ESTIMATION OF THE EFFECT OF AUTONOMOUS EMERGENCY BRAKING SYSTEMS FOR PEDESTRIANS ON REDUCTION IN THE NUMBER OF PEDESTRIAN VICTIMS

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ABSTRACT

Considering the significant sensitivity of impact velocity to pedestrian casualty rate, it is important to accurately estimate the effect of autonomous emergency braking systems for pedestrians (AEBP) on the casualty rate to further reduce pedestrian victims. This study developed a methodology to estimate the reduction of pedestrian casualties resulting from AEBP activation by applying the exact logic of a particular AEBP system to Japanese accident statistics. Focus was given to the sensitivity of applying the exact logic of a particular AEBP system and the parameters considered in the fatality/serious injury rate prediction to the estimated effect of the AEBP system.

Due to the difference in accident parameters relevant to the function of the AEBP system and the impact configurations and outcomes, two sets of accident data, which include different accident parameters with some overlap, were used to estimate the distribution of impact speed and the reduction in the fatality/serious injury rates. One dataset was used to estimate the impact speed distribution by applying the exact logic of a particular AEBP system, and the other dataset was used to determine the fatality/serious injury rates. The reduction of the number of victims was estimated by lumping the estimated impact speed distribution and the estimated fatality/serious injury rates into the accident scenarios defined by the common parameters. The sensitivity to the reduction in the number of victims was investigated for the application of the exact logic, and the parameters considered in the estimation of the fatality/serious injury functions.

The estimated reduction in the number of victims was 20% for the AEBP system investigated in this study. Relative to the use of a simple logic of the system, the application of the exact logic of the system resulted in the difference in the estimated reduction of fatalities and serious injuries by 5% and 12%, respectively. The most severely injured body region, the pedestrian age, and the vehicle category are the most sensitive to the estimated effect among the accident parameters used in the dataset relevant to impact configurations and outcomes except for the vehicle travel speed.

INTRODUCTION

According to Japan accident statistics (Institute of Traffic Accident Research and Data Analysis [1]) in 2014, pedestrians accounted for 36.4% of all traffic fatalities and 21.9% of all serious injuries. This suggests that reduction of pedestrian victims in traffic accident is one of the most important issues to further reduce the number of the traffic accident victims.

In order to reduce pedestrian victims in traffic accidents, crash safety performance for pedestrian has been evaluated by New Car Assessment Programs (NCAPs) and regulations. On the other hand, Autonomous Emergency Braking systems for Pedestrian (AEBPs) have been developed and adopted to some production vehicles in order to mitigate or even avoid pedestrian accidents. Considering the significant sensitivity of impact velocity to pedestrian casualty rate, it is important to accurately estimate the effect of AEBP on the casualty rate to further reduce the number of pedestrian casualties in traffic accident.

Since the AEBP system alters the impact speed distribution of pedestrian accidents, the following steps are needed to estimate the effect of AEBP on the reduction of the number of pedestrian victims in traffic accident. First, the change of the distribution of impact speed with AEBP activation is estimated for each of the accident scenarios. Then, the fatality/serious injury rate is estimated for the same accident scenarios. Finally, the reduction of the number of pedestrian victims is estimated by combining them. The entire range of pedestrian accidents needs to be taken into consideration for accirate estimation. Ferenczi et al. [2] and Paez et al. [3] estimated the effect of the AEBP system from the actual logic of the system. However, their studies focused only on some specific accident scenarios which do not represent the entire pedestrian accident. Rosen [4] estimated the effect of the AEBP on the reduction of the number of the pedestrian victims by using the German In-Depth Accident Study (GIDAS) database. Fredriksson et al. [5] investigated the effect of the AEBP system on the reduction of the head injury probability in accidents from the GIDAS database where pedestrians sustained head injuries. Although these studies considered the entire pedestrian accidents, they estimated the effect of AEBP systems by applying one single fatality/serious injury rate as a function of impact speed to the entire range of accident scenarios. Lubbe et al. [6] estimated the reduction of the casualty cost by the AEBP also by capturing the entire pedestrian accidents. However, they predicted the distribution of impact speed using only one single time to collision (TTC) to the vehicle without taking into consideration the relevant accident parameters such as the vehicle travel speed and the walking direction and speed of a pedestrian. Although Chauvel et al. [7] determined the fatality/serious injury rate functions for different impact speed and pedestrian ages, they did not consider other relevant parameters, such as the injured body regions, vehicle category and direction of vehicle travel, which could affect the fatality/serious injury rate. None of the past studies considered all of the aforementioned steps needed to be considered for accurate estimation.

The objective of this study is to develop a methodology to estimate the reduction of pedestrian victims with AEBP activation by applying the exact logic of a particular AEBP system and fatality/serious injury rates as a function of relevant accident parameters to the entire range of Japanese pedestrian accident statistics. As it is impossible to validate the estimated effect of a particular AEBP system due to the lack of the accident data, this study investigates the sensitivity of the application of the exact logic of the system as well as the use of relevant parameters considered in the fatality/serious injury rates to the estimatoin of the effect of the system.

METHODS

The reduction of the number of pedestrian fatalities and serious injuries were estimated by using two sets of the accident data with the following steps:

1. Estimate the impact speed distribution by AEBP for each of the accident scenarios defined by the accident parameters relevant to the function of the AEBP system
2. Determine the fatality/serious injury rates as functions of the impact speed for each of the accident scenarios determined by the accident parameters relevant to the crash conditions and injury outcomes.
3. Lump the estimated impact speed distributions and the fatality/serious injury rate functions into the accident scenarios defined by the common parameters to estimate the reduction of the number of pedestrian fatalities and serious injuries by combining them.

Accident Dataset

This study used accident data collected by the Japan Institute for Traffic Accident Research and Data Analysis (ITARDA) from year 2009 to 2011. The ITARDA data includes all of the pedestrian accidents resulting in fatalities and injuries that occurred nationwide. Two accident datasets were extracted from the same pedestrian accident data. One dataset (hereafter called Dataset A) was used for the estimation of the change of impact speed distribution, while the other dataset (hereafter called Dataset B) was used for the determination of the fatality/serious injury rates. The following inclusion criteria were used for Dataset A:

1. Accidents that do not involve a backing vehicle
2. First collision to a pedestrian
3. Walking or running pedestrian
4. Passenger vehicle or mini vehicle (so called Kei-car).
5. Pedestrian collision to the front of the vehicle
6. Vehicle travel direction is either straight forward or turn left/right

The fatality/serious injury rates were assumed to vary by the vehicle type, injury source, and most severely injured body regions, while they were assumed not to affect the estimation of impact speed distribution by AEBP. Dataset B was extracted by adding the following inclusion criteria:

1. A passenger vehicle categorized in 8 vehicle types (small sedan, mid-sized sedan, large sedan, mini-van, SUV, sports car, Kei-car and mini freight vehicle)
2. A pedestrian not injured by the vehicle tires
3. A pedestrian whose most severely injured body region is known

Although the total number of the accidents in Dataset B was different from that in Dataset A, the influence of this difference was assumed to be negligible based on the assumption that these additional inclusion criteria would not affect the estimation of impact speed distribution. Dataset A consisted of the accidents defined by the parameters relevant to the function of the AEBP system, including the accident time, weather, impact location, vehicle travel speed, vehicle travel direction and pedestrian walking direction. Dataset B consisted of the accidents defined by the parameters relevant to the crash configuration and outcome, including the impact location, vehicle travel speed, vehicle travel direction, pedestrian walking direction, most severely injured body region, vehicle category, pedestrian age, gender, injury source. Both datasets shared the common accident parameters (impact location, vehicle travel speed, vehicle travel direction and pedestrian walking direction) so that the reduction of the number of the pedestrian victims can be estimated from the estimation of the impact speed distribution with the AEBP system. The accident parameters and their levels used in both accident datasets are summarized in Tables 1 to 3. Figure 1 shows the definition of the pedestrian walking direction and vehicle travel direction. "Forward" in the pedestrian walking direction is set as the opposite direction to the traveling direction of the load, while "Forward" in the vehicle travel direction is set as the same direction as the rtaveling direction of the load. Due to the lack of the detailed information for the vehicle travel direction in the accident data, "Turn Left" and "Turn Right" in the vehicle travel direction is assumed to be 45 degree from "Forward".

Table 1.
Specific parameters for Dataset A

Parameters	Levels
Accident Time	Dawn, Dusk, Night, Day
Weather	Rain, Cloud, Shine

Table 2.
Common Parameters for both Dataset A and Dataset B

Parameters	Levels
Impact Location	Center, Right, Left
Vehicle Travel Direction*	Forward, Turn Left, Turn Right
Pedestrian Walking Direction*	Left, Right, Forward, Rearward, Left Rearward, Left Forward, Right Forward, Right Rearward
Vehicle Travel Velocity (km/h)	0-10, 0-20, 20-30, 30-40, 40-50, 50-60, 60-70

* Vehicle travel direction and pedestrian walking direction were identified in Figure 1

Table 3.
Specific Parameters for Dataset B

Parameters	Levels
Pedestrian Age (years old)	0-6, 7-11, 12-15, 16-44, 45-64, 65-74, 75-84, 85-
Gender	Female, Male
Vehicle Category	Small Sedan, Middle Sedan, Large Sedan, Kei-car, Minivan, SUV, Sports, Mini Freight Vehicle
Injury Source	Vehicle, Other
Most Severely Injured Body Region	Whole Body, Head, Face, Neck, Chest, Abdomen, Back, Lumbar, Arm, Leg

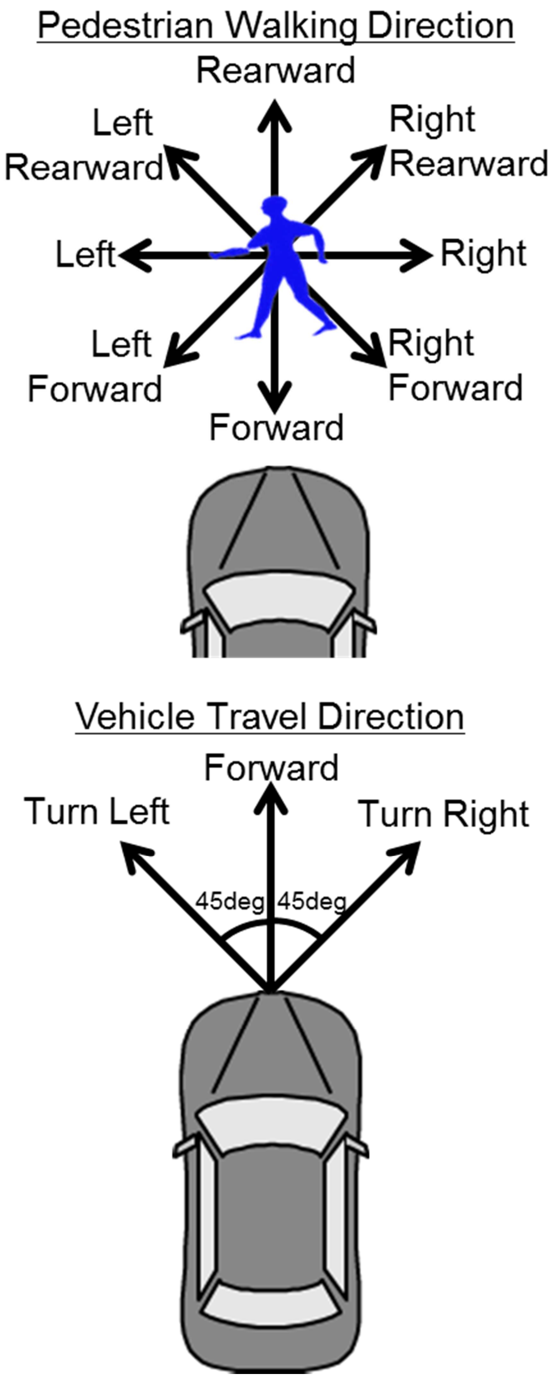

Figure 1. Definition of the pedestrian walking direction and vehicle travel direction. Note: "Turn Left" and "Turn Right" in vehicle travel direction is assumed to be 45 degree from "Forward".

Estimation of the Change of the Impact Speed Distribution by AEBP

In some accidents, the AEBP system cannot detect a pedestrian due to the low visibility in the night and heavy rain. For this reason, the impact speed distribution for each accident scenario in Dataset A was calculated from the weighted average of the impact speed distributions for the detectable and non-detectable conditions by using the pedestrian detection rates as the weighting factor.

The impact speed distribution from the accident data was used for the accident scenarios in non-detectable conditions. On the other hand, the impact speed distribution in detectable conditions was estimated by applying the location of the pedestrian in the direction of vehicle travel when the pedestrian is at 5 m laterally to the vehicle (hereafter called appearance of the pedestrian), walking direction, speed relative to the vehicle and vehicle speed to the AEBP system logic.

The detection rates for night and rain were assumed from the other data source [8] due to the lack of the accident data. For accident time, the detection rate at night was assumed to be 0.3 by considering the light distribution of the headlight. The detection rate at dawn and dusk was assumed to be the average of the detection rate at daytime and night. For weather, the detection rate during rain was assumed to be 0.9 by considering the frequency of the rainy day whose amount of rainfall in a day exceeded thirty millimeters, which was assumed to provide low visibility, obtained from in the Tokyo weather statistics collected by the Japan Meteorological Agency [8]. The pedestrian detection rate for each accident scenario was estimated by multiplying the detection rates for the time and the weather.

Appearance of the pedestrian Although the appearance of the pedestrian and the walking speed of the pedestrian relative to the vehicle are needed to estimate the impact speed distribution by using the exact logic of an AEBP system, these were not included in the accident data. Since this study assumed that there was no braking by the driver and no effect of the warning by the system due to the lack of the accident data, the appearance of pedestrian was defined by Equation 1.

$$L_x = {(v_0 - v_{px}) \times (L_y - L_{IP})}\Big/{v_{py}} \qquad \textbf{(Equation 1)}$$

where v_0 is vehicle travel speed, v_{px} is the component of the walking speed in the direction of vehicle travel, v_{py} is the component of the walking speed perpendicular to the direction of vehicle travel, L_y is the lateral position of the appearance of pedestrian in the side walk relative to the vehicle and L_{IP} is the lateral impact location of the pedestrian to the vehicle. In this study, L_y was set at 5 m by considering the width of the traffic lane and side walk in Japan. The pedestrian walking speed was assumed to be normally distributed whose average and standard deviation was determined from Sekine et al. [9] (average and standard deviation were 1.5m/s and 0.15m/s, respectively). Since the accident data only classifies the impact location into left, center and right, each of the impact location was divided into five detailed area. The lateral impact location (L_{IP}) was defined by the center of each detailed areas. In addition, the occurrence probability of each detailed area in the simplified impact location was assumed to be same. The pedestrian walking direction relative to the vehicle was defined from the vehicle travel direction and pedestrian walking direction.

Impact speed distribution with AEBP activation

The impact speed for each combination of the pedestrian walking speed and the detailed impact location was estimated by applying these conditions to the exact logic of a particular AEBP system. The impact speed distribution in the detectable condition for each scenario was calculated from the weighted average of the impact speed estimated for each combination of the pedestrian walking speed and the detailed impact location by using the occurrence probability as the weighting factor.

Determination of the Fatality/Serious Injury Rate

The fatality/serious injury rate was determined from Dataset B as function of the vehicle travel speed for each of the accident scenarios define by the parameters relevant to impact configurations and outcomes except for the vehicle travel speed. The fatality rate was defined as the ratio of the number of fatalities to the summation of the number of fatalities, serious injuries and minor injuries, while the serious injury rate was defined by the ratio of the number of serious injuries to the summation of the number of fatalities, serious injuries and minor injuries.

Estimation of the Reduction of the Number of the Pedestrian Victims

The number of the pedestrian fatalities and serious injuries was estimated by using the impact speed distribution with AEBP activation and the fatality/serious injury rates as a function of the accident parameters.

Since the total number of the accidents and accident parameters differ between Dataset A and Dataset B, the impact speed distribution for each accident scenario in Dataset A was averaged for each of the accident scenarios defined by the common accident parameters by using the frequency of each accident scenario defined in Dataset A as weighting factor. The same procedure was also applied to the fatality/serious injury rates estimated for each of the accident scenarios defined in Dataset B.

The reduction of the number of pedestrian fatalities/serious injuries were estimated by multiplying the estimated distribution of the impact speed by the fatality/serious injury rates as functions of the impact speed for each of the accident scenarios defined by the common accident parameters.

Sensitivity Analysis to the Estimation

Sensitivity of applying the exact logic of AEBP system In order to clarify the sensitivity of applying the exact logic of AEBP system, the estimated reduction of the number of pedestrian fatalities and serious injuries were compared between the use of a simple logic of AEBP system and the exact logic of a particular AEBP system. The activation of a particular AEBP system used in this study is determined from the estimation of a possibility of an impact when the driver tries to avoid the impacts with the pedestrian by varying the TTC for the activation for each of the accident scenario. A simple logic was defined by using one single TTC determined by the average TTC of the brake activation by the logic of the system used in this study to determine the timing of the brake activation, as has been done by Rosen et al. [4] and Fredriksson et al. [5]. In this analysis, the fatality and serious injury rates were determined as a function of all of the relevant accident parameters.

Sensitivity of the parameters considered in estimating fatality/serious injury rate function In order to clarify the sensitivity of the parameters considered in estimating the fatality/serious injury rate functions to the effect of the AEBP, the reduction of the number of pedestrian fatalities and serious injuries estimated by eliminating each of the parameters defined in Table 3 from the consideration of fatality/serious injury rate functions individually were compared to the baseline. The estimation from the use of the exact logic of a particular AEBP system and fatality/serious injury rates as a function of all of the relevant accident parameters was used as the baseline condition.

RESULTS

Sensitivity of Applying the Exact Logic of AEBP System

Figure 2 shows the estimated percent reduction of the number of pedestrian fatalities and serious injuries with each of the exact logic and the simple logic of the AEBP system in the condition when the fatality/serious injury rates were determined for each of the accident scenarios determined by all of the relevant accident parameters. The percent reduction of the number of the fatalities and serious injuries with the exact logic were 33% and 18%, respectively, while those with the simple logic were 38% and 30%.

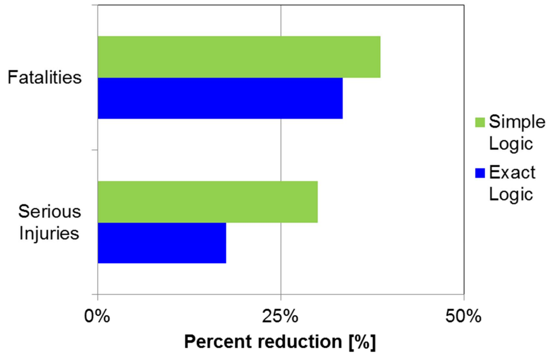

Figure 2. Comparison of the percent reduction of the number of pedestrian fatalities and serious injuries between the exact logic and the simple logic of the AEBP system.

Sensitivity of the Parameters to Be Considered in Fatality/Serious Injury Rate Function

Figure 3 and 4 show the comparison of the percent reduction of the number of pedestrian fatalities and serious injuries for each of the estimations calculated by eliminating each of the parameters defined in Table 3 from the consideration of fatality/serious injury rate functions individually. Eliminating the most severely injured body region and the pedestrian age from the consideration of fatality/serious injury rate functions were the most sensitive to the reduction of the number of fatalities. On the other hand, the most severely injured body region and the vehicle category were the most sensitive to that of serious injuries.

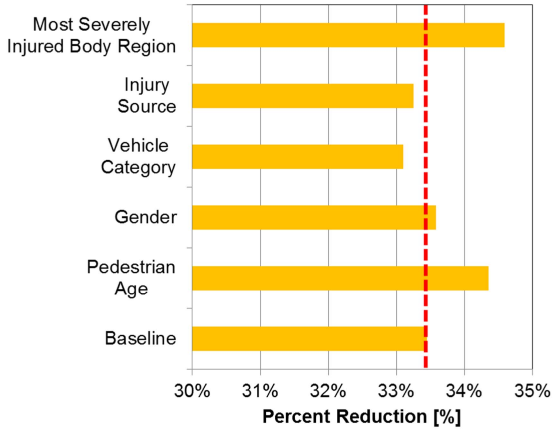

Figure 3. Percent reduction of the fatalities from the baseline condition (consideration of all parameters into fatality/serious injury rate function shown by the red dashed line).

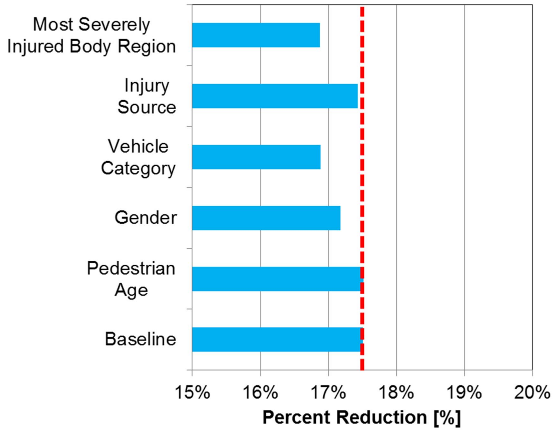

Figure 4. Percent reduction of the serious injuries from the baseline condition (consideration of all parameters into fatality/serious injury rate function shown by the red dashed line).

DISCUSSION

Figure 2 shows that applying the exact logic of a particular AEBP system had a high sensitivity to the estimation of the number of fatalities/serious injuries. Since the TTC for the brake activation by the actual system was varied by the accident parameters, such as the vehicle travel speed and pedestrian walking direction and speed, the results suggest that the inclusion of such parameters in estimating the effect of the system is crucial for accurate prediction

Figure 3 shows that the most severely injured body region and the pedestrian age had the highest sensitivity to the estimation of number of pedestrian fatalities. For the most severely injured body region, Figure 5 shows the fatality rate for each MAIS by body region from US accident statistics (NASS-CDS: National Automotive Sampling System Crashworthiness Data System) analyzed by Yanaoka et al. [10], showing that fatality rate differed among the body region in same injury severity. Additionally, it was assumed that the injury severity was different among the body region even if the impact location of the body region to the vehicle was same due to the difference of the contact area and tolerance for the injury by the body region. These can be reasons for the high sensitivity of the most severely injured body region to the estimation of the fatalities. For the pedestrian age, Figure 6 shows the fatality rate for each MAIS by age from NASS-CDS analyzed by Yanaoka et al. [10], showing that fatality rate significantly increased with age in same injury severity due to the high frailty of the elderly. This can be one of the reasons for the high sensitivity of the pedestrian age to the estimation of pedestrian fatalities. On the other hand, the vehicle category had high sensitivity to the estimation of number of pedestrian serious injuries while the pedestrian age had low sensitivity to this. The injured body region which also has high sensitivity to the estimation of the number of serious injuries (see Figure 4) was determined from the interaction of the body region with the vehicle which is assumed to be varied among the vehicle category. This can explain the reason for the high sensitivity of the vehicle category to the estimation of number of pedestrian serious injuries. In addition, these suggest that considering the pedestrian age, the most severely injured body region and the vehicle category in estimating the fatality/serious injury rates as a function of impact speed is important to further improve the accuracy of the estimation of the effect of an AEBP system.

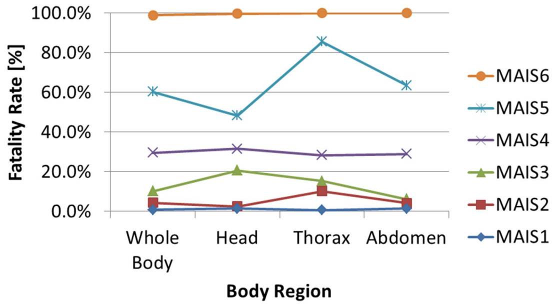

Figure 5. Fatality rate for each MAIS by body region (data from NASS-CDS from year 2001 to 2007). Adapted from Yanaoka et al. [10].

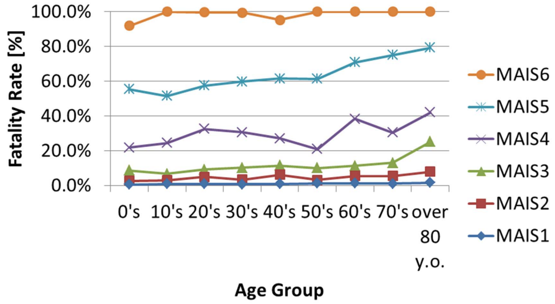

Figure 6. Fatality rate for each MAIS by age (data from NASS-CDS from year 2001 to 2007). Adapted from Yanaoka et al. [10].

Although this study developed the methodology to estimate the effect of the AEBP by applying the exact logic of a particular AEBP system to Japanese accident data, similar investigation needs to be done when estimating the effect of the AEBP system in other countries.

LIMITATION

This study assumed the detection rate at night and rain weather, and the pedestrian walking speed distribution was estimated from other data sources due to the lack of accident data. In addition, the effect of the warning by the system was ignored in this study due to the lack of data. These issues need to be further investigated for more accurate estimation when more data are available.

CONCLUSION

A methodology to estimate the effect of the AEBP on the reduction of the number of pedestrian victims was developed by applying the exact logic of a particular AEBP system. Following were also clarified; 1) Applying the exact logic of a particular AEBP system had a high sensitivity to the estimation of the number of fatalities/serious injuries, and 2) The most severely injured body region, the pedestrian age, and the vehicle category are most sensitive to the estimated effect among the accident parameters used in the dataset relevant to impact configurations and outcomes except for the vehicle travel speed.

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