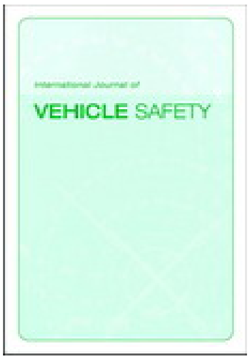

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Research on test scenarios of AEB pedestrian system based on knowledge and accident data

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Abstract: Since pedestrians are Vulnerable Road Users (VRU), the collision proportion and casualty rate are still high between vehicle and pedestrian, while the current Autonomous Emergency Braking (AEB) system lacks relative overall pedestrian test scenarios. Based on the National Automobile

Accident In-depth Investigation System (NAIS) in-depth accident data about the collision accidents between passenger car and pedestrian in 220 cases, five typical AEB pedestrian system scenarios are obtained by clustering analysis and chi-square test in this paper; then, based on the second typical scenario, three more severe test scenarios are obtained by analysing pedestrian-vehicle collision avoidance model and the actual road traffic situation in China from the perspective of user acceptance; finally, eight times field operation test shows that the test vehicle is subject to premature braking. This paper provides a reference for establishment and further optimisation of AEB pedestrian test scenario in China.

Keywords: AEB pedestrian system; accident in-depth investigation; clustering analysis; typical scenarios; user acceptance; field operation test.

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1 Introduction

Reducing road traffic accidents and improving vehicle safety has always been an appeal from consumers and also the goal pursued by vehicle manufacturers. Meanwhile, automated vehicles are also facing this problem. As an important part of automated driving, Advanced Driving Assistance System (ADAS) can help drivers avoid or mitigate accident hazards. The BASt's study shows that 70% of serious traffic accidents can be avoided by using ADAS (Vollrath et al., 2006). AEB system is one of the most concerned types in the ADAS system and has a great effect on improving vehicle safety. According to the research data provided by the Insurance Institute for Highway Safety (IIHS), the AEB system can reduce 27% of traffic accidents (Seewald, 2011).

The AEB system uses sensors to monitor the condition in front of vehicle in real-time and predict the hazard of current condition based on the algorithm. When the sensors detect a risk of potential collision in the front, the AEB system warns the driver to take measures to avoid danger. When the warning signal is not responded by the driver in time or braking force is insufficient, and collision risk becomes urgent, the AEB system avoids the occurrence of a collision accident or reduces the severity of a collision accident by using some active intervention measures, such as automatic braking (Wesley et al., 2013; Fildes, 2012; Fildes et al., 2015). The European New Car Assessment Programme (Euro NCAP) officially incorporated the AEB system into the new car assessment procedures in 2014 and include the AEB pedestrian system as part of the VRU protection (Euro NCAP, 2016). Since 2018, the China New Car Assessment Programme (C-NCAP) also began to include the AEB system in the scoring system, including the AEB pedestrian test (C-NCAP, 2018). The European APROSYS project has three types of pedestrian crash accident scenarios based on the GIDAS database (De Lange, 2014). The European vFSS designed four types of AEB pedestrian test scenarios by studying four databases (Niewöhner et al., 2011). AEB Group designed five test scenarios through clustering analysis method (Lesemann et al., 2012). Based on the actual road conditions recorded by the driving recorder, Lin et al. (2014); Liu et al. (2014) and Jiang et al. (2014) from Tongji University focused on the analysis of the AEB system test scenarios and simulated the test in PreScan. He et al. (2014) obtained the AEB test scenarios that meets the characteristics of road traffic in Shanghai and calculated the proportion of injured people that can be reduced by using the AEB system by analysing the rear-end conditions in Shanghai. Based on accident data, Chen et al. (2015) analysed three typical pedestrian hazard scenarios in China and obtained the result that the use of the AEB system can eliminate 20% of pedestrian collision accidents. Based on the analysis of pedestrian dangerous conditions in the natural driving data collected from five cities in China, Su et al. (2017) obtained four typical pedestrian traffic collision scenarios. However, none of the above studies involved the AEB system user acceptance test scenarios.

In recent years, the application of the AEB system in the Chinese market has gradually increased. However, the user experience and satisfaction related to the AEB system are different, which is inconsistent with the driving habits of Chinese drivers and complicated traffic environment in China, resulting in many complaints. In terms of the AEB system test scenarios, the current research focuses on security testing. Research on user acceptance test is very limited, but the AEB system has caused car recalls due to the defects in the face of complex road traffic environment filled with false alarms and misuses in China. Therefore, the user acceptance test of the AEB system still requires be subject to in-depth research. The ECE Regulation No. 131 stipulates that the scope of the AEB system only includes the situations in which braking can be used to avoid the occurrence of accident or mitigate the severity of accident during drive and no action is taken during normal drive (ECE Regulation No. 131, 2013). The research made by Sivaraman and Trivedi (2009) shows that the false detection rate of intelligent system used on vehicle is 19.82% and the false detection rate reflects whether the system will have misuses. When the German automotive club ADAC (Allgemeiner Deutsche Automobile Club) proposed to test the performance of the AEB system, it considered effectiveness test and reliability test, that is, whether the AEB system generates unnecessary alarms or too frequent alarms and other negative effects under normal circumstances (ADAC, 2011). Stellet et al. (2016) analysed the theoretical limitations of sensor measurement and uncertainty prediction models on the AEB system. Nilsson et al. (2015) proposed a method for evaluating the AEB system, based on sensor measurements and predictions of behaviours taken by surrounding road users. Jiang (2014) obtained dangerous conditions based on a large number of actual traffic conditions and proposed the AEB misuse conditions by combining with the data and literature related to accident conditions. Based on the statistical analysis of typical driving habits of Chinese drivers, Huang (2018) from Tongji University proposed typical AEB misuse scenarios for the unreasonable design of AEB system control strategy leading to premature alarm or braking. The AEB system's wrong or premature collision alarms not only cause driver dissatisfaction, but also may even cause acceptance reduction. Wrong or premature braking must be avoided by various methods; otherwise, the risk of collision may increase, instead of avoiding accidents. Therefore, the research on user acceptance to the AEB system has very important practical significance.

In view of the security test and user acceptance test of the AEB system, this paper firstly screens the cases of frontal collision between passenger car and pedestrian based on the NAIS in-depth investigation accident data, selects the parameter variables related to the function of the AEB system for clustering analysis and obtains typical AEB pedestrian system scenarios. Then, based on the typical scenarios, this paper proposes different test situations by analysing the pedestrian-vehicle collision avoidance model and the actual road traffic situation in China. Finally, the actual vehicle test results show that the AEB pedestrian system used on test vehicle is subject to premature braking, which provides a reference for optimisation of AEB pedestrian system.

2 Data sources

The basic data used in this paper is derived from the National Automobile Accident In-depth Investigation System (NAIS). NAIS mainly collects serious road traffic accidents in China. The collection range covers the alpine region in the Northeast, high temperature and humidity region in the South, mountainous and plateau areas in the Southwest, plain area in the North and coastal areas in the East. According to the information about accident scenes, the entire accident process is restored through PC-Crash simulation analysis, video analysis and traffic police data analysis. Meanwhile, it is refined into more than 2200 parameters for recording accident information.

By the end of 2018, there were 3185 accident cases in the NAIS database. There are 414 cases of collision accidents between vehicle and pedestrian, accounting for 13%, as shown in Figure 1. In view of the number of accidents, it is seen that the collision accident between passenger car and pedestrian is much higher than the motor two or three-wheeled vehicle, which is also VRU. This is inseparable from pedestrians' weak traffic safety awareness and much violations of traffic regulations in the actual road traffic in China. At the same time, the casualty of collision accident between vehicle and pedestrian is the highest in various types of accidents provided by the NAIS, i.e. 78%, as shown in Figure 2. Therefore, based on the NAIS actual accident data, it is of great practical significance to study the AEB pedestrian system test scenarios in China. Based on the applicable conditions of the AEB system, the following screening conditions are proposed in this paper:

1. The vehicle is a passenger car;
2. Only one pedestrian is involved;
3. Frontal collision between the vehicle and pedestrian;
4. Multiple collision accidents are excluded;
5. Reversing accidents are excluded.

Based on the above screening conditions, 220 cases are selected from the NAIS accident data. Analysing from pre-crash passenger car, pedestrian, road, environment and other factors to provide the reference for establishing the AEB pedestrian system test scenarios in China.

Figure 1 Distribution of NAIS accidents types

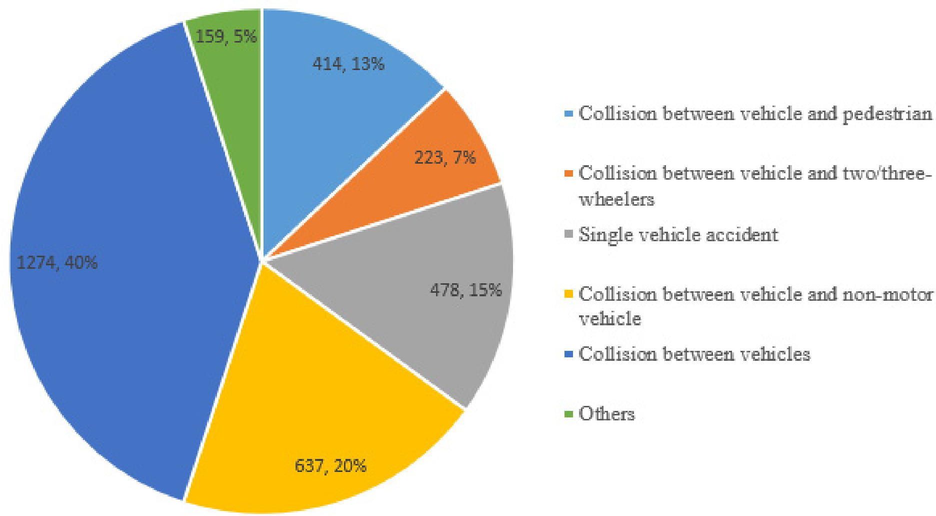
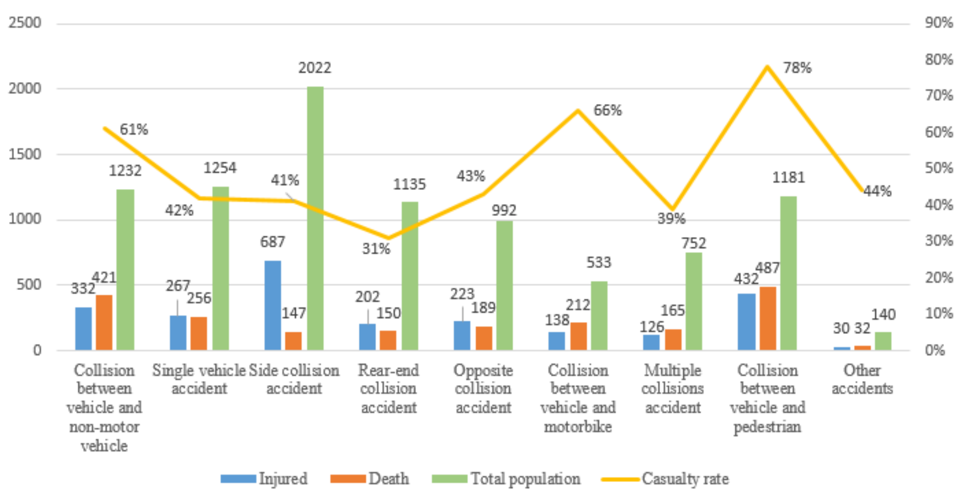


Figure 2 Casualties in various types of accidents



3 Clustering analysis and extraction of typical scenarios

3.1 Selection of parameter variables

Based on the analysis on more than 2200 parameter variables involved in NAIS, some parameters that are not suitable for clustering analysis are removed. For example, the difference of the variables of pedestrian type, casualty and whether the driver's sight is blocked is unobvious, as shown in Figure 3. Such parameters are not suitable for clustering analysis, but can be used as references in the design of specific scenarios to test the AEB system comprehensively. Meanwhile, the data of the AEB system that are related to sensors and easily to be replicated in the field operation test is combined to finally determine six parameter variables in four types, including road parameter, environmental parameter, test vehicle parameters and pedestrian parameters as follows:

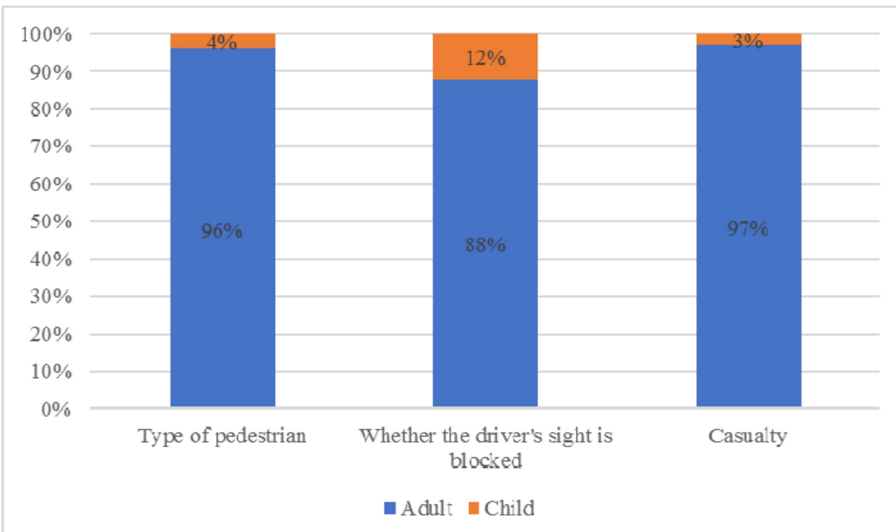
1 Road parameter: section;

2 Environmental parameter: light;

3 Test vehicle parameters: passenger car motion and speed;

4 Pedestrian parameters: pedestrian motion and speed.

Figure 3 Parameters with unobvious difference



The above six parameter variables are divided into two categories in this paper: interval scale variable and nominal scale variable. Specially, interval scale variable is a continuous variable, such as passenger car speed, while nominal scale variable is a category scale, such as section, light and passenger car motion, etc. Firstly, the value of each variable is numerically represented in Table 1.

3.2 Clustering analysis and chi-square test

In the clustering analysis, individuals or objects are classified, so that the similarities between objects in the same class are stronger than those between other objects. This paper uses the Hierarchical Cluster Method (He, 2010) to extract the typical scenarios of collision accidents between passenger car and pedestrian. It can avoid the influence of the analyst's subjective consciousness and has strong repeatability on the scenario classification (Su et al., 2017).

The calculation of distance in the clustering process includes three levels: variable, sample and class. The variables involved in this paper include interval scale variable and nominal scale variable. Specially, interval scale variable should firstly normalise all sample values when the distance is calculated. The distance between different variables is the absolute value of the normalised difference. The calculation of the distance between nominal scale variables should follow the principle that the distance is 0 when the variable values are the same and the distance is 1 when the variable values are different. Therefore, the three-valued variable should be converted into three two-valued variables. The specific calculation method is shown in Table 2.

Table 1 Types and values of variables

Variable	*Type of variable*	*Value of variable*	*Value representation*
Section	Nominal	Intersection straight road	1
			2
Light	Nominal	Daytime light at night no light at night	1
			2
			3
Motion of passenger car	Nominal	Go straight	1
		Turn left	2
		Turn right	3
Passenger car speed	Scale	7 (minimum speed)	0
		106 (maximum speed)	1
Motion of pedestrian	Nominal	Go straight along the road	1
		Cross the road from the left	2
		Cross the road from the right	3
Pedestrian speed	Nominal	Walk slowly	1
		Walk quickly	2
		Run	3

Table 2 Three-valued nominal scale variable calculation method

Light	*Before conversion*	*After conversion*		
Daytime	1	0	0.5	0.5
Light at night	2	0.5	0	0.5
No light at night	3	0.5	0.5	0

In this paper, 220 accident cases are regarded as 220 samples. The distance between samples is calculated by Squared Euclidean Distance. The distance between classes is calculated by between-groups linkage. Hierarchical Cluster Method is performed by using SPSS. According to the clustering coefficient, 220 samples are finally classified into 10 classes.

The clustering result of the nominal scale variables obtained by clustering analysis is shown in Table 3. The first six classes (accounting for 95% of the total samples) with relatively more samples are taken as research objects. Difference significance between different types of scenarios obtained in chi-square test can be used as a method to determine the typical value of variable (Li et al., 2014). For the non-significant variables, the proportion of different variable values' sample size accounting in the number of this type and the difference of different variables' value proportion are compared. The significant difference is used as the basis for selecting typical value. For example, the light specified in the first class does not have significant difference value after the chi-square test. The number of samples with light at night accounts for 36.1% in the number of first type of samples, while the number of samples no light at night accounts for 34.7%. The difference in number of samples by percentage is 1.4% and the difference between the two values' proportion is 10.5%. Therefore, no light at night is selected as a typical value for this variable. The green area represents the typical values in each class obtained in chi-square test (90% confidence), while the dark areas indicate the typical values obtained by comparison and analysis. In addition, the distribution of passenger car speed is shown in Table 4.

Table 3 Results of clustering analysis (see online version for colours)

Variable			*Type*							*Total*
			1	*2*	*3*	*4*	*5*	*6*	*7-10*	
Section	Number	Intersection	0	54	0	18	6	5	11	94
		Straight road	72	0	54	0	0	0	0	126
	Percentage/%	Intersection	0	57.45	0	19.15	6.38	5.32	11.70	
		Straight road	57.14	0	42.86	0	0	0	0	
	Chi-square value		53.71	72.38	40.29	24.13	8.04	6.70	14.74	
Light	Number	Daytime	21	15	11	14	6	0	1	68
		Light at night	26	27	25	2	0	3	6	89
		No light at night	25	12	18	2	0	2	4	63
	Percentage/%	Daytime	30.88	22.06	16.18	20.59	8.82	0	1.47	
		Light at night	29.21	30.34	28.09	2.25	0	3.37	6.74	
		No light at night	39.68	19.05	28.57	3.17	0	3.17	6.35	
	Chi-square value		1.34	2.16	2.81	18.55	13.41	2.24	2.46	
Motion of passenger car	Number	Go straight	72	53	54	15	0	0	1	195
		Turn left	0	1	0	1	4	0	4	10
		Turn right	0	0	0	2	2	5	6	15
	Percentage/%	Go straight	36.92	27.18	27.69	7.69	0	0	0.51	
		Turn left	0	10	0	10	40.00	0	40	
		Turn right	0	0	0	13.33	13.33	33.33	40	
	Chi-square value		9.23	5.09	6.92	0.58	62.44	68.33	69.10	

Table 3 Results of clustering analysis (see online version for colours) (continued)

Variable			*Type* 1	2	3	4	5	6	7-10	*Total*
Motion of pedestrian	Number	Go straight along the road	18	6	1	0	0	0	3	28
		Cross the road from the left	29	30	32	3	3	0	4	101
		Cross the road from the right	25	18	21	15	3	5	4	91
	Percentage/%	Go straight along the road	64.29	21.43	3.57	0	0	0	10.71	
		Cross the road from the left	28.71	29.70	31.68	2.97	2.97	0	3.96	
		Cross the road from the right	27.47	19.78	23.08	16.48	3.30	5.49	4.40	
	Chi-square value		9.79	2.05	7.19	13.31	0.89	7.09	2.11	
Pedestrian speed	Number	Walk slowly	66	45	0	0	6	2	4	123
		Walk quickly	5	7	33	9	0	3	1	58
		Run	1	2	21	9	0	0	6	39
	Percentage /%	Walk slowly	53.66	36.59	0	0	4.88	1.63	3.25	
		Walk quickly	8.62	12.07	56.90	15.52	0	5.17	1.72	
		Run	2.56	5.13	53.85	23.08	0	0	15.38	
	Chi-square value		37.61	16.93	68.56	24.45	4.73	3.26	10.41	
Total	Numbers		72	54	54	18	6	5	11	220
	Percentage/%		32.73	24.55	24.55	8.18	2.73	2.27	5	100

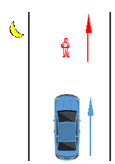
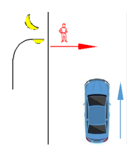
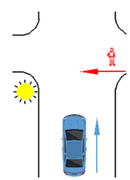
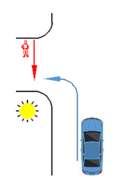
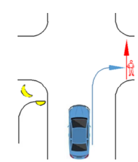
Table 4 Distribution of passenger cars speed

Type	*Vehicle speed* Average value	Value at 10%	Value at 25%	Value at 50%	Value at 75%	Value at 90%
1	55.33	30	40	54.9	68.5	84.5
2	52.94	34.85	40.25	54	63.45	69
3	61.85	41.5	50	60	71.8	80.7
4	49.06	32.9	37.75	50	59.5	72.4
5	19.67	12	17.75	22	24.75	25
6	32.66	21.8	23	32.5	41	43.88

3.3 Analysis and extraction of typical scenario

The typical values of nominal scale variables in accident scenarios obtained by clustering analysis are integrated, and interval scale variables' values are selected by the principle of appropriate rounding and multi-level increment of 10th percentile value. Considering the maximum collision avoidance speed of the current mainstream AEB system, the maximum speed of the tested vehicle is set to 80km/h. Based on the principle of pedestrian movement and considering the passenger car motion, five typical scenarios of AEB pedestrian system are obtained, as shown in Table 5.

Table 5 AEB Pedestrian system typical scenarios

Variable / *Type*	*1*	*2*	*3*	*4*	*5*
Section	Straight road	Intersection /Straight road	Intersection	Intersection	Intersection
Light	No light at night	Light at night	Daytime	Daytime	Light at night
Motion of passenger car	Go straight	Go straight	Go straight	Turn left	Turn right
Passenger car speed	30+10*n* (*n*=0, 1, 2, 3, 4, 5)	30+10*n* (*n*=0, 1, 2, 3, 4, 5)	30+10*n* (*n*=0, 1, 2, 3, 4, 5)	10+5*n* (*n*=0, 1, 2, 3)	20+5*n* (*n*=0, 1, 2, 3, 4)
Motion of pedestrian	Go straight along the road	Cross the road from the left	Cross the road from the right	Cross the road from the right	Cross the road from the right
Pedestrian speed	Walk slowly	Walk slowly/Walk quickly	Run	Walk slowly	Walk quickly
Simplified sketch					

Tables 3, 4 and 5 show that the first class typical scenario's sample number is relatively large, accounting for 32.73%, indicating that the conflict between passenger car and pedestrian going straight along the road ahead is still an important dangerous scenario in the actual road traffic environment in China. The clustering analysis result shows that the difference in sample size distribution under various lighting conditions is small. It indicates that such dangerous scenario is mainly caused by the negligence of human driver, which further illustrates the importance of studying the AEB system. The second class of typical scenario shows that there are pedestrians cross road from the left side of the passenger car on the straight road, reflecting the fact that Chinese pedestrians have serious violations of traffic rules when they are crossing road. Therefore, study on such scenarios has important practical significance. Although the sample size of the fourth and fifth scenarios is relatively small, it means the conflict with the pedestrian when the passenger car is turning. Its class characteristics are obvious and typical. Further analysis shows that the vehicle speed is relatively low, resulting in less probability of accident. It is the reason why the samples of these two scenarios are relatively low.

From the perspective of safety, the characteristics of collision accidents between vehicle and pedestrian in the NAIS in-depth accident data can be analysed to reflect the actual road conditions in China in a real and effective method. The available typical scenarios of AEB pedestrian system can be used as the basic scenario to test the AEB pedestrian system.

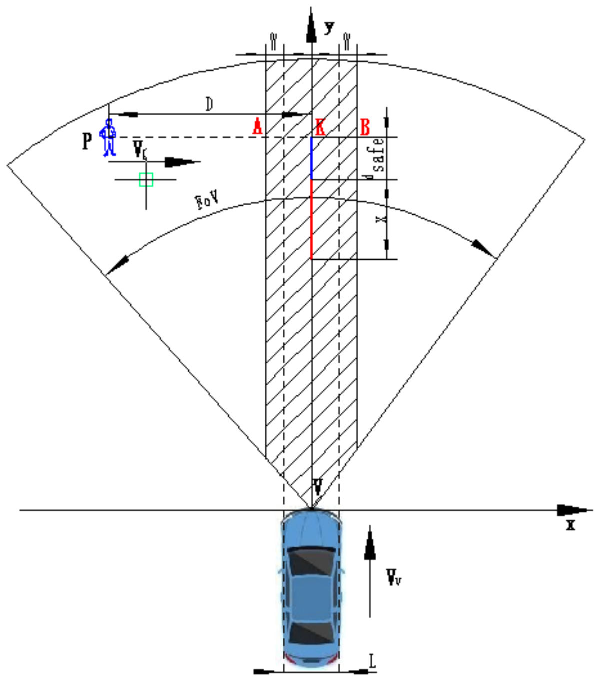
4 Analysis of user acceptance test based on typical scenarios

4.1 Analysis of pedestrian-vehicle collision avoidance model

The test on the AEB system can be divided into three categories as follows: the first is to test whether the AEB system is effective, that is, whether collision can be avoided or mitigated; the second is to test whether the AEB system has a misuse, that is, whether it gives alarm or makes brake when it should not work; and the third is to test whether the AEB system is too conservative, that is, whether it gives alarm or braking too early. The test expressions of first two types are relatively straightforward and intuitive, so the research is relatively easy. However, the conservativeness of the AEB system requires considering many factors, so the research is more difficult. If the AEB system is too conservative, it may cause driver dissatisfaction and even bring challenge to market acceptance. Therefore, from the perspective of user acceptance, this paper studies the more severe test scenarios of the AEB pedestrian system based on the typical scenario of pedestrian crossing the road from the left. This method can provide a reference for derivation of other typical scenarios.

The key to the AEB system is collision avoidance algorithm. The collision avoidance algorithm determines the timing and logic of warning. The core problem is to determine the timing of intervention. The AEB system alarm and braking time must be determined in combination with the vehicle braking performance and drivers' driving habits. For braking moment, two principles must be followed: firstly, braking moment should be later than the drivers' latest braking moment and the drivers' latest turning moment; secondly, the braking moment should be earlier than the latest braking moment of braking system (ECE, 2009). The AEB pedestrian system is firstly required to predict the trajectory of vehicle and pedestrian to determine whether there is a possibility of collision. If the prediction time is too early, there is a case where the activation time of the AEB system is correspondingly advanced, but it will increase the possibility of AEB misuse when the prediction time is out of the theoretical range (Eckert et al., 2013; Park et al., 2017). Therefore, this paper establishes the following model to analyse the collision situation of pedestrian crossing the road in front of the vehicle.

Figure 4 Pedestrian-vehicle collision avoidance model



As shown in the figure, the coordinate system is established by taking the road position at the front centre of the vehicle as the origin and the front of the road where the vehicle is located as the positive direction of the *Y*-axis. Where: vehicle speed is V_V, pedestrian speed is Vp, intersection of vehicle path and pedestrian path is $K(0, y_P)$, vehicle position coordinate is $V(0, y_v)$, initial position coordinates of vehicle are $V(0,0)$, pedestrian position coordinates are $P(x_p, y_p)$, initial position coordinate of pedestrian is $P_0(x_0, y_p)$ and W is the trigger width, which refers to the maximum lateral distance between the pedestrian and the side of vehicle when the pedestrian is identified as a dangerous obstacle and the AEB system is triggered. Considering the reality, the collision between the pedestrian and the left side of vehicle is excluded. Therefore, the possibility that the vehicle collides with the pedestrian in current state is satisfied with the following two conditional equations:

$$-\left(\frac{L}{2}+W\right) \le x_0 + V_P t \le \frac{L}{2}+W \tag{1}$$

$$V_v t = y_p \tag{2}$$

When it is judged that the pedestrian will collide with the vehicle, it enters the AEB system collision avoidance process. The current collision avoidance algorithms mainly include two types: safety distance logic algorithm and safety time logic algorithm (Song et al., 2008). The safety distance logic algorithm takes the distance as the judgment index and determines vehicle safety distance threshold based on the vehicle speed. The safety time logic algorithm uses time as the judgment index to indicate the time from the current situation to the occurrence of collision.

Depending on simulation software, four safety distance models (i.e. Mazda model, Honda model, Berkeley model and Seungwuk Moon model) and TTC model are analysed (Hu et al., 2017). It is concluded that the longitudinal collision avoidance performance of TTC algorithm is optimal without disturbing the driver's normal driving. Therefore, TTC algorithm is taken as the research algorithm to study the early alarm or braking of AEB system. TTC is the ratio of relative distance to relative speed. d is relative distance, V_{rel} is relative longitudinal speed. The longitudinal relative speed under the traverse condition is vehicle speed, as shown in equation (3). $TTC_{\max}$ is the time that the AEB system should adopt full braking to avoid collision. t_{ramp} is the response time of braking system, i.e. the time from starting brake to providing the maximum braking acceleration, as shown in equation (4). d_b is braking distance, indicating the sum of the minimum braking distance x and the safety distance d_{safe} ($d_{safe} = 3m$) (Hu et al., 2017), as shown in equations (5) and (6). When equation (7) is satisfied, the vehicle can be braked by full force to avoid collision.

$$TTC = \frac{d}{V_{rel}} \tag{3}$$

$$TTC_{\max} = \frac{d}{V_{rel}} + t_{ramp} \tag{4}$$

$$v_v^2 - v_0^2 = -2a_{\max} x \tag{5}$$

$$d_b = x + d_{safe} = \frac{v_0^2}{2a_{\max}} + d_{safe} \tag{6}$$

$$TTC \le TTC_{\max} \tag{7}$$

Specially, the maximum deceleration $a_{\max}$ and braking system response time t_{ramp} are related to the vehicle braking system. Different vehicles have different values, while the specific values can be obtained through test, which is regarded as known values. Therefore, the obtained collision avoidance model is a function related to vehicle speed, as shown in equation (8).

$$TTC \le TTC_{\max} = \frac{v_0}{2a_{\max}} + \frac{3}{v_0} + t_{ramp} \tag{8}$$

In view of the above analysis of pedestrian-vehicle collision avoidance model, the more rigorous test situation 1 for AEB pedestrian system is designed. It is based on the second typical scenario obtained in Part 3, and considered the convenience for field operation test and existence of excessive setting of the trigger width W and longitudinal safety distance d_{safe}. That is to say, where the vehicle and pedestrian maintain initial motion and the test vehicle AEB system does not work, the test vehicle reaches the point *K* and the pedestrian will not collision with vehicle, as shown in the Table 6.

Table 6 Pedestrian-vehicle collision avoidance model test scenario

Situation	*Section*	*Light*	*Motion of passenger car*	*Passenger car speed*	*Motion of pedestrian*	*Pedestrian speed*
1	Straight road	Daytime	Go straight	30+10*n* (*n*=0,1,2,3,4,5)	Cross the road from the left	Walk slowly, stop by the right side of the vehicle Xm

4.2 Test situation under actual road traffic conditions

A research by Lv et al. (2017) shows that drivers have the lowest acceptance to ADAS on urban roads. The AEB system judges whether there is danger in the current state of motion, but the motion state of pedestrian is uncertain in reality. There are three modes for pedestrian crossing the road: once crossing, twice crossing and rolling gap crossing strategy (Zhou, 2017). In Chinese complicated road traffic environment, twice crossing and rolling gap crossing strategy undoubtedly put forward higher requirements for the AEB system.

Pedestrian twice crossing means the situation that when no vehicle passes on the pedestrian side, pedestrian continues to cross the side lane and wait at the middle of the road or at the pedestrians' safety island. When there is no vehicle passing on the other lane or the gap is large, pedestrian crosses the lane continuously (Zhou, 2017). Therefore, for the AEB pedestrian system, there is a situation where the equation (3) is satisfied when pedestrian is crossing the middle line of the road in twice crossing, but the walking speed of pedestrian gradually decreases until stop. The AEB pedestrian system has the trigger width W. That is to say, the AEB system may be triggered only when the danger target appears within the trigger width. Usually, the AEB trigger width is in the range of 0–5 m. Some AEB systems tend to set a wider trigger width for considering the recognition of cut-in condition. Therefore, there is a mistake where the objects on both sides of land may be identified as dangerous targets (Rosén, 2013; Liu, 2017) and test situation 2 is designed for this case. That is to say, when the test vehicle AEB system does not work, the vehicle moves to the point *K* of the intersection between the vehicle and pedestrian under initial condition, and the pedestrian moves under initial condition and then stops at the test vehicle left side Xm. Rolling gap crossing refers to a kind of discontinuous crossing behaviour of pedestrian in the process of crossing the road. In order to cross the road quickly, pedestrian chooses to cross the road and avoid conflict with vehicles by stopping, waiting, changing pace, backward motion and other ways (Zhou, 2017). Therefore, since pedestrian may stop or wait in the process of crossing the road, test situation 3 is designed. That means that the pedestrian moves under initial condition and then stops at the point *K*. Finally, the test situation for the second typical scenario of the AEB pedestrian system is shown in Table 7.

Table 7 AEB Pedestrian system test situations

Situation	*Section*	*Light*	*Passenger car motion*	*Passenger car speed*	*Pedestrian motion*	*Pedestrian motion status*
1	Straight road	Daytime	Go straight	30+10n (n=0, 1, 2, 3, 4, 5)	Cross the road from the left	Walk slowly, stop by the right side of the vehicle Xm
2	Straight road	Daytime	Go straight	30+10n (n=0, 1, 2, 3, 4, 5)	Cross the road from the left	Walk slowly, stop by the left side of the vehicle
3	Straight road	Daytime	Go straight	30+10n (n=0, 1, 2, 3, 4, 5)	Cross the road from the left	Walk slowly, stop on the point K

5 Field operation test

Since there are many conventional AEB pedestrian system simulation analyses and real vehicle tests, this paper selects three more rigorous situations of the second typical scenario to carry out field operation tests. The test vehicle AEB system is a system that integrates a millimetre-wave radar with a camera. During the test, ABD driving robot (including steering, braking and throttle robots), OxTS gyroscope, base station and pedestrian targets defined in Euro-NCAP and other devices are used for real-time acquisition of velocity, acceleration, pedestrian speed, TTC, relative longitudinal distance of test vehicle and other relevant data.

Figure 5 ABD driving robot, OxTS gyroscope and pedestrian target

In order to obtain the maximum deceleration $a_{\max}$ and response time t_{ramp} of the test vehicle, the field operation test in the third situation of the second typical scenario is performed at the first time. Test scenario parameter variable is daytime. The vehicle goes straight in a straight road at a speed of 30 km/h, and the pedestrian crosses the road at a speed of 5km/h (Liu et al., 2014; Yang et al., 2015) from the left side of the vehicle and then stops at the point *K*. When the vehicle AEB system does not work, the vehicle will collide with the pedestrian at the point *K*. The test result shows that the test vehicle successfully avoids collision. The difference between the test targets speed and setting speed is in the range of ±0.3 km/h, so the basic test requirements are met. The speed, acceleration, relative longitudinal distance and TTC are showed in the figures as follows.

Figure 6 Desired vehicle speed and actual speed

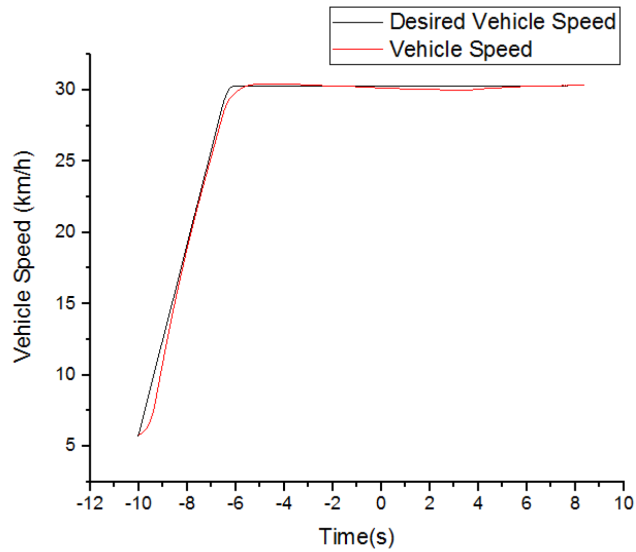


Figure 7 Desired pedestrian speed and actual speed

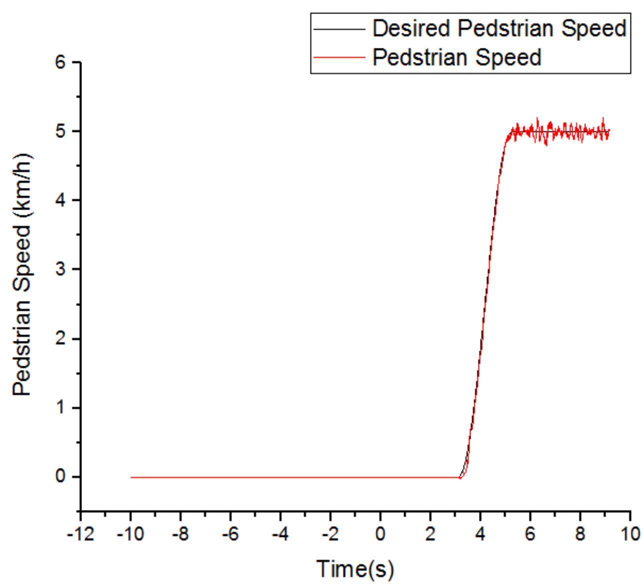


Figure 8 Vehicle speed and forward acceleration

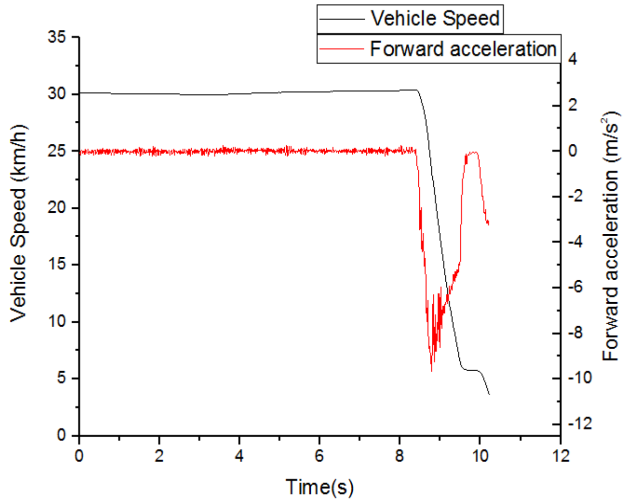
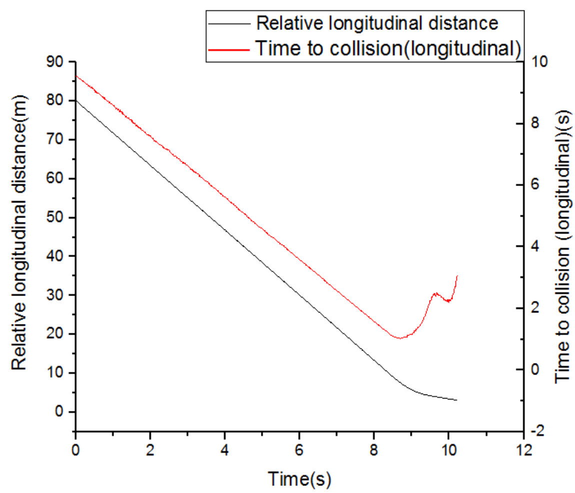


Figure 9 Relative longitudinal distance and TTC



Based on the test result, the maximum deceleration of the test vehicle is 9.67 m/s^2 and the response time of brake system is 355 ms. Therefore, the collision avoidance model is determined by using the equation (9):

$$TTC \le TTC_{\max} = \frac{v_0}{19.34} + \frac{3}{v_0} + 0.36 \tag{9}$$

At the same time, five field operation tests are conducted by changing the lateral distance X in the first situation of the second typical scenario. In the second situation, two tests are conducted by changing the speed of test vehicle. The test results are shown in Table 8.

Table 8 Test results of typical scenario's test situations

Test scenario's situation	*Vehicle speed*	*Pedestrian speed*	*Braked or not*	*Collision or not*	*TTC at the beginning of brake*	*Relative longitudinal distance at braking*	*Distance between vehicle and pedestrian*
1	30 km/h	5 km/h	Yes	No	1.12 s	9.33 m	0.5 m (Right side of vehicle) 0.79 m (longitudinal distance)
1	30 km/h	5 km/h	Yes (Continue to move after braking)	No	1.18 s	9.83 m	1 m (Right side of vehicle)
1	30 km/h	5 km/h	Yes (Continue to move after braking)	No	1.20 s	10.06 m	1.5 m (Right side of vehicle)
1	30 km/h	5 km/h	Yes (Continue to move after braking)	No	1.20 s	9.95 m	2 m (Right side of vehicle)
1	30 km/h	5 km/h	No	No	——	——	2.5 m (Right side of vehicle)
2	30 km/h	5 km/h	No	No	——	——	0.25 m (Right side of vehicle)
2	40 km/h	5 km/h	No	No	——	——	0.25 m (Right side of vehicle)
3	30 km/h	5 km/h	Yes	No	1.15 s	9.67 m	3.14 m (longitudinal distance)

When the test vehicle speed is 30 km/h, $TTC_{\max}$ is 1.15 s, which is basically consistent with the equation (9) and related research (Yang et al., 2015; Liu et al., 2018), and it is conservative. It can be used as a criterion for evaluating whether the AEB pedestrian system is too conservative. The test results are analysed in Table 8. The first test result of the first situation shows: the test vehicle is braked during drive and finally stopped when the pedestrian is 0.5 m away from the right side of the vehicle; the initial braking time TTC is 1.12 s; the longitudinal distance from the pedestrian is 0.79 m after stop and the design of AEB pedestrian system is relatively reasonable. After increasing the *X*-value based on the first test, the test vehicle has braking during drive, until *X* is 2.5 m. In addition, the initial braking time in the second, third and fourth tests TTC is larger than $TTC_{\max}$ and the strategy designed is too conservative. The results of five tests show that the AEB pedestrian system used on the test vehicle has premature braking condition for the scenario in the first situation, which can provide a reference for the optimisation of AEB pedestrian system. In the scenario of the second situation, the test vehicle speeds were 30 km/h and 40 km/h, no braking occurred in the tests and the performance was good. The AEB system is reasonably designed in the scenario recognition and control strategy in the scenario of the third situation. In the whole process that the pedestrian crossed the road and then stood in front of the vehicle, the test vehicle was braked twice. During the first process of braking, the test vehicle speed was reduced from 30 km/h to 5.78 km/h and the maximum deceleration 9.67 m/s^2 was achieved after braking 355 ms. After the vehicle was stopped, the longitudinal distance to the pedestrian was 3.14 m. So, it indicates that the strategy is reasonably designed.

Based on the results of the above eight tests, it is showed that the test vehicle can effectively avoid collision with pedestrian when pedestrian motion is changed. However, the control strategy is relatively conservative in the first situation of the second typical scenario, the performance should be further improved and it may cause driver dissatisfaction. At the same time, the above tests can be used to well evaluate the AEB pedestrian system, which provide a reference for the optimisation of AEB pedestrian system.

6 Conclusions

Depending on the actual traffic accident cases in China, the AEB pedestrian system test scenario that is more in line with Chinese national conditions can be obtained by combining theoretical analysis with actual road traffic analysis. The research results can provide a basis for establishing a complete test scenario and provide a reference for the optimisation of AEB pedestrian system. Based on the NAIS in-depth accident data about the collision accidents between passenger car and pedestrian in 220 cases, five types of typical AEB pedestrian system test scenarios are extracted by clustering analysis and chi-square test in this paper. Then, the different test situations of the typical scenario are analysed by combining pedestrian-vehicle collision avoidance model with the actual road traffic situation in China. In addition, through the research, the main conclusions are as follows:

1 This paper analyses and extracts five typical scenarios for AEB pedestrian system. Typical scenarios derived from NAIS in-depth accident data from safety perspective cover 95% of the samples, which have strong typicality and representativeness. The

test situation of typical scenario obtained in terms of user acceptance provides a reference for improving the test scenario for the AEB pedestrian system in China. Specially, the first, second and third typical scenarios are similar to the CPLA (Car-to-Pedestrian Longitudinal Adult), CPFA (Car-to-Pedestrian Farside Adult), and CPNA (Car-to-Pedestrian Nearside Adult) scenarios specified in the Euro NCAP 2019. However, the test situation of second typical scenario obtained in this paper considers the security and user acceptance of AEB system, so the test scenarios are more complete. The fourth and fifth typical scenarios obtained by the NAIS in-depth accident data are similar to the upcoming CPTA (Car-to-Pedestrian Turning Adult) scenario specified in Euro NCAP 2020, indicating that such test scenarios are also needed in China.

2 The pedestrian-vehicle collision avoidance model obtained by deriving the triggering time of AEB system is a function related to vehicle speed. The triggering time gradually increases with the increase of vehicle speed in the range of general collision avoidance speed. Therefore, different parameter values are selected as the basis for evaluating the conservative of the AEB system in different countries. At the same time, the three test situations of the typical scenarios based on the actual road traffic conditions in China provide a reference for the derivation of AEB system typical scenarios.

3 The field operation test results show that the AEB pedestrian system is too conservative in the more rigorous test scenarios, which provides a reference for the optimisation of AEB pedestrian system. When the vehicle predicts to collide with pedestrian, the more conservative situation can be avoided by appropriately reducing safety distance, so as to improve the driver's acceptance.

This paper is based on the 220 cases of collision accidents between vehicle and pedestrian for analysis. Owing to the limited number of accidents, the samples of some scenarios are relatively small, and the comprehensiveness of the scenario needs to be further improved. However, the research methods specified in this paper have important implications for subsequent research and testing on the AEB system. In addition, the extraction of different test situations is only studied in two aspects of vehicle control strategy and pedestrian crossing behaviour, without the consideration of the challenges from road infrastructure and environmental factors. The subsequent research on the AEB pedestrian system will be further conducted by integrating with more cases of collision accidents and considering more variable factors.

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