Research on the Characterization of Collision Dangerous Conditions of Dangerous Goods Transport Vehicles

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Abstract: Aiming at the scientific problem of complex driving environment representation, based on the analysis of road traffic accidents in China, the influencing factors of collision accidents are dissected from four aspects of people, vehicle, road and environment. Based on the data of collision dangerous conditions extracted from the natural driving data of dangerous goods transport vehicles, 12 driving behaviors are identified in comparison with 37 types of pre-crash scenarios summarized by NHTSA. The data analysis system architecture of dangerous condition is built from three aspects: driving dangerous road, driving environment and driving operation. The K-means clustering algorithm is optimized to quantify and analyse the dangerous collision scenarios of dangerous goods transport vehicles from the perspective of time and space, and to design test parameters and correct the types and spaces by combining Euro-NCAP, C-NCAP and SAE test standards. Finally, the active crash prevention and control performance of dangerous goods transportation vehicle under different dangerous working conditions is tested in the test site of the Ministry of Transportation to verify the environmental adaptability of the system. It effectively solves the problem of difficulty in quantifying and lack of realism of the automatic driving simulation scenarios and closed road test scenarios.

1. Introduction

In recent years, heavy goods vehicles such as dangerous goods vehicles have developed rapidly and are widely used, and have become one of the main means of transport for road freight. However, with the continuous development of China's transportation industry, major traffic accidents caused by the collision of dangerous goods transport vehicles have also emerged, and research shows that dangerous goods transport vehicles have the characteristics of large volume, large weight, high carrying capacity, high driving speed and small braking reaction time. In the actual transport of trucks, over speed, overload, fatigue driving and other bad driving conditions are appeared in order to get greater economic benefits, which will result serious or fatal accidents. In particular, great hidden danger of traffic accident threats highway traffic safety [1].

Due to the extremely complex, unpredictable and non-exhaustive nature of the crash prevention and control technology assessment scenarios, the scenarios should meet the requirements of quantifiability, reproducibility and high fidelity [2]. At present, the analysis methods for driving scenes are generally based on natural driving data and accident data to extract characteristic parameters and use methods such as cluster analysis to obtain typical dangerous scenarios [3]. In overseas IVBSS-FOT (Integrated Vehicle-Based Safety Systems), for various ADAS products, the testers divided the dangerous conditions into three types of conditions: tailgating, lane change and off-road interference, and set screening thresholds, but the classification was not satisfactory [4-5]. In the study of natural driving, Tongji University defined the threshold of dynamic parameters and the subjective evaluation of multiple people through China-FOT (China Field Operational Test) database to obtain the most common seven types of dangerous conditions in China's road traffic environment and drivers' operating habits [6]. Then, the seven types of dangerous working conditions are summarized into three categories: straight line, lane change and steering [7]. Guo Jinghua et al. obtained three typical scenes by clustering the dangerous segment data in the natural driving data and extracted the characteristics of speed and acceleration in each scene to predict the random motion state of the vehicle in front [8].

The existing analysis of domestic working conditions is mostly based on the characteristic parameters of driving behavior of vehicles, ignoring the complex road traffic environment and the influencing factors of collision in China. In order to explore test method of the active prevention and control technology of dangerous goods transportation collision suitable for China's traffic conditions, based on the driving data of dangerous goods transportation vehicles, the dangerous condition data analysis method is proposed according to the road traffic elements affecting the vehicle collision, and the closed test site collision dangerous condition is constructed through cluster analysis.

2. Collision Dangerous Factors and Driving Behavior Analysis

Just like the road traffic system elements, the impact factors of collision dangerous conditions include four major target elements: people, vehicle, road and environment, which have the characteristics of openness, non-linearity and dynamic equilibrium. Due to the mutual conflict, incompatibility or incoordination among the elements, the road traffic system has a certain probability of failure and evolves into a road traffic accident [9]. Among the four elements, human is the most critical factor affecting road traffic safety and is the core of the system. Through the interaction and coordinated operation of the four elements, the safety requirements of the road traffic system are realized. Through researching into collision, as a common type of road traffic accidents, the traffic elements affecting collision are analysed, the relationship between the elements is sorted out, and the collision hazard conditions are organized, thus a theoretical basis for collision avoidance can be provided [10].

2.1. Collision Dangerous Element Analysis

The common collision dangerous conditions in China's road traffic environment are complex and special, and the specific cause of collision dangerous conditions is not a single factor, which requires comprehensive consideration of many factors. For dangerous transport vehicles, according to the sample data of collision accident, five types of elements are described in this paper, which include: collision location, driving environment, vehicle status, driving speed and driver status. The specific impact factors of collision dangerous conditions are shown in Table 1. Based on the above collision influencing factors, the causes of collision dangerous conditions, driver's behavioral intentions and liability determination can be comprehensively analysed, which are of guidance to actively avoid the occurrence of collision danger.

Table 1: Impact factors of collision dangerous conditions.

Collision scene element	Content
Collision location	Highway, Urban road, Country road, Intersection、Uphill and Downhill、Bridges and Tunnels
Driving environment	Road (wet、dry)、Light conditions(daytime、night) Weather(sunny、cloudy、rain、snow、fog) Transport infrastructure(traffic light 、traffic signs and markings)
Vehicle status	Driving state(Go straight、turn、acceleration、emergency brake) Vehicle performance(normal、overload、out of control)
Driving speed	Low speed、Medium speed、High Speed Speed limit sign
Driver status	Technological factors(Perceptual decision error、Driving Skills) Physiological factors(fatigue driving、age、gender) Psychological factor(Tension、Radical、Steady)

2.2. Driving Behavior Analysis

The NHTSA (National Highway Traffic Safety Administration) summarized 37 categories of pre-crash scenarios based on the GES (General Estimates System) database from approximately 5942000 crashes [11].

In order to characterize the dangerous conditions of dangerous goods transport vehicles, for the China's road traffic environment, as well as the active prevention and control analysis before the accident, the driving behavior is divided into 12 categories according to the driving characteristics of the real vehicle [12]. The 12 types of driving behaviors and their incidence rates on highways and urban roads are shown in Table 2.

Table 2: 12 types of driving behaviors and their incidence rates on highway and urban road.

	Driving behavior	Highway	Urban road
1	Straight line following driving	73.01%	45.27%
2	Overtaking/obstacle avoidance	10.88%	7.23%
3	Curve driving	5.81%	4.78%
4	Start and stop	1.56%	15.30%
5	Lane change	1.60%	3.19%
6	Through special areas	3.16%	1.91%
7	Low visibility driving	2.34%	1.70%
8	Through intersections	1.04%	16.79%
9	Preparation for traffic and access to parking spaces	0.13%	1.06%
10	Meeting the car	0.22%	1.06%
11	Turnaround	0	0.43%
12	Emergencies	0.26%	1.28%

Data analysis shows that dangerous scenes of dangerous goods transport vehicles mostly occur on the highway, accounting for 68.23%, which is very different from ordinary light vehicles often driven on the city roads. The top three driving behaviors with the highest frequency of accidents on the highway are straight line following driving, overtaking/collision avoidance, curve driving, and the top three driving behaviors with the highest frequency of accidents on the urban road are straight line following driving, passing through intersections,and starting and stopping.

2.3. Collision Dangerous Condition Data Analysis Method

In order to analyse the influence of the three elements of driving road, driving environment and driving behavior on the process, data information such as video and vehicle motion parameters recorded during the whole process of dangerous occurrence is needed. The information obtained at the accident site often cannot restore the whole process before and after the accident, but the data information such as video and vehicle motion parameters recorded in the natural driving conditions can provide the whole process before the hazard occurs, which provides a basis for analysing the influence of the three elements such as driver, vehicle and environment on the process [13].

The SAE J2980 standard recommends the use of six elements to construct the design Operational Design Domain(ODD), from six elements of location, road conditions, driving operations, vehicle status, other considerations, and other vehicle characteristics and the included attributes to construct the framework. NHTSA also recommends the use of six elements to construct the design ODD, from six elements of infrastructure, operational constraints, surrounding targets, interconnection, environmental conditions, and area and the included attributes to construct the framework [14]. For the actual situation of China's road traffic combined with the framework structure of SAE and NHTSA, the ODD is designed from three dimensions of driving dangerous road, driving environment and driving operation.

Figure 1 shows the data information collection process. The latitude and longitude information from the GPS can determine the vehicle driving path, road information. The dangerous scene video and picture information can determine the driving behavior, driving lane, weather, visibility and other information. The vehicle sensor can obtain the vehicle speed, acceleration, distance and other data which are used to determine the driving operation status. From these data, we can analyse the information of the driving road section, driving environment and the driving status of the vehicle when the vehicle collision danger occurs.

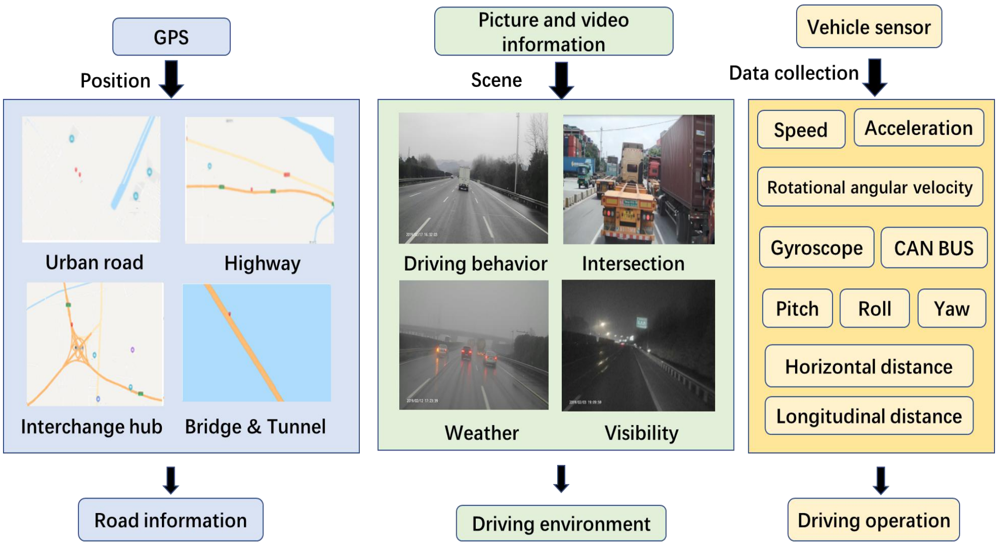


Figure 1: Collision dangerous conditions data collection and analysis method.

3. Clustering Analysis of Collision Dangerous Condition

3.1. K-means Clustering Algorithm

For the problem of clustering a large number of data points, it is proposed in the k-mean algorithm idea: get the set of k groups of categories, calculate the centroids of each group of k groups (calculate the mean points), and get the centroids of each group. At this point, the k-group centroids are considered as the new clustering centers. If the cluster centers obtained from this calculation are identical to the previous ones, then it means that the classification is done. If not, based on the newly obtained clustering centers, the above operation is performed again until the newly computed clustering centers and the previous clustering centers match exactly.

The algorithm flow is as follows:

(1) Randomly initialize K clustering centers,μ_1,μ_2,μ_3,$\cdots$, μ_k

(2) while the new clustering center does not match the previous clustering center

for i = 1:m {Calculate the distance between the ith sample and the cluster center, and mark the center of the cluster nearest to $x^{(i)}$ as $c^{(i)}$,and write down the centroid to which the sample belongs}

In this loop, the center of clustering μ_1,μ_2,μ_3,…, μ_k is kept constant. Change $c^{(i)}$ so that the objective function J is as small as possible.

for i =1: k {Calculate the average of the coordinates of all samples belonging to this cluster center, and use this average as the new cluster center of this class of samples}

In this loop, keep $c^{(i)}$ constant and change the cluster centers μ_1 ,μ_2 ,μ_3 ,…, μ_k , so that the objective function J is as small as possible

(3)Determine whether the new clustering center is the same as the previous one, and repeat step (2).

The distance between the sample element $x^{(i)}$and the centroid μ_k is generally expressed by the following equation.

$$D = \left\| x^{(i)} - \mu_{c^{(i)}} \right\|^2 \quad (1)$$

Find the value of k that minimizes D, i.e., the centroid of the class to which the sample element $x^{(i)}$ belongs.

The distance formulas commonly used in clustering algorithms is as follows.

n-dimensional Euclidean distance

$$d_{ij} = \sqrt{\sum_{i=1}^{n} \left| x_{ik} - x_{jk} \right|^2} \quad (2)$$

n-dimensional Manhattan Distance

$$d_{ij} = \sum_{i=1}^{n} \left| x_{ik} - x_{jk} \right| \quad (3)$$

n-dimensional Minkowski Distance:

$$d_{ij} = \sqrt[\sigma]{\sum_{i=1}^{n} \left| x_{ik} - x_{jk} \right|^\sigma} \quad (4)$$

Where $\sigma \in R$

Standardized Euclidean distance

$$X^* = \frac{X-m}{s} \quad (5)$$

$$d_{ij} = \sqrt{\sum_{i=1}^{n} \left| \frac{x_{ik}-x_{jk}}{s_k} \right|^2} \quad (6)$$

Where m is mathematical expectation or mean of sample data; S is standard deviation of sample data.

The objective function J can be expressed as

$$J\left(c^{(1)}, \dots, c^{(m)}, \mu_1, \mu_2 \dots, \mu_k\right) = \frac{1}{m}\sum_{i=1}^{m}\left\|x^{(i)} - \mu_{c^{(i)}}\right\|^2 \quad (7)$$

Where $c^{(i)}$ is the subscript k of the centroid of the class to which the mth sample belongs.

3.2. Dangerous Driving Scenario Clustering

3.2.1. Static Driving Scene Clustering

In order to perform cluster analysis of driving scenes, it is necessary to assign values to each feature of the driving scenes because of manually calibrated analysis of the scenes without data features. The input variables were converted into parameters, and differential assignment was used to distinguish the features of each parameter and perform a cluster analysis based on spatial distance. Combined with the above analysis of each scenario feature, it was decided to analyse each driving behavior distinguishing between highway and urban roads, and to select dangerous road sections, line type, weather, visibility, etc. as feature parameters for cluster analysis. The scene elements are assigned as shown in Table 3.

Table 3: Scene element assignment.

Highway	Assign ment	Urban road	Assign ment	Line type	Assign ment	Weather	Assign ment	Visibility	Assign ment
Travel lanes	0	Expressways	0	Straight road	0	Sunny	0	Good	0
Ramps	100	Trunk Roads	100	Big bend	100	Cloudy	100	Poor	100
Service area	200	Secondary Roads	200	Medium bend	200	Rainy	200	Very poor	200
Toll stations	300	Branch Roads	300	Small bend	300	Foggy	300		
		Intersections	400	Sharp bend	400	Snowy	400		
		Parking lots	500						

Table 4 clustered the highway straight line following scenarios, and as shown in Table 4 that the clustered four working conditions scenarios basically match the distribution of each feature. Both the highest occurrence scenario 1 and the less frequent but obvious scenarios 2 (cloudy), scenario 3 (sunny foggy, poor visibility) and scenario 4 (service area, toll station) are listed.

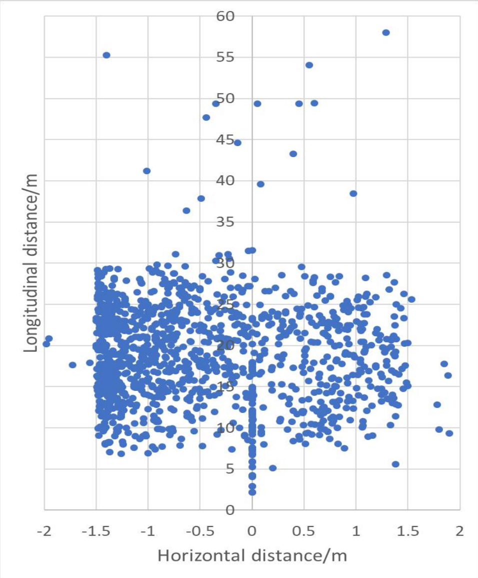
Table 4: Cluster analysis of highway straight line following scenes.

Scenario	1		2		3		4	
Roadway	1.3474	Travel lanes	0.6944	Travel lanes	0.8197	Travel lanes	250	Service area Toll stations
Linearity	4.5236	Straight road	4.1667	Straight road	2.0492	Straight road	0	Straight road
Weather	0	Sunny	100	Cloudy	257.787	Sunny Foggy	8.3333	Sunny
Visibility	8.0847	Good	29.167	Good	74.590	Poor	16.667	Good
Number of clusters	1039	65.63%	288	18.20%	244	15.41%	12	0.76%

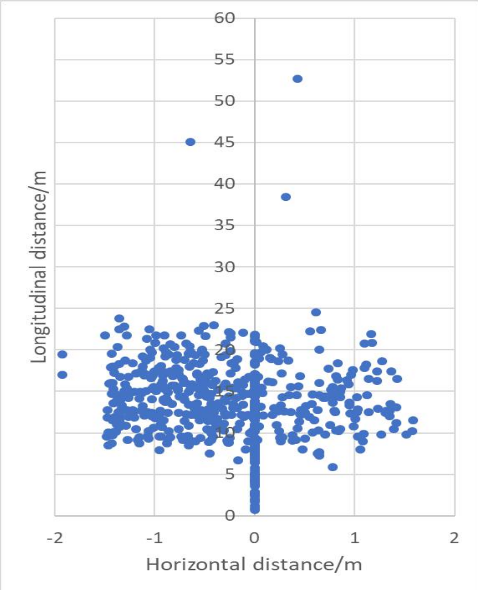
3.2.2. Closed Test Site Conditions Construction

Based on the collision accidents of hazardous material transportation vehicle in China and the collected data of drivers' collision dangerous conditions, the test parameters of the closed test site are analysed according to the road traffic factors affecting vehicle collisions.

Vehicle spacing is an important factor influencing the occurrence of collisions and closely related to the driving speed. Figure 2 shows the distribution of danger distance for straight line following scenarios. From the figure we know that the danger distance of the highway straight line following scenario with a speed of 60-80km/h is concentrated in the range of 10-30m, and the danger distance of the urban road straight line following scenario with a speed of 30-60km/h is concentrated in the range of 10-25m.



(a) Highway speed 60-80km/h.



(b) Urban road speed 30-60km/h.

Figure 2: Dangerous distances for straight line following scenes.

Braking deceleration is also one of the important elements affecting the occurrence of collision. The deceleration is related to the speed and the driver's operating habits. Figure 3 shows the relationship between speed and deceleration for straight line following scenes on the highway and the urban road. The figure shows that the deceleration is concentrated within -3.5m/s2 at speeds of 60-80km/h on highway and -2.5m/s2 at speeds of 30-60 km/h on urban road.

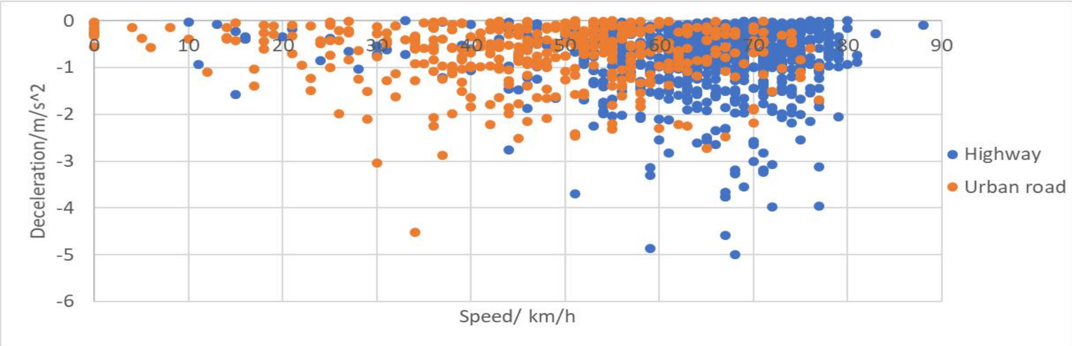


Figure 3: Relationship between speed and deceleration for straight line following scenes.

In order to build the closed test site working conditions, for the China's road traffic environment, based on the results of cluster analysis of the crash dangerous working conditions of dangerous goods transport vehicles, the closed test site testing parameters are determined and the correction types and spaces are verified. Combined with Euro-NCAP, C-NCAP and SAE standards to abstractly extract the working environment and test parameters, the closed test site test conditions with multiple elements of behavior space are constructed as shown in Table 5.

Table 5: Cluster analysis of highway straight line following scenes.

Test	Test Items	Type of road	Speed	Deceleration	Dangerous distance	Target Status
1	Forward warning and braking tests	Highway	80km/h	$-3.5m/s^2$	10-30m	Front car stationary/braking
2			80km/h	$-3.5m/s^2$	10-30m	The front car is at a constant speed of 12km/h
3		Urban road	30km/h	$-2.5m/s^2$	10-25m	Front car stationary/braking
4			30km/h	$-2.5m/s^2$	10-25m	The front car is at a constant speed of 12km/h
5			30km/h	$-2.5m/s^2$	10-25m	Pedestrian stationary
6			30km/h	$-2.5m/s^2$	10-25m	Pedestrian crossed the road
7	Backward warning	Highway	80km/h	$-3.5m/s^2$	30m	Rear car 100km/h
8			100km/h	$-3.5m/s^2$	30m	Rear car 120km/h
9		Urban road	40km/h	$-2.5m/s^2$	10-25m	Rear car 60km/h
10			60km/h	$-2.5m/s^2$	10-25m	Rear car 80km/h

The environmental working conditions are shown in Table 6. Combining with weather conditions, time factors and visibility, the driving environment is divided into four major categories from the time dimension, fully considering the interrelationship of weather, time of day, visibility and other factors and they effect on the driver's perceptual ability, responsiveness and vehicle driving status.

Table 6: The environmental working conditions.

Conditions.	Weather	Time	Visibility
1	Sunny	11:00-17:00	Good
2	Cloudy Rainy	11:00-17:00	Poor
3	Sunny	17:00-23:00	Poor
4	Cloudy Rainy	17:00-23:00	Very poor

3.3. Real Vehicle Testing

In this paper, the active prevention and control performance of the vehicle under different working conditions is tested in a closed road test site. By installing sensors on the vehicle to obtain information on obstacles ahead, V2X is used to achieve communication with the vehicle and the road, and the status information of the vehicle can be monitored in real time. The test vehicle and equipment installation are shown in Figure 4.

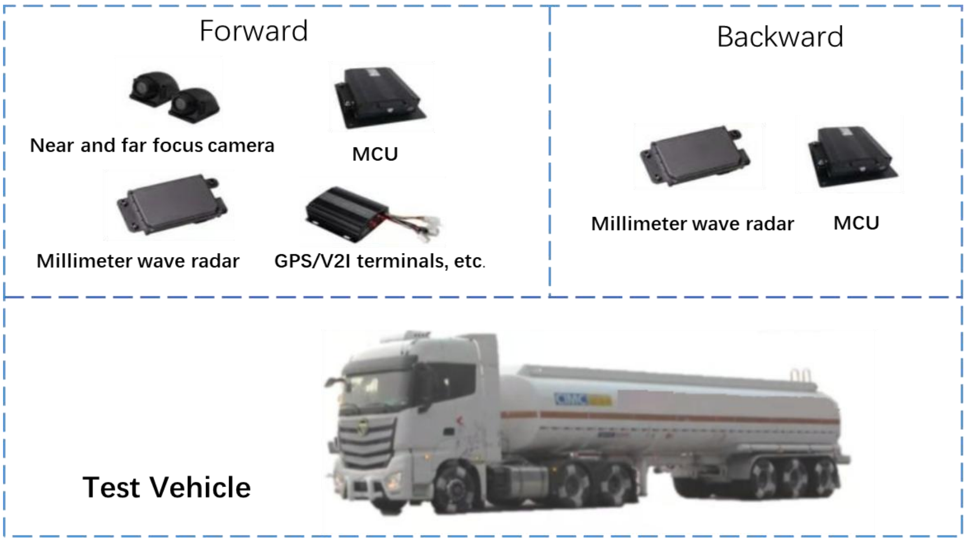


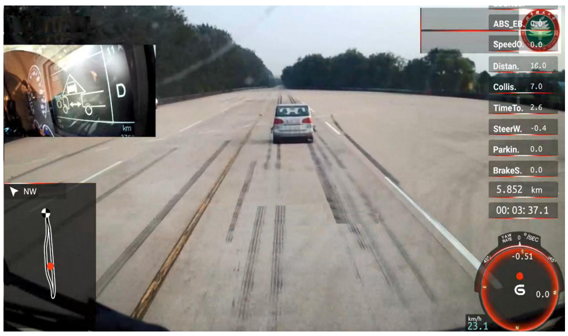
Figure 4: Test vehicle and equipment installation.

When an obstacle appears in front, the image information of the obstacle, distance, speed, azimuth, etc. can be read out from the remote video data based on the vehicle network. And it can calculate the collision time such as TTC in real time. For the vehicle, CAN information can be used for brake control to realize automatic emergency braking of dangerous goods transport vehicles. Its data collection interface is shown in Figure 5.

Figure 5: Data collection interface.

As shown in Figure 6(a) is a front car stationary collision test, corresponding to Table 5(test1), a normal vehicle parked in front. During the test, the front vehicle is at a standstill, and the rear vehicle maintains a speed of 80km/h. When the target vehicle is detected to be within 200m, the self-vehicle starts to detect the dangerous target and gives a warning at the dangerous distance, and makes a deceleration operation as the distance decreases, until the vehicle comes to a complete stop.

As shown in Figure 6(b) is a front pedestrian crossed the road collision test, corresponding to Table5(test6). During the test, the vehicle to maintain a speed of 30km/h, the dummy is located on the side of the road, the dummy crosses the road at a constant speed, at 50m from the dummy detects the dummy crossing the road, the vehicle begins to brake until the vehicle deceleration to 0.



(a) Front car stationary.

(b) Front pedestrian cross the road.

Figure 6: Crash active prevention and control test.

4. Conclusions

Aiming at the scientific problem of complex driving environment characterization of dangerous goods transport vehicles, this paper analyses the influencing factors of collision accidents based on the natural driving data of dangerous goods transport vehicles,and determines 12 types of driving behaviors by analysing 37 types of pre-crash scenarios summarized by NHTSA. The data analysis method of collision dangerous condition is proposed. K-means clustering algorithm is used to study the closed field test method, and the effectiveness is verified by the real vehicle test. Through the above research, we reached the following conclusions:

1)The five types of elements can describe the factors affecting of collisions, which include: collision location, driving environment, vehicle status, driving speed and driver status.

2) Based on the driving characteristics of real vehicles, driving behaviors can be divided into 12 types. The top three driving behaviors with the highest frequency of accidents on the highway are straight line following driving, overtaking/collision avoidance, curve driving, and the top three driving behaviors with the highest frequency of accidents on the urban road are straight line following driving, passing through intersections, and starting and stopping.

3)Collision dangerous condition data analysis method can be designed from three dimensions of driving dangerous road, driving environment and driving operation.

4) For scene elements with no data features, input variables can be transformed into parameters through feature assignment. The feature parameters such as dangerous road sections, line type, weather, visibility were selected for cluster analysis to characterize dangerous driving scenarios.

5) The three elements of velocity, deceleration and dangerous distance are introduced to modify the closed test field test parameters and combine with environmental factors to construct 10 types of behavioral space crash dangerous conditions and 4 types of environmental conditions.

Overall, this paper constructs the dangerous collision condition of dangerous goods transport vehicles through data analysis and cluster analysis and carries out multi-condition test verification through the real vehicle test in the closed test site.

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