of AEB in the case of straight road and simple target condition. Hence, the performance of AEB in curve or other driving situation cannot be guaranteed. Also, they focused only on the avoidance and mitigation of the collision which means the excessive control of AEB system cannot be verified through their regulation.

ISO ISO also announce the regulation of AEB system. They evaluate the performance AEB with the vehicle speed from 15 km/h to the maximum available speed. They suggest that the AEB system should be able to reduce the impact speed more than 20 km/h for the stationary target, and to avoid the collision for the moving target with the speed of 12 km/h. Also, they regulate about the warning timing of AEB system. However, they also regulate the performance of AEB only in simple cases: straight road and single target condition.

REPRESENTATIVE FACTORS OF AEB TEST SCENARIO

For the evaluation of the performance of AEB system, test scenario should represent not only the frequently occurred collision case but also physically meaningful situation. Hence, many factors such as driving mode, road type, environment, and AEB system element should be considered to evaluate the performance of AEB system. The typical factors are summarized in fig. 1. The AEB test scenario should contains these factors to varify the performance of AEB in various situation.

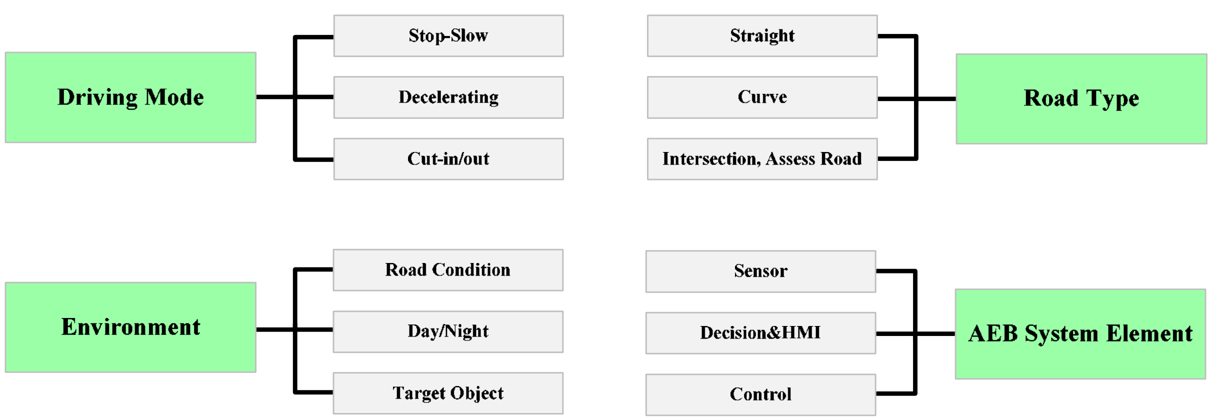


Figure1. Representative factors of AEB scenario.

Driving Mode

The performance of AEB should be guaranteed in various kinds of driving condition especially about the behavior of preceding vehicle. To evaluate the performance of AEB, the vehicle with AEB should be tested in both normal and severe conditions. The typical examples of these driving modes are introduced in this section.

Preceding Stop-Slow Vehicle In city-driving condition, lots of crashes occur between the stationary or stop preceding vehicle and following vehicle. Hence, the response of AEB about the slow or stop preceding vehicle should be evaluated.

Preceding Decelerating Vehicle Many drivers do not use large deceleration in normal driving condition. However, dangerous situation makes driver to use large deceleration which can make a secondary accident with the following vehicle. If the preceding vehicle is decelerating with large deceleration in some reasons, it is difficult to react quickly for the driver of following vehicle. Hence, AEB should indicate the danger to the driver and should determine to decelerate the vehicle automatically in proper moment unless the driver reacts about the dangerous situation. Although the AEB cannot prevent the crash perfectly, it should decrease the severity of the accident. Hence, the performance of AEB about the preceding decelerating vehicle should be verified.

Preceding Cut-in/out Vehicle Sudden Cut-in or Cut-out situation can be a risk to the following vehicle. In this situation, the flexible reactions about each case are very important. If the Cut-in or Cut-out situation makes the situation dangerously, the proper reaction of the driver is required. In this situation, AEB should indicate the danger to the driver and determine to decelerate the vehicle in proper moment to avoid the crash or decrease the severity of the crash unless the driver reacts about the danger. Hence, the performance of AEB in Cut-in or Cut-out situation should be also evaluated. Also, if the Cut-in/out situation is not dangerous to the following vehicle, AEB should not be activated. The undesired and unnecessary reaction of AEB could disturb the driver. Hence, the deactivation of AEB in safe Cut-in/out situation should be verified.

Road Type

In City road condition, various types of road are exists which could effect on the performance of the AEB. Including the straight road condition, AEB should guarantees the performance on curve or other road types.

Straight Road According to the NHTSA's report, for about 40 percent of the collision was longitudinal collision. [11] Hence, the performance of AEB in longitudinal collision situation should be evaluated importantly

Curve In slow speed condition, dangerous situation is occurred when the distance between the vehicles is relatively small. In this situation, the effect of curvature of the road is small because the lateral offset of the preceding vehicle at dangerous situation is relatively small. However, in high speed region, the effect of curvature of the road is not negligible. AEB system should classify the vehicles which are on the same lane and which are not. If AEB system is failed to recognize the preceding vehicle on the same lane in curve, AEB could not response about the danger at proper moment which can lead to an accident. If AEB response about the vehicle on other lane and decelerate the vehicle, it can disturb the driver. Hence, deactivation of the AEB by the vehicle on other lanes should be also verified as well as the activation by the vehicle on same lane.

Other Road (Intersection, Access Road) Various types of road condition including the mentioned situation are exists in normal city driving condition. Although the straight and curve road condition are more frequent, complex road conditions such as intersection and assess road is more dangerous. However, the performance of AEB cannot be guaranteed perfectly in these complex situations due to the limitation of the perception range of AEB system. Hence, the evaluation of the performance of AEB in complex driving mode such as intersection and assess road is not considered in this paper. However, these topics are suggested to be considered on the evaluation of the performance of advanced active safety system or advanced driver assistance systems (ADAS).

Environment

AEB should also guarantee the performance in unusual environment. Although the performance of AEB on unusual environment cannot be perfect, AEB should guarantee a certain level of safety performance. Hence, AEB performance on unusual environment condition should be evaluated.

Road Condition Braking distance of the vehicle became longer in wet road condition. In this situation, AEB should response about the danger quickly than usual situation. Even if AEB cannot estimate the road condition, it should guarantee a certain level of safety performance on the wet road condition.

Day/Night Condition In night-time driving condition, driver's sight became narrow which makes the required time to recognition and decision became larger. Hence, AEB system should indicate the danger to the driver and response about the danger properly in night-time driving condition. However, some kind of sensors such as vision sensors are vulnerable to a night condition. Also, although vehicles are visible at night due to the headlight and taillight of the vehicle, pedestrian or other kind of obstacles are not visible. Hence, the performance of AEB in night-time driving condition is suggested to be evaluated.

Target Object In city-driving condition, pedestrian or other obstacles on the road can lead to an accident. Hence, AEB should perceive the pedestrian or other obstacles as well as the preceding vehicles. Especially, AEB should be able to perceive the pedestrian and response about the danger because car to pedestrian accident can lead to a fatal accident. Hence, the performance of AEB about the pedestrian target should be verified.

AEB System Element

AEB system should contain four parts: sensor part, decision and Human Machine Interface (HMI), control, and actuator. The characteristics and general requirements of each part are explained in this section.

Sensor Sensor part perceives the target in the range. It should classify the target type such as preceding vehicle, pedestrian and other kind of obstacles and it also should be able to classify the two-wheeled vehicle or other specific targets. It should provide the target information including the type of target, target position, and preceding vehicle relative velocity. Multi-target perception and tracking should be available. The longitudinal and lateral perception range of sensors should satisfy the range requirement for the operation of AEB. Certain level of accuracy in unusual driving condition should be also guaranteed as well as in normal driving condition.

Decision & Human Machine Interface (HMI) Decision part selects the proper target between the perceived multi targets and recognizes the risk. Decision part should be able to track the multi-target simultaneously and select the proper target to response in dangerous situation. Hence, this target selecting ability should be also guaranteed in multi-vehicle condition and curve or other complex driving conditions. Also, tracking ability including the tracking delay about new target should be evaluated. In order to evaluate the safety performance of AEB, warning and decelerating timing can be a standard of evaluation.
HMI is the part which indicates the danger to the driver and responses about the drivers input. HMI should indicate to the driver visually, acoustically, or in other ways to make driver react about the danger. In this situation, HMI should perceive the change of driver's behavior. If driver react about the danger, HMI should hand over the control authority to the driver. This change of control authority should be evaluated as well as the safety performance of AEB with and without driver's braking input: for example, if the amount of brake of the driver is not enough, AEB should make the vehicle to decelerate more.

Control Control part decelerate the vehicle in proper amount of deceleration for each situation. Although a small amount of deceleration can be lead to an accident, large amount of deceleration can disturb the driver and make driver inconvenient. The appropriate range of deceleration which doesn't make driver inconvenient is difficult to be determined theoretically. Hence, driving data based determination is usually suggested to guarantee the comfort of driver as well as the safety performance of AEB.

Actuator In order to guarantee the performance in real driving condition, the actuator part should be durable. Hence, the durability about vibration, repetitive decelerating condition, and environmental change should be guaranteed.

AEB TEST SCENARIO

Based on the international AEB regulation and the typical factors of AEB test scenario which are mentioned in previous chapters, the required AEB test scenario for the evaluation of the performance of AEB system can be determined. However, although the exact performance of AEB system in various situation can be evaluated through a great number of test scenarios, limited test is available due to the limitations. Hence, significant and necessary test scenario should be selected. The summarized test scenario for the evaluation of the performance of AEB system is described in table 1. In this chapter, only three cases of test scenario is explained.

Table1.
AEB test scenario.

Item	Preceding Vehicle	Specifics		Test No.
Test No. 1 Straight	Stop Vehicle	Vehicle Target	Dry Asphalt	1-1D
			Wet Asphalt	1-1W
		Pedestrian Target		1-1P
	Slow Vehicle			1-2
	Decelerating Vehicle			1-3
	Cut-in Vehicle			1-4
Test No. 2 Curve	Stop Vehicle			2-1

Straight Road Preceding Decelerating Vehicle

The main purpose of AEB system is avoidance or mitigation of the collision in longitudinal direction. Preceding deceleration vehicle is one of the typical scenario of longitudinal traffic accident.

Scenario In straight road, the large deceleration of preceding vehicle can cause an accident. Especially, if the driver of subject vehicle fails to recognize the deceleration of the preceding vehicle, it can lead to a fatal accident. Hence, warning and braking of the AEB system in this situation should be evaluated.

Performance evaluation In straight road preceding vehicle decelerating situation, AEB should indicate the danger to the driver. Also, unless the driver reacts about the danger, AEB should determine to decelerate the vehicle automatically to avoid or mitigate the danger. For this, AEB should be able to perceive the target in proper range and recognize the danger. Hence, the warning and decelerating timing of the AEB system should be evaluated. Also, the relative speed of the impact and the reduction of the subject vehicle speed should be in safe region.

Straight Road Preceding Cut-in Vehicle

AEB system should be able to response about sudden change of traffic condition such as cut-in case.

Scenario The test scenarios of the Euro-NCAP and ISO already include the preceding stop, slow, and decelerating vehicle. However, these three scenarios cannot evaluate the response about an unexpected obstacle or vehicle. Preceding cut-in vehicle situation is one of the representative situations of the danger caused by unexpected obstacles or vehicles. However, in normal driving condition, cut-in vehicle with similar speed does not always lead to an accident. In this situation, the response of AEB system could disturb the driver and make the driver inconvenient. Hence, the response of AEB system about both safe and dangerous Cut-in cases should be verified.

Performance evaluation When the preceding vehicle cuts in with deceleration, AEB should be able to recognize the danger and indicate the danger to the driver. Unless the driver reacts about the danger, AEB system should determine to decelerate the vehicle automatically to avoid or mitigate the collision. However, if the cut-in of preceding vehicle doesn't cause a danger, AEB system should not be activated. Hence, the deactivation of AEB system in safe Cut-in situation should be evaluated as well as the activation of AEB system in dangerous Cut-in situation. In the case of cut-in with decelerating situation, the warning and decelerating timing should be checked as well as the collision avoidance or reduction of the impact speed. Also, in the case of safe cut-in situation, the deactivation of AEB should be verified.

Curve Road Preceding Stop Vehicle

Regulation of Euro-NCAP and ISO evaluate the performance of AEB only in straight road condition. However, in city and inter-urban case, the driver should meet lots of curves. Hence, AEB performance in curve road also should be evaluated.

Scenario City and Inter-Urban condition contains lots of curve road situation. Hence, AEB system should guarantee the safety performance in curve road condition to guarantee the safety in city or inter-urban driving condition. For this, AEB system performance in curve road condition should be evaluated. In curve road situation, target perception and decision part is the most important part while other performance of AEB can be also evaluated in the case of straight road condition. Curve road stop vehicle situation is the most typical and simple scenario between the curve road situation.

Performance evaluation factor In the case of curve road stop vehicle scenario, the most important part is perception and recognition of the target on same lane. For this, activation by the preceding vehicle on same lane and deactivation by the obstacle on other lanes should be assessed. The effect of curvature became larger at high speed region. Hence, the performance of AEB system should be evaluated in high speed region. For the same lane stationary obstacle, perception and recognition of the AEB system should be evaluated as well as warning and decelerating timing. Since the test should be proceeded in high speed region, impact speed and relative impact speed also should be verified. For the stationary obstacle on other lanes, failure of the perception or recognition should be verified.

SIMULATION AND VEHICLE TEST RESULT

In this chapter, the simulation and field test result of the proposed AEB test scenario is proposed. For this, AEB algorithm which is presented in previous research is introduced in the first section. Using this AEB algorithm, computer simulation was conducted using simulation toll Carsim and MATLAB/Simulink. Also, vehicle test was also conducted. However, cut-in and curve test scenario couldn't be included due to the limitation of test equipment and safety.

AEB Algorithm

In the study of Lee, AEB algorithm based on a new safety index was proposed. [Lee 2015] The new safety index was developed by using time to collision (TTC) and warning index (x). TTC and warning index is defined as:

$$TTC = \frac{C}{v_{rel}} \qquad \textbf{(1)}$$

$$x = \frac{C - d_{br}}{d_w - d_{br}} \qquad \textbf{(2)}$$

where C is clearance, v_{rel} is relative velocity, and d_{br}, d_w are braking-critical and warning-critical distances which are defined as follows. [13]

$$\begin{aligned} d_{br} &= v_{rel} \cdot t_{brake} - \frac{v_{rel}^{\ 2}}{2a_{\max}} \\ d_w &= v_{rel} \cdot t_{thinking} + v_{rel} \cdot t_{brake} - \frac{v_{rel}^{\ 2}}{2a_{partial}} \end{aligned} \qquad \textbf{(3)}$$

where t_{brake} is system delay, which is given by the brake-system hardware, $a_{\max}$ is the maximum deceleration of the vehicle under driving conditions, $t_{thinking}$ is the delay in human response between recognition and manipulation. [14] Using these indices, new longitudinal safety index can be defined as follows. [7]

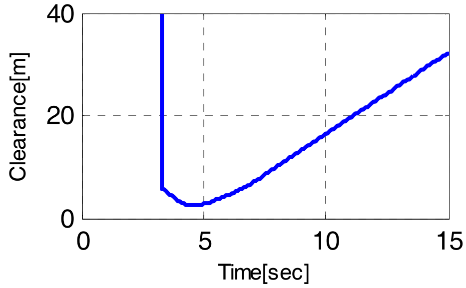
$$S_{Longi} = \sqrt{\left(\frac{TTC - TTC_{Partial}}{TTC_{Emergency} - TTC_{Partial}}\right)^2 + \left(\frac{x - x_{Partial}}{x_{Emergency} - x_{Partial}}\right)^2} \qquad \textbf{(4)}$$

where $TTC_{Partial}$, $TTC_{Emergency}$, $x_{Partial}$, *and* $x_{Emergency}$ are the thresholds for the control mode selection of AEB system which can be determined physically:Warning mode, Partial braking mode and Emergency braking mode.
Based on this new longitudinal safety index, AEB algorithm select the control mode: warning mode determines to indicate the danger to the driver, partial braking mode determines to decelerates the vehicle with small deceleration, and emergency braking mode determines to decelerate the vehicle with the maximum deceleration.

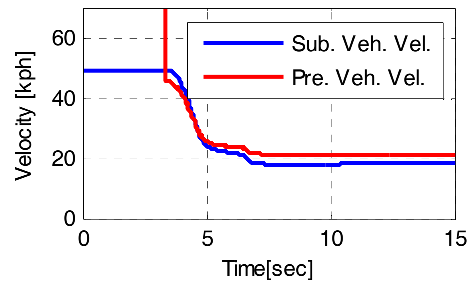
Simulation Result

Computer simulation was conducted using simulation tool Carsim and MATLAB/Simulink. In this paper, the simulation result of Cut-in with decelerating vehicle scenario is presented.

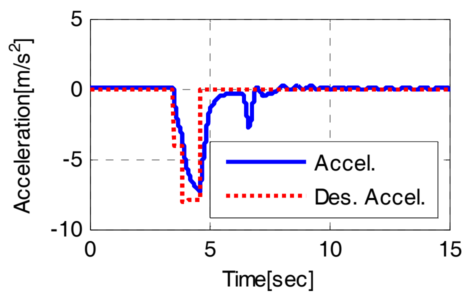
Simulation Case: Cut in with Decelerating Vehicle The simulation result of Cut-in with decelerating vehicle scenario is shown in fig.2. Initially, radar sensor of subject vehicle failed to detect the preceding vehicle due to the lateral offset of preceding vehicle. After the preceding vehicle started to cut in, lateral offset decreased and radar based target perception became possible. However, since the preceding vehicle was decelerating during the cut-in, clearance between the preceding vehicle and subject vehicle is smaller than 10 m when the preceding vehicle started to be detected. Hence, as described in fig.2 (d), AEB started to indicate the danger, and started to decelerate the vehicle due to the assumption that driver didn't look forward at that moment. As described in fig.2 (a), collision was avoided and the velocity of subject vehicle was successfully decelerated. This result shows that the proposed AEB system performs well in the Cut-in with decelerating vehicle scenario.



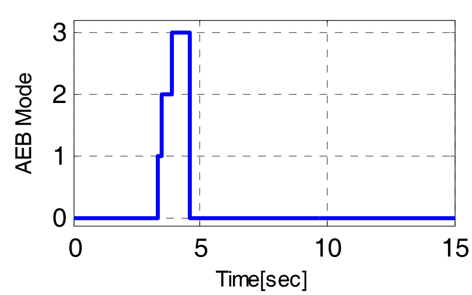
(a) Clearance



(b) Velocity of each vehicle



(c) Acceleration



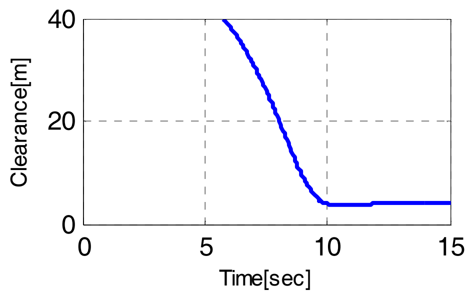
(d) AEB Control Mode

Figure2. Simulation result of AEB system in preceding cut-in with decelerating vehicle scenario.

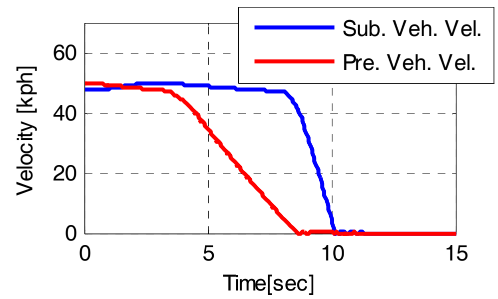
Vehicle Test

To confirm that the proposed AEB test scenario is realistic and physically meaningful, vehicle test have been conducted. The proposed AEB algorithm is implemented on vehicle. A millimeter wave radar sensor and carge-coupled device (CCD) camera are equipped to detect the preceding tret, pedestrian, and obstacles. The Euro-NCAP vehicle target which is physically linked with another vehicle was used as a preceding vehicle target for the preceding moving target cases. In this section, test result of the straight road decelerating vehicle scenario which is also included in the regulation of Euro NCAP is presented.

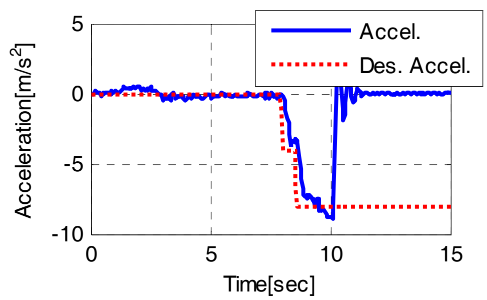
Test Case: Straight Road Decelerating Vehicle The test result of the straight road decelerating vehicle scenario is shown in fig.3. The initial speed of subject and preceding vehicle was 50 km/h and initial clearance was about 50m. As shown in fig.3, after the preceding vehicle started to be decelerated with constant deceleration of 0.2g, clearance between the preceding vehicle and subject vehicle was also decreased. However, the subject vehicle maintained the initial speed according to the assumption that there was no reaction of driver about the danger. Therefore, AEB system indicates the danger to the driver which is expressed as AEB Mode 1, and AEB system started to decelerate the vehicle automatically which is expressed as AEB Mode 2. Fig.3 shows that proposed AEB algorithm performed well in the straight road preceding decelerating vehicle situation.



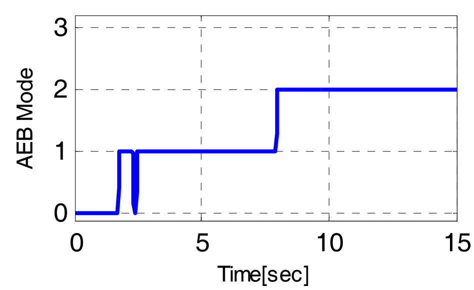
(a) Clearance



(b) Velocity of each vehicle



(c) Acceleration



(d) AEB Control Mode

Figure3. Test result of AEB system in preceding decelerating vehicle scenario.

CONCLUSIONS

In this paper, a safety assessment procedure for evaluation of enhanced longitudinal safety by Advanced Emergency Braking (AEB) system has been developed. The proposed AEB test scenario consists of 7 cases which include straight road cut-in vehicle scenario and curve road stop vehicle scenario. In order to determine the AEB test scenario which represents the real driving condition, the typical factors such as driving mode, road type, environment, and AEB system element should be considered to guarantee that the proposed AEB test scenario represent not only the frequently occurred situation but also physically meaningful situation. The proposed AEB test scenario has been validated based on the investigation on international regulation of AEB system and traffic accident statistics. In order to verify the proposed AEB test scenario, AEB algorithm of prior study was conducted via computer simulation and vehicle test. The simulation and vehicle test results show that the proposed AEB test scenario was realistic and physically meaningful.
In order to develop the specific regulation such as rating criteria and detail procedure of each test scenario, additional experimental test should be conducted with various AEB systems.

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