

Research Article

Influence of Large Vehicles on the Speed of Expressway Traffic Flow

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Large vehicles impact the quality of traffic flow. To predict the impact of large-scale vehicles on the average speed of traffic flow, vehicle speeds under different vehicle mixing rates were collected through field observations. A laser roadside traffic survey instrument with automatic vehicle type identification functionality was used to collect cross section traffic flow data. The v/C ratio, large vehicle mixing rate, and average speed of traffic were calculated for each data set. A total of 158 traffic flow data sets were captured and divided into three groups according to the v/C ratio of the expressway. The v/C ratio ranges of the three groups are $v/C \leq 0.35$, $0.35 < v/C \leq 0.55$, and $0.55 < v/C \leq 0.90$. SPSS software was used to analyze the correlation between the vehicle mixing rate and the average speed under different traffic flow conditions, and a model was determined between the average speed of the vehicle flow and the large vehicle mixing rate. Analysis of the results with SPSS revealed a negative logarithmic linear relationship between the average traffic speed and the mixing rate of large vehicles. The results could also be applied to passenger cars. The models are considered as corrections of the average speed of the traffic flow after the mixing of large vehicles. When the mixing rate of large vehicles is close to zero, the forecast value of the model is the average speed of passenger cars. Furthermore, as the traffic volume of the road section increased, the influence of the mixing rate on traffic flow speed became more obvious. The adaptability of the proposed prediction model of the expressway mixing rate was verified by evaluating model predictions against actual measurements.

1. Introduction

Due to the large vehicle structure and low dynamic performance, large vehicles in expressways show low speed, inflexible driving, and excessive occupation of road time and space, resulting in a bottleneck effect on traffic flow. Moreover, large vehicles have a negative impact on safe car following and overtaking behavior [1, 2]. Recently, some scholars have successfully reached mutual confirmation from the microresearch and macroresearch. The research shows that the driver's acceptable risk level is often lower when following or driving a larger vehicle [3]. Many specialized studies have investigated the road running characteristics attributable to large vehicles. Related research mainly analyzed the bottleneck effect of large vehicles from the microscopic theory and obtained some generally accepted conclusions [4–11]. In 1992, Gazis and Herman [4]

proposed a mobile bottleneck concept for vehicle queuing caused by slow vehicles on low-speed roads and proposed a mobile bottleneck model for symmetric lane changing in two-lane highways. The model analyzes the formation and evolution of queuing after slow vehicles when the upstream flow rate is constant, and the model results indicated that a fleet will be formed when the flow upstream of a local train reaches a certain threshold and that heavy-duty trucks affect the express capacity of slow-moving expressways. Chowdhury et al. [5] extended the NS cellular automaton model, allowing for different maximum speeds of vehicles. In the simulation of nonuniform traffic flow with mixed fast and slow cars, the existence of a slow train was found to have a significant influence on the traffic flow. Ebersbach et al. [6] used the NS model to add trucks into passenger car flow. Trucks were found to have a significant impact on single-lane traffic characteristics, but this effect was negligible for

high-density vehicles, and the impact of trucks could be completely ignored for low-density traffic flow or low truck ratios. Baruya [7] investigated traffic speed and accidents on European highways and found a correlation between the truck mixing rate and running speed. The study points out that the traffic speed decreases significantly with the increasing truck mixing rate. At a sufficiently high truck mixing rate, the traffic speed approaches a certain fixed speed, which is related to the expected speed of the truck. Some scholars have studied the dynamics of heavy vehicle interactions in car following [8–12]. By simulating the behavior of following in the congested traffic conditions and the lane changing operation of heavy vehicles, it was found

that the existence of heavy vehicles will lead to larger space and time headways, longer reaction time, and more robust car-following behavior. In terms of the quantitative influence of the mixing rate on traffic flow speed, the representative research results are provided in the Highway Capacity Manual (HCM) 2000 [13]. For grading the road service level, the manual proposes a speed prediction model for different traffic volumes and free-flow speeds of traffic flow. The average speed prediction model of the traffic flow of large vehicles in the HCM, which can be obtained according to the correction of the speed of large vehicles, is as follows:

$$55 < \text{FFS} \leq 70 \text{ and } V_p \leq (3400 - 30 \text{ FFS}): \quad (1)$$

$$S = \text{FFS},$$

$$55 < \text{FFS} \leq 70 \text{ and } (3400 - 30 \text{ FFS}) < V_p \leq (1700 + 10 \text{ FFS}): \quad (2)$$

$$S = \text{FFS} - \left\{ \frac{1}{9} (7 \text{ FFS} - 340) \times \left[\frac{(V \times [1 + P_T (E_T - 1)]) / (\text{PHF} \times N \times f_p) + 30 \text{ FFS} - 3400}{40 \text{ FFS} - 1700} \right]^{2.6} \right\},$$

$$70 < \text{FFS} \leq 75 \text{ and } (3400 - 30 \text{ FFS}) < V_p \leq 2400: \quad (3)$$

$$S = \text{FFS} - \left\{ \left(\text{FFS} - \frac{160}{3} \right) \times \left[\frac{(V \times [1 + P_T (E_T - 1)]) / (\text{PHF} \times N \times f_p) + 30 \text{ FFS} - 3400}{30 \text{ FFS} - 1000} \right]^{2.6} \right\},$$

where FFS is free-flow velocity, mile/h; V is hour volume, veh/h; PHF is peak-hour factor; N is the number of lanes; E_T is passenger-car equivalents for large vehicles in the traffic stream; P_T is the proportion of large vehicles in traffic flow; and f_p is driver population factor.

It can be found that the average speed of the traffic flow passenger car is negatively correlated with the traffic mixture rate and traffic volume of the large vehicles, and it is the correction of large vehicle mixing rate and flow rate for free-flow velocity.

Chinese scholars have also extensively researched the impact of large vehicles on highway traffic. Many scholars have used the simulation technology to study the disturbance effects of large vehicles on traffic flow from the microlevel [14–22]. Liu et al. [14] proposed a new model, Intelligent Driver Model (IDM), which was based on a nonlinear ordinary differential car-following model. The research shows that the mixture of congested and free-flow regime occurs when the trucks reach their maximum speeds. Cars and trucks can both stabilize and destabilize the traffic flow, depending on the combination type and the equilibrium velocity. Wang et al. [17] proposed a multiclass traffic flow model based on Smulders fundamental diagram to analyze the influence of overloaded HVs on traffic conditions. The tests indicate that the increase of overloaded HVs leads to both a higher congestion level and longer duration. A large number of research results show that freight vehicles

have a disturbing effect on highway traffic flow. As the proportion of freight vehicles increases, the average speed of traffic flow decreases. When the truck mixing rate reaches a certain value, the entire traffic flow becomes saturated and enters a slow driving state.

In summary, existing traffic flow research systematically investigated disturbance caused by the mixing of large vehicles, but the starting point is to grasp the change rule of mobile bottlenecks caused by the mixing of large vehicles and propose improvement measures based on the change rule. From the macroscopic point of view, there is still a lack of systematic and in-depth discussion on the adverse effects of the mixing of large vehicles on traffic flow speed. In addition to existing quantitative research results, such as the model established by the HCM, more parameters need to be determined to quickly estimate the average speed of traffic flow, which would benefit traffic management departments.

Heavy vehicles have different physical (e.g., size) and operational characteristics (e.g., acceleration/deceleration capability) than passenger cars. More importantly, overloaded HVs are often observed on highways in most parts of China [17]. For example, the average overloading proportion (i.e., the total number of overloaded HVs/population of HVs) on the freeway is 15%, and it could be more than 40% at midnight in Eastern China [23, 24]. In addition, Chinese drivers are used to driving below the posted speed limit, drivers of large vehicles, especially heavy vehicles, tend to

travel at extremely low speeds. In summary, considering that China's vehicle composition, vehicle performance, and driving habits are still different from those of western countries, the applicability of the model in China needs to be verified.

Therefore, the aim of the study was to verify the impact of large vehicles on the traffic flow by using field tests. The mixing rate was adjusted by controlling the number of large vehicles entering the expressway. Cross-section traffic flow data under different traffic flow conditions and mixing rates were collected using a laser roadside traffic survey instrument with automatic vehicle-type identification. The collected data included traffic volume, speed, and vehicle type data. The mixing rate, average speed of the traffic flow, and average speed of the passenger cars were calculated for each data set. The obtained data sets were divided into three groups according to the saturation degree of the traffic flow. The influence of the mixing rate on the average speed of traffic flow is discussed for each group. The correlation between the mixing rate of large vehicles and the average speed of traffic flow was analyzed with SPSS software. In addition, a traffic flow speed prediction model based on the mixing rate of large vehicles was developed.

The remainder of this manuscript is organized as follows. Section 2 introduces the methodology employed in this study, including the design of the tests, test control measures, and data preprocessing. In Section 3, the results obtained from the analysis of the collected field data are presented and discussed in detail, traffic flow speed prediction models of the mixing rate of large vehicles are presented, and accuracy verification is performed on both the established model and the HCM prediction model. Section 4 is the main conclusion of this study.

2. Test Design and Control

As stated above, in order to verify the impact of large vehicles on the average speed of traffic flow, field tests were used to verify the correlation between the large vehicle mixing rate and the average speed of traffic flow.

2.1. Large Vehicle Definition. Different vehicle loads and sizes have different effects on other vehicles in the traffic flow. According to the Technical Standards for Highway Engineering of China [25], the dimensions of the vehicle are categorized as shown in Table 1.

Referring to the above classification, the standards for large vehicles as defined in this paper are trucks and articulated trains.

2.2. Test Design. The basic idea of the test is to set up large vehicle control measures at the entrance of the expressway and set observation points at the basic sections of the expressway for traffic flow observation. The essential of the field experiments is to ensure the change of the mixing rate of large vehicles at the observation point. In order to change the mixing rate, management measures were performed at the five ramp entrances before the observation point. Before

the test, communicate with the expressway management department and issue a public announcement on the regulation of large-scale vehicles on the expressway.

As shown in Figure 1, the test is mainly divided into three stages:

- (i) Stage 1: the entrance of the ramp does not allow large vehicles to enter the expressway. During the test, the toll station staffs at the entrance of the ramps did not allow large vehicles to enter the expressway, guiding large vehicles to wait in line at the toll station plaza. At this time, the observation point began to collect traffic flow data with low mixing rate, and data collection time lasts 2 hours.
- (ii) Stage 2: some of the ramp entrances allow large vehicles to enter the expressway. After the first stage of traffic flow data collection is completed, five ramp entrances are gradually opened at two hour intervals, allowing large vehicles to enter the highway.
- (iii) Stage 3: all ramp entrances allow the large vehicles to enter the expressway.

Through the above process control, it is possible to ensure that the level of the mixing rate of the large vehicles at the observation point changes.

2.3. Test Condition Control. The following basic requirements were met when the test sections and observation points are arranged, in order to eliminate the influence of factors other than the mixing rate of large vehicles on the observation results.

Road sections such as long longitudinal slopes, sharp bends, construction areas, ramp entrances, bridges, and tunnel structures should be avoided; fluctuations in the mixing rate of large vehicles should be realized; traffic flow data should be collected under various density conditions; and observations should be made under fine weather conditions.

In accordance to all the above requirements, the national expressway G5 Huxian section was selected as the basic section for observation. Figure 2 shows a schematic diagram of the observation point. Vehicle control measures, which are not all marked, were set at the entrances of five ramps before the observation point.

At the same time, in order to avoid the influence of observers on driving behaviours, an AxleLightRLU11 vehicle classification statistical instrument was selected to conduct in-field traffic flow measurements, as shown in Figure 3. The device with automatic vehicle type identification function can collect traffic flow data such as volume, speed, vehicle type, and headway distance, and the vehicle types are divided by the wheelbase and can be divided into more than 13 types.

2.4. Test Sample Size Control. The data collection time is from 8:30 am to 6:00 pm, and the experiment time is from September 27, 2018, to October 2, 2018, for a total of 6 days, including working days, nonworking days, and holidays. In

TABLE 1: Car exterior size classification.

Vehicle type classification	Total length (m)	Total width (m)	Total height (m)	Remarks
Passenger car	6	1.8	2	Passenger car with seat ≤ 19 seats and truck with load $\leq 2t$
Medium vehicle	13.7~18	2.5	4	Passenger car with seat > 19 seats and $2t < \text{Truck}$ with load $\leq 7t$
Truck	12	2.5	4	$7t < \text{Truck}$ with load $\leq 20t$
Articulated train	18	2.55	4	Truck with load $> 20t$

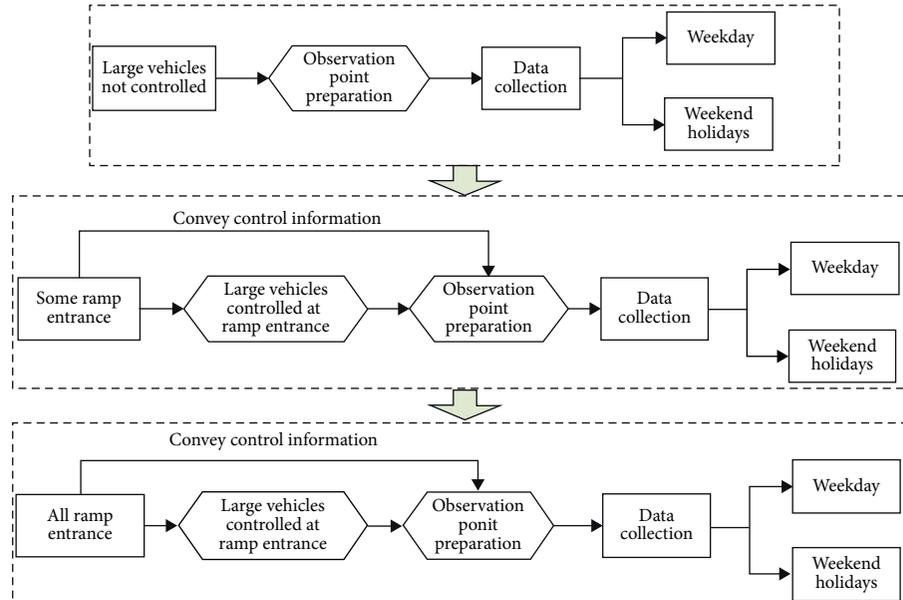


FIGURE 1: Test flow chart.

each set of traffic flow surveys, the observation time for each sample is 30 minutes, and the minimum number of vehicles required at each observation point is greater than 320. After the data collection was completed, 172 sets of data were obtained, totalling more than 127300 vehicles.

2.5. Data Preprocessing. In order to ensure the accuracy of survey data, the total number of vehicles in each sample was checked and samples with a total number of vehicles of less than 320 were discarded. When all test samples are reliable, outlier data in the samples, such as the driver's deceleration when driving in the emergency lane and speed while drivers answered mobile phones, were discarded. Finally, 158 sets of valid data were obtained, totalling more than 117200 vehicles. According to the requirements of the specification, the vehicle type of each sample is classified, the number of large vehicles and passenger cars in each sample is counted, and the mixed rate of the large vehicles, the average speed of the traffic flow, and the average speed of passenger cars are calculated. Through the analysis of 158 groups of samples, the number of large vehicles is 29885, the number of passenger cars is 87315, and the mixed rate of large vehicles in the samples fluctuates between 1.2% and 37.8.

2.6. Division of Traffic Flow Patterns. As shown in Equations (2) and (3) of the first part, it shows that both the traffic volume and the mixing rate of large vehicles affect the traffic flow speed. The HCM manual gives the traffic flow average speed prediction model at each service level based on the traffic flow. Therefore, when analyzing the influence of the mixed rate of the large vehicles on the traffic flow speed, traffic flow patterns were classified into six levels according to the ratio v/C . The ratio v/C is used to describe the flow patterns of expressway, and it is the ratio of the maximum service traffic volume to the basic traffic capacity. There are important differences in the design speed, number of lanes, traffic composition, and other factors of road sections. The "v" in v/C is an objective reflection of actual traffic flow, while "C" accounts for modifications of the above factors. Its calculation formula is as follows [13]:

$$v/C = \frac{v}{C_B \times f_w \times f_{HV} \times f_p}, \quad (4)$$

where v is the traffic volume on the road, $\text{pcu}/(\text{h}\cdot\text{ln})$; C_B is the capacity volume of the road, $\text{pcu}/(\text{h}\cdot\text{ln})$; and f_w , f_{HV} , and f_p are correction factors.

According to the Technical Standards for Highway Engineering of China [24], the level of service is divided into

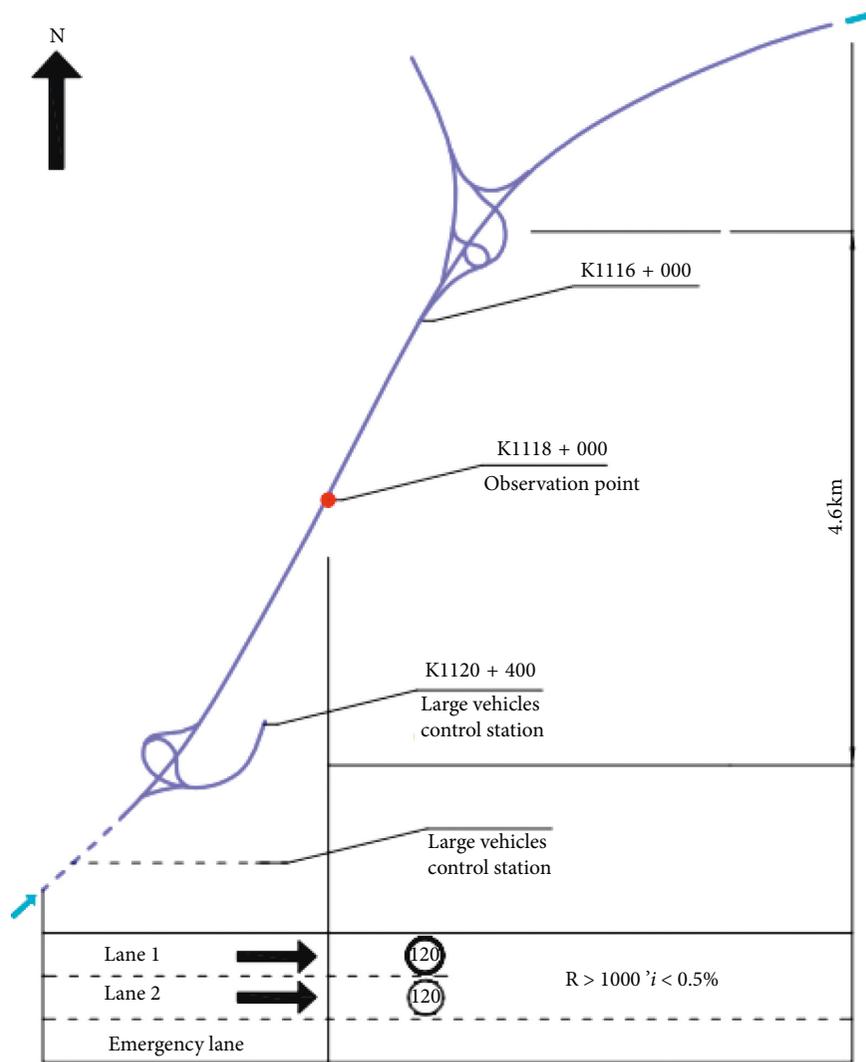


FIGURE 2: Layout of observation points.



FIGURE 3: Vehicle classification statistical instrument.

six levels based on the v/C ratio. Table 2 shows the level of service for basic expressway segments.

Grade A service level corresponds to the free-flow condition, under which vehicles do not interfere with each other and may travel at relatively high speeds with radon acceleration and deceleration options. Grade B service level

corresponds to the relatively free-flow condition, under which drivers can basically choose the speed they want, but they should notice other users in the traffic flow. Grade C and D service level corresponds to the steady flow condition, where individual vehicle speed may be disturbed by other vehicles; traffic flow is generally continuous. In the event of a traffic accident, driving conditions are disturbed and vehicles speeds are reduced. Therefore, the collected 158 traffic flow data sets were divided into three groups according to the v/C ratio, 55 sets of $v/C \leq 0.35$, 52 sets of $0.35 < v/C \leq 0.55$, and 51 sets of $0.55 < v/C \leq 0.90$.

3. Results and Discussion

3.1. Test Results. Based on the previous data foundation, the influence of large vehicles on the traffic flow speed is analyzed. Figures 4 and 5 show the trend of the average speed of traffic flow and the average speed of passenger cars with the mixing rate of large vehicles under different traffic flow patterns.

TABLE 2: Level of service for basic expressway segments.

Level of service	v/C
A	$v/C \leq 0.35$
B	$0.35 < v/C \leq 0.55$
C	$0.55 < v/C \leq 0.75$
D	$0.75 < v/C \leq 0.90$
E	$0.90 < v/C \leq 1.00$
F	$v/C > 1.00$

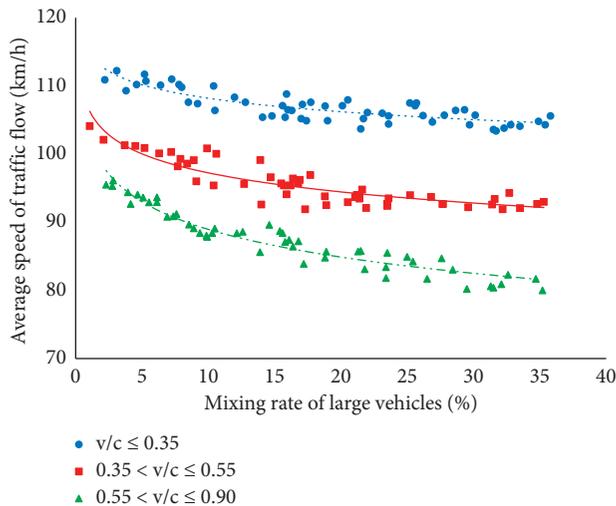


FIGURE 4: Relationship between the mixing rate of large vehicles and average speed of traffic flow.

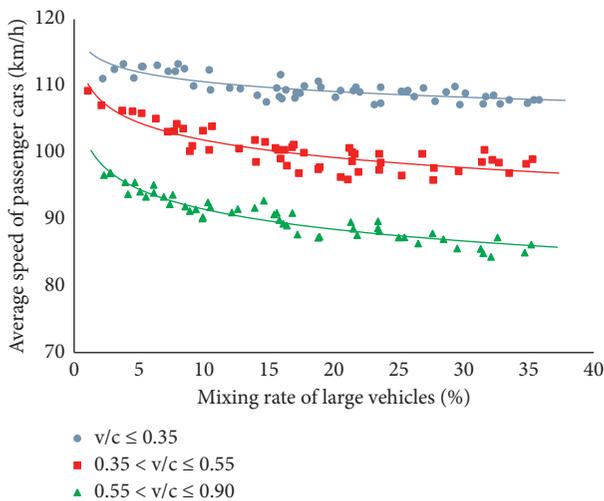


FIGURE 5: Relationship between the mixing rate of large vehicles and average speed of passenger cars.

The average speed of traffic flow and the average speed of passenger cars were found to decrease with increasing proportion of the mixing of large vehicles. Under the free-flow pattern of traffic flow, the average speed of traffic flow and the average speed of cars slowly decreased as the proportion of large vehicles increased. Under the steady flow pattern, with the increase of the mixing of large vehicles,

passenger cars were hindered by large vehicles and the average speed of traffic flow decreased. When the mixing rate of large vehicles reached 20% or more, the downward trend of the traffic flow slowed down. It could be estimated that if the mixing rate of the truck is sufficiently large, the traffic speed may approach a certain fixed speed.

Pearson's correlation coefficient between the average speed and the mixing rate of large vehicles was between -0.84 and -0.95 . It is necessary to establish the specific quantitative relationship models between the mixing rate of large vehicles and average speed.

Regression analysis was performed using SPSS with the mixing rate as the independent variable, the average speed as the dependent variable, and linear, quadratic, cubic, logarithmic, and exponential equations. The goodness-of-fit test (R examination), significance test of the model (F examination), and significance test of each parameter in a model (T examination) were assessed. The logarithmic model was the most significant, followed by the linear model. The determination coefficients R^2 were greater than 0.6 for all models.

Residual analysis was performed on the linear and logarithmic regression models to verify the reliability of the original experimental data used for regression analysis. The standardized residuals of the prediction model all fall within $(-2, 2)$, and the standardized residuals in the residual PP graph have irregular fluctuations in a small range above and below the standard line. According to the principle of mathematical statistics, it could be judged that the residuals have equal variance and a normal distribution, so no data were removed from the original data used in the regression analysis.

Tables 3 and 4 show prediction models of the average speed of traffic flow and average speed of passenger cars.

As evident from Tables 3 and 4, the average speed of traffic flow and the average speed of passenger-cars in the traffic flow are negatively correlated with the mixing rate of large vehicles. Predictive model 1 can clearly be expressed as $v = -A \ln(x) + B$, and model 2 can be expressed as $v = -Ax + B$. The models can be understood as corrections of the average speed of the traffic flow after the mixing of large vehicles, where A is the coefficient of the mixing rate and B is the average speed of the traffic flow of pure passenger cars. As the traffic volume increased, the value of A was found to show an increasing trend, indicating that the influence of large vehicles on traffic flow speed became more obvious. When the mixing rate of large vehicles is close to zero, traffic flow includes only passenger cars. The average speeds of traffic flow calculated by the model are basically same with the values calculated by the models of average speed of passenger cars.

As indicated in Tables 3 and 4, the R^2 (coefficient of determination) of model 1 and model 2 are both greater than 0.5, and the R^2 of model 1 is better than that of model 2. Based on the statistical test results and previous analysis, the correlation between mixing rate and average speed is nonlinear. Therefore, model 1 is selected as the speed prediction model of the mixed traffic rate of large vehicles. In order to prevent overfitting of data caused by human subjective factors, the measured data were used to verify the models.

TABLE 3: Traffic flow average speed prediction model for the mixing rate of large vehicles.

Traffic flow patterns	Prediction model 1	Prediction model 2
$v/c \leq 0.35$	$v_a = -2.85 \ln(x) + 113.7$ $R^2 = 0.716$	$v_a = -0.192x + 110.5$ $R^2 = 0.653$
$0.35 < v/c \leq 0.55$	$v_a = -4.02 \ln(x) + 106.5$ $R^2 = 0.802$	$v_a = -0.299x + 101.0$ $R^2 = 0.715$
$0.55 < v/c \leq 0.90$	$v_a = -5.86 \ln(x) + 102.4$ $R^2 = 0.917$	$v_a = -0.437x + 94.5$ $R^2 = 0.889$

TABLE 4: Passenger-car speed prediction model for the mixing rate of large vehicles.

Traffic flow patterns	Prediction model 1	Prediction model 2
$v/c \leq 0.35$	$v_c = -2.1 \ln(x) + 114.4$ $R^2 = 0.625$	$v_c = -0.144x + 112.4$ $R^2 = 0.598$
$0.35 < v/c \leq 0.55$	$v_c = -3.76 \ln(x) + 110.5$ $R^2 = 0.768$	$v_c = -0.262x + 105.1$ $R^2 = 0.601$
$0.55 < v/c \leq 0.90$	$v_c = -4.33 \ln(x) + 101.4$ $R^2 = 0.894$	$v_c = -0.322x + 95.6$ $R^2 = 0.864$

v_a is the average speed of traffic flow (km/h), v_c is the average speed of passenger-cars (km/h), and x is the mixing rate of large vehicles (%), $0 \leq x \leq 40$.

TABLE 5: : Model prediction of the average speed of passenger cars in G65.

No.	LOS	v/C	Mixing rate (%)	Hourly volume (veh/h)	Average speed of passenger cars	Model 1		HCM model	
						Forecast value	Relative error (%)	Forecast value	Relative error (%)
1		0.30	25.7	866	105.6	107.6	1.89	120	13.64
2	A	0.33	28.9	983	105.5	107.3	1.71	120	13.74
3		0.33	23.7	988	102.9	107.8	4.76	120	16.62
4		0.34	12.0	1030	108.8	109.2	0.37	120	10.29
5		0.38	21.8	1266	98.6	98.9	0.30	120	21.67
6		0.39	15.3	1478	100.3	101.2	0.90	120	19.64
7	B	0.55	11.1	2048	96.4	101.4	5.19	117.8	22.24
8		0.50	11.2	1895	100.9	101.4	0.50	119.0	17.97
9		0.54	9.9	1942	100.2	101.9	1.70	119.1	18.89
10		0.48	7.3	1976	101.6	103.0	1.38	119.6	17.70
11		0.57	10.5	2083	95.8	91.2	-4.80	117.8	22.97
12		0.65	8.4	2237	97.3	92.2	-5.24	117.4	20.71
13	C, D	0.68	8.6	2343	95.1	92.1	-3.15	116.0	22.00
14		0.75	3.9	2715	93.9	95.5	1.70	115.6	23.13
15		0.84	5.2	2867	88.7	94.3	6.31	111.4	25.54
Average absolute relative error						—	2.66	—	19.12

3.2. *Model Verification.* To evaluate the accuracy of the model established and to verify the adaptability of the HCM model, traffic flow data of another highway were selected. When selecting the verification highway section, the influence factors other than the mixing rate of large vehicles were excluded. Finally, the K903+800 section of the G65 expressway was selected because the posted speed limit and d route condition of this section is consistent with G5.

G65 is a suburban highway with two lanes, a single lane width of 3.75 m, the right-shoulder lateral clearance is 2.5 m, and interchange density is less than 0.5 interchange per mile. According to the HCM manual, the free-flow speed (FFS) of the section is 75 mi/h (120 km/h), peak-hour factor (PHF) is 0.90, number of lanes (N) is 2, passenger-car equivalents for large vehicles in the traffic stream (E_T) is 4.5, driver

population factor f_p is 1, and V is hour volume. Based on the measured traffic flow data, the predicted value of the HCM model is calculated.

Tables 5 and 6 are comparison tables of model forecast value and actual speed.

As shown in Table 5, the forecast values from the HCM manual are higher than the measured speeds by approximately 10.2%–25.5%. Therefore, there is a large error. The error may be related to two main factors: first, the basic assumptions of the HCM model do not modify the speed limit and the degree of police enforcement. Secondly, there are some differences in driving habits in different countries. Studies have shown that the V_{85} speed is usually higher than the posted speed limit in developed countries, while drivers in China usually choose lower speeds than the posted speed

TABLE 6: Model prediction of the average speed of traffic flow in G65.

No.	LOS	V/C	Mixingrate of large vehicles (%)	Average speed of traffic flow (km/h)	Model 1		
					Forecast value (km/h)	Relative error(%)	
1		0.30	25.7	100.6	104.4	3.78	
2	A	0.33	28.9	100.1	104.1	4.00	
3		0.33	23.7	99.9	104.7	4.80	
4		0.34	12.0	103.1	106.6	3.39	
5		0.38	21.8	94.9	94.1	-0.84	
6	B	0.39	15.3	97.0	95.5	-1.55	
7		0.55	11.1	93.3	96.8	3.75	
8		0.50	11.2	99.4	96.8	-2.62	
9		0.54	9.9	98.8	97.3	-1.52	
10		0.48	7.3	100.6	98.5	-2.09	
11		0.57	10.5	92.3	88.6	-4.01	
12	C,	0.65	8.4	96.6	89.9	-6.94	
13		D	0.68	8.6	94.5	89.8	-4.97
14			0.75	3.9	90.3	94.4	4.54
15		0.84	5.2	88.5	92.7	4.75	
Average absolute relative error						3.57	

limit [26]. Therefore, series corrections are needed when using the HCM speed prediction model.

Comparing Tables 5 and 6, model forecast values for the four models are basically consistent with the real value of speed, and the average absolute relative error is less than 5%. This indicates that the speed prediction models have good adaptability. Therefore, based on the previous analysis, model 1 is selected as the speed prediction model of the mixed traffic rate of large vehicles.

4. Conclusions

This paper proposes a speed prediction model based on the mixing rate of large vehicles for predicting the average speeds of traffic flow and passenger cars. Considering the influence of traffic volume, the traffic flow state was divided into six levels according to the classification of service levels, and the respective vehicle mixing speed prediction models were established. According to different traffic flow patterns, the speed prediction model of the mixing rate of large vehicles was established. By comparing model forecast values and the actual velocities, the adaptability of the model was verified.

Based on the results obtained, it can be concluded that (1) the incorporation of large vehicles reduces traffic flow speed. The average speed of traffic flow and the average speed of passenger cars in traffic flow are negatively correlated with the mixing rate of large vehicles. (2) According to the data acquired, there is an evident negative logarithmic linear relationship between average traffic speed and the mixing rate of large vehicles, and the results could also be applied to passenger cars. The predictive model can be expressed as $v = -A \ln(x) + B$, where A is the coefficient of the mixing rate and B is the average speed of the traffic flow of pure passenger cars. When the mixing rate of large vehicles is

close to zero, the forecast value of the model is the average speed of passenger cars. (3) The value of A is 2.85, 4.02, and 5.86 under traffic patterns of $v/c \leq 0.35$, $0.35 < v/c \leq 0.55$, and $0.55 < v/c \leq 0.90$, respectively. As the traffic volume increased, the value of A was found to show an increasing trend, indicating that the influence of large vehicles on traffic flow speed became more obvious as the traffic volume increased. (4) In addition, the traffic speed decreases significantly with the increasing mixing rate. At a sufficiently mixing rate, the traffic speed approaches a certain fixed speed, which may be related to the expected speed of the large vehicles. (5) By comparing the forecast values of the HCM model with the measured speeds, it shows that the posted speed limit of the road is an important factor when predicting the average speed of traffic flow through the mixing rate.

The results obtained from the study are useful for determining the classification control of highway vehicles. However, due to traffic volume restrictions, the impact of large vehicles on traffic flow under congested patterns remains to be further studied. In addition, the research considered only the speed limit of 120 for the selected section. In future, the impact of the mixed speeds of large vehicles on traffic flow speed under different speed limit standards will be further studied.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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