Simulation-based Estimation of Effectiveness of Automatic Emergency Braking in Pedestrian Collisions

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I. INTRODUCTION

According to the annual report issued by the National Police Agency in Japan, nearly 40% of traffic fatalities are pedestrians. More than half of them are involved in collisions when crossing roads other than crosswalks or ignoring signals [1]. Drivers tend not to anticipate a pedestrian ahead when running on straight roads without traffic lights or crosswalks. It may be difficult to stop the vehicle if a pedestrian suddenly appears from the roadside. Even if the driver notices the pedestrian, a collision could occur if the timing of braking is not early enough. Automatic emergency braking (AEB) was developed to help avoid collision and to mitigate collision severity. The effectiveness of AEB is usually assessed in laboratory tests following a prescribed protocol. In reality, there may be various scenarios in which crossing pedestrians are at risk of collision. Research efforts were made to estimate the effectiveness of AEB in realistic conditions [2-5]. One approach was to use collision databases. Filters and/or rules were used to identify collision scenarios and/or conditions being relevant to AEB. Injury mitigation effect was estimated using injury risk curves with respect to physical measurements such as collision speed. Simulations were also used in recent studies. Functions of AEB were replicated in the simulation models to predict the effectiveness in collision avoidance and injury mitigation. Stochastic methods were used to consider various collision scenarios. Crash simulations were conducted in some studies to better predict injury risk under specific collision scenarios. However, full-scale finite element (FE) models were not generally preferred for stochastic simulations due to the computational cost. This paper describes a full-scale continuous simulation methodology for holistic estimation of the effectiveness of AEB in collision avoidance and injury mitigation.

II. METHODS

Crossing is the most common scenario for pedestrians to be involved in fatal collisions. A base simulation model was generated to replicate the scenario where a pedestrian crosses the road in front of a vehicle (Fig. 1). Variation models were generated changing the walking speed and angle of the pedestrian and the running speed and position of the vehicle. The effect of AEB was estimated by comparing equivalent cases with and without AEB Two effects were expected for AEB: one is collision avoidance effect and the other is damage (injury) mitigation effect. Precrash simulations were conducted to estimate the collision avoidance effect of AEB. Crash simulations were conducted to estimate the injury mitigation effect of AEB. The collision conditions for the crash simulations were duplicated from the results of the precrash simulations.

Precrash Simulations

A total of 385 models were generated for the variation study. Three parameters were defined to describe the pedestrian motion: walking speed, crossing angle and timing. Another three parameters were defined to describe the vehicle motion: travel speed, lateral position and visibility. The parameter ranges were determined based on the previous study [6]. The first 385 simulations were conducted without AEB (human driver) and the next 385 cases were with AEB. A driver model was developed to mimic braking operation by a human driver. Four steps were assumed for the braking operation: detection, gas-pedal off, brake-pedal on and stopping. The model represented individual variation in each step. The reaction time varied from 0.2 sec to 0.7 sec based on the literature data [7]. A simple bilinear profile was assumed for the braking deceleration. The jerk and peak value (up to 1 g) varied between the cases taking into account individual variation. On the other hand, the model did not include driver errors such as distraction or lack of attention. It was assumed that the driver perfectly recognises when the pedestrian entres the field of view (FOV) with an angle of 100 degrees. An AEB model was

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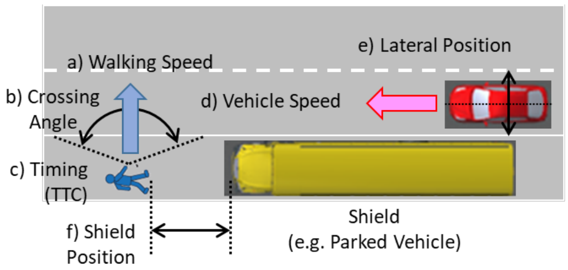
generated to replicate a prototype system. An FOV of 46 degrees was assumed for the sensor fusion of the millimeter wave radar and monocular camera. In this portion of the study, the model did not assume driver intervention. The braking deceleration profile had two steps: light brake (3.5 m/s^2) and full brake (9.8 m/s^2). The vehicle dynamics simulator CarMaker™ was used for the precrash simulations. Three results were anticipated: (a) collision was avoided in both with and without AEB; (b) collision occurred without AEB but was avoided with AEB; and (c) collision occurred both with and without AEB. The collision avoidance effect of AEB was calculated as (b)/{(b)+(c)} where each term indicates the number of results.



Parameters			Range (±3σ)	Distribution
Pedestrian	a	Walking Speed	0.8 ~ 2.0 m/s	Normal
	b	Crossing Angle	-70 ~ +70 deg	Normal
	c	Timing (TTC)	0.7 ~ 10 sec	Log-normal
Vehicle	d	Vehicle Speed	10 ~ 60 kph	Normal
	e	Lateral Position	-0.8 ~ +0.8 m	Normal
	f	Shield Position	4 ~ 24 m	logarithmic

Fig. 1 Base simulation model which assumes scenario where pedestrian suddenly appears and crosses road in front of vehicle.

Crash Simulations

Crash simulations were conducted for the collision cases. The general purpose FE analysis programme LS-DYNA™ was used for the crash simulations. It was assumed that all collisions occurred between a midsize sedan vehicle and a midsize adult male pedestrian. Figure 2 shows the sample simulation model. The vehicle model represented a prototype vehicle and was assumed to show realistic force-deformation responses in pedestrian collisions. The virtual human body model THUMS™ was used to represent the pedestrian. The model was previously validated to pedestrian impact responses documented in the literature [8]. The positions and motions of the vehicle and the pedestrian at the time of collision were copied from the precrash simulations and fed to the crash simulations as the initial condition. The vehicle model and the pedestrian model were placed on a rigid flat plate representing the ground. The gravity was applied to the entire model after the initiation of crash simulation. Contacts were defined between the vehicle body panels and the pedestrian body surface. Injury risk was predicted only for the head as a proof of concept study. Each simulation was performed until the head contacted the vehicle body. Then the head injury criterion (HIC_{15}) was calculated. A serious head injury was considered to have occurred when the HIC_{15} value exceeds 700. The brain injury risk was not predicted in this study. The injury mitigation effect of AEB was estimated as the reduction of HIC_{15} value.

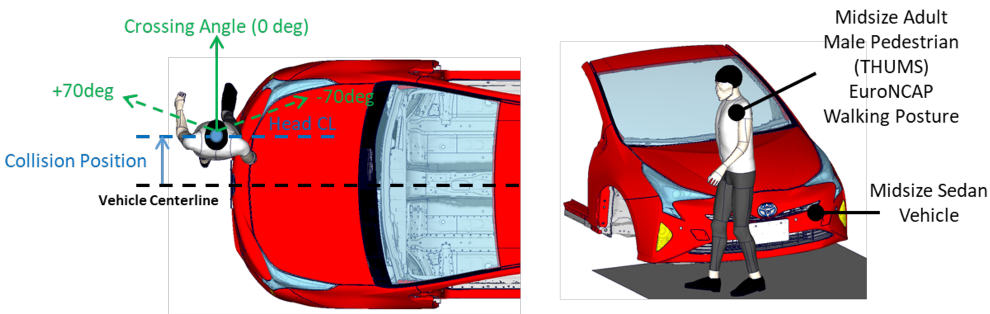
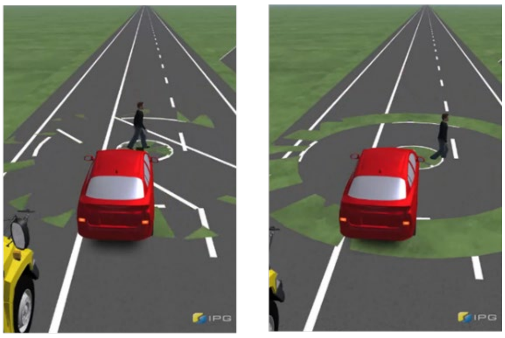


Fig. 2 Sample simulation model for vehicle-pedestrian collision. Midsize sedan vehicle and midsize adult male pedestrian were assumed. Parameters were determined based on precrash simulation results.

III. INITIAL FINDINGS

Precrash Simulations

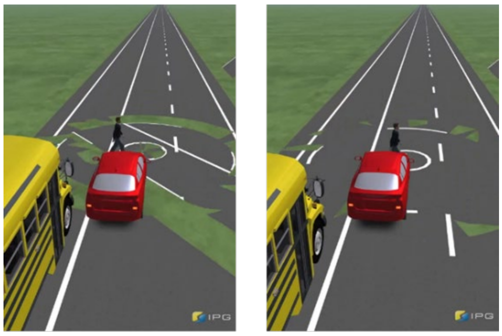
Without AEB, collision was avoided in 312 out of 385 cases. In these same 312 cases, the collision also was avoided with AEB. Result (a) therefore was found to be 312. Collision was not avoided without AEB in 73 cases. In 61 cases of these 73, collision was avoided by activating the AEB. The numbers of results (b) and (c) were 61 and 12, respectively. As a result, the collision avoidance effect of AEB in the simulation cases was estimated at 83.6%. Figure 3 shows a pair of examples of the results (b) in which collision occurred without AEB but was avoided with AEB. The conditions other than AEB were the same in the two cases. When the driver detected the pedestrian coming out from behind the bus, it was too late for the driver to stop the vehicle in front of the pedestrian. With AEB, the brake was immediately activated when the sensor detected the pedestrian in FOV. It was early enough to stop the vehicle before reaching the pedestrian. Figure 4 shows another pair of examples of the results (c) in which collision occurred both with and without AEB. The timing of pedestrian detection was late in both cases. However, the vehicle speed at the time of collision was lower in the case with AEB.



Without AEB
Collison Occurred
Speed: 37.9 km/h

With AEB
Collison Voided
(Speed: 0 km/h)

Fig. 3 Example of results (b) in which collision occurred without AEB but was avoided with AEB.



Without AEB
Collison Occurred
Speed: 52.8 km/h

With AEB
Collison Occurred
Speed: 12.7 km/h

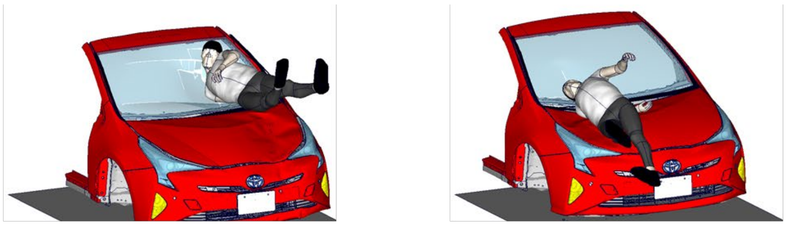
Fig. 4 Example of results (c) in which collision occurred both with and without AEB.

Crash Simulations

Crash simulations were conducted for the 12 collision cases predicted by the precrash simulations. Figure 5 shows the pair of examples corresponding to those in Figure 4. In the first case, the vehicle speed was 52.8 km/h at the time of collision. The pedestrian position was at the left of the vehicle front. In the second case, the vehicle speed was 12.7 km/h; the pedestrian position was at the right. Each frame shows the pedestrian motion when the head contacted the vehicle body. The head contacted the windshield glass in both cases. The calculated HIC_{15} value was 385 in the first case while 4.29 in the second case. The comparison indicates the injury mitigation effect of AEB in the selected two cases. Figure 6 shows the distribution of collision speeds in each group (with/without AEB) of 12 cases. The collision speed ranged from 10 km/h to 60 km/h without AEB while it ranged no more than 30 km/h with AEB. Figure 7 shows the distribution of HIC_{15} values in each group (with/without AEB) of 12 cases. The highest HIC_{15} value exceeded 700 without AEB while no more than 300 with AEB. The average HIC_{15} value with AEB was lower than that without AEB by 68%.

IV. DISCUSSION

The collision avoidance effect of AEB, as estimated at 83.6% by the precrash simulations, was mainly due to the fast activation and braking of AEB immediately after detecting the pedestrian. The human driver takes time from pedestrian detection to braking; the duration of free travel, the deceleration rise rate, and the maximum deceleration can all vary between individuals and even between events for a single driver. As long as pedestrians are detected perfectly, AEB is more advantageous in avoiding collisions owing to the fast activation and braking compared to the human driver. Yet, the study results also highlights the injury mitigation effect of AEB. The reduction of collision speed worked to mitigate the impact severity even if the collision was not avoided. The resultant HIC_{15} value was also influenced by the stiffness of the vehicle body part where the head contacted. A contact with the A-pillar could raise the HIC_{15} value even at low speed. Nevertheless, the calculated HIC_{15} values with AEB were distributed in the lower range compared to those without AEB. This suggests that the injury mitigation effect of AEB was robust against variation of head contact point.



Without AEB
Collison Occurred
Speed: 52.8 km/h
Contact Position: Left
HIC_{15}: 385

With AEB
Collison Occurred
Speed: 12.7 km/h
Contact Position: Left
HIC_{15}: 4.29

Fig. 5 Crash simulation results corresponding to precrash simulation results (c) where collision occurred both with and without AEB.

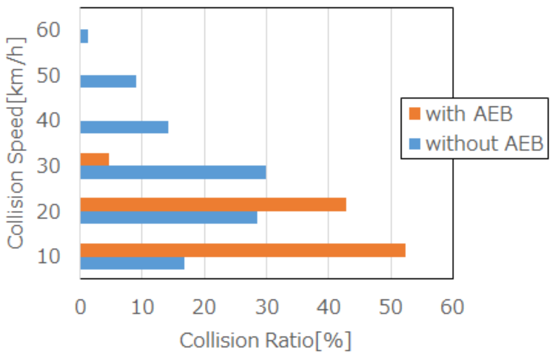


Fig. 6 Distribution of collision speeds in 12 cases with and without AEB. Collision speeds with AEB ranged lower than without.

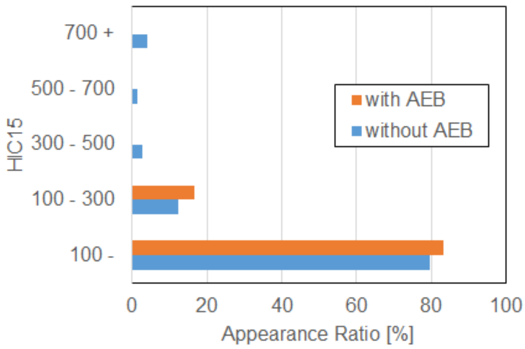


Fig. 7 Distribution of HIC_{15} values in 12 cases with and without AEB. HIC_{15} values with AEB ranged lower than without.

It should be noted that the simulation model did not include any errors in human or system performance. The driver model did not mimic any errors such as distraction or lack of attention but perfectly recognised the pedestrian when entering FOV. The AEB model did not miss the pedestrian in FOV but instantly started braking when detecting. The actual effect of AEB may be higher or lower than the estimate depending on the driving situations. Despite such limitations, the simulation technology is considered to be effective for quantitatively estimating the effect of AEB. In this study, only HIC_{15} values were used to estimate the injury mitigation effect as a proof of concept. Future research will focus on other collision scenarios, strain-based (brain) injury prediction, and whole-body injury assessment.

V. REFERENCES

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