Research on deceleration lane length of special ramp for freight cars on passenger-freight separation expressway

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Abstract. In order to obtain the truck-specific ramp deceleration lane length index for passenger
and cargo separation, the UMRR chain Kepler radar speedometer is used to collect the vehicle
speed data under the free-flow state of the ramp feature points (starting point, diversion point
and small nose point of the transition section). The KS normal distribution test is carried out on
the sample data. On the basis of satisfying the test requirements, the speed and acceleration
characteristics of the deceleration lane vehicle are analysed, and then the parameters in the
secondary deceleration theory are re-determined. Based on this, the deceleration lane length
value of the truck-specific ramp is calculated.

1. Introduction
Our country’s highway accident model research shows that, the number of truck accidents accounts for
more than half of the total. Vehicles leaving expressways have to leave at the exit of interchange
(hereinafter referred to as interchange) [1]. Accident statistics show that about 30% of the total accidents
occur at the exit sections of expressways in our country. Most of the reasons may be related to the design
indexes of speed change lanes. At present, the research on the design indexes of special speed reduction
lanes for passenger cars and freight cars in our country has just started. Therefore, it is necessary to
study the speed reduction lane indexes of special ramp for freight cars.

Mason J F et al [2] proposed various structures of truck lanes and related control methods. Janson,
B.N et al [3] developed a computer analysis program that can be applied to the evaluation of truck lanes.
Vidunas et al. [4] based on Janson’s relevant research results, applied it to Virginia highway in the United
States. The results show that the use of truck-only lanes can effectively improve the traffic safety level
of roads, improve and optimize traffic management conditions, and significantly reduce the degree of
pavement damage.

Fang Chen and others [5] analyzed the necessity of dividing passenger and freight lines, and put
forward the quantitative index of setting conditions for dividing passenger and freight lines. On the basis
of expounding the concept of separation of passenger and freight, Guocai Tang [6] focused on the
geometric design indexes of special roads for passenger cars and freight cars. Na Ni [7] analyzed the
adaptability of the three settings of passenger and freight separation based on AHP and traffic simulation.

2. Data collection and inspection

2.1. Acquisition conditions
Based on the observation of 8 interchanges on Guangzhou Guanghe Expressway and West Second Ring Expressway, this paper investigates and collects the actual running speed. The data acquisition conditions are roads with high visibility and good conditions, sunny weather and suitable temperature, and the morning or afternoon with less interference between vehicles is selected.

2.2. Control Conditions
The data acquisition instrument is a chain Kepler radar velocimeter, and the radiation mode of the sensor of the instrument is a fan-shaped radiation centered on radar, which can return and record vehicle operation data every 50 ms. The location of the speed measuring radar is within a certain range of 2m from the front of the gradual change section of the deceleration lane to the outer edge of the lane outside the main line. The radar head should be horizontal and approximately parallel to the driving direction. The setup instrument is connected to the computer equipped with DR3-TMC Configurator software, and the whole process of acquisition is recorded. During the software test, the vehicle is ensured to travel along the central line of the lane. After passing the test, the data is formally collected and saved.

![Figure 1. Position diagram of speed measuring radar](image)

2.3. Normal Test of Velocity Data
In order to obtain the observation accuracy that meets the requirements and reflect the actual driving conditions of truck vehicles at the characteristic section, the selected sample size should be well controlled. According to the statistical principle, the minimum sample size required for the speed measuring section of the exit section can be determined by equation (1)

\[ N_{\text{min}} = \left( \frac{\delta K}{E} \right)^2 \]

Where: \( N_{\text{min}} \) is the minimum sample size; \( \delta \) is the standard deviation of the sample, calibrated according to actual data, and selected as 10km/h after a large number of tests; \( E \) is the allowable error, generally 2.5 km; \( K \) is the confidence probability coefficient.

With a 95% confidence level and a confidence probability coefficient of 1.96, it can be calculated that the data acquisition needs to meet the requirements of 62 minimum samples.

| Numbering | Position  | Sample size | Z value | Progressive significance level (bilateral) p |
|-----------|-----------|-------------|---------|---------------------------------------------|
| 1          | shunt point | 63          | 0.581   | 0.896                                      |
| 2          | shunt nose  | 66          | 0.638   | 0.821                                      |
| 2          | shunt point | 65          | 0.592   | 0.891                                      |
| 2          | shunt nose  | 68          | 0.627   | 0.806                                      |
| 3          | shunt point | 84          | 0.507   | 0.924                                      |
| 3          | shunt nose  | 66          | 0.861   | 0.46                                       |
| 4          | shunt point | 72          | 0.607   | 0.864                                      |
| 4          | shunt nose  | 67          | 0.378   | 0.462                                      |
| 5          | shunt point | 76          | 0.911   | 0.355                                      |
| 5          | shunt nose  | 84          | 0.662   | 0.476                                      |
| 6          | shunt point | 70          | 0.991   | 0.293                                      |
| 6          | shunt nose  | 75          | 0.853   | 0.767                                      |
It can be seen from Table 2 that the minimum sample size meets the requirements, and the test Z values are all greater than 0.05, and the progressive significance level (both sides) are all greater than 0.20, meeting the requirements of normal distribution.

3. Analysis of Vehicle Braking Characteristics Based on Operating Characteristics

At present, there is no example of expressway separating passenger and freight in China, so the data of truck running speed at the interchange exit under free flow condition are collected to analyse the characteristics of truck drivers’ behavior and vehicle running. The essence of speed control is reflected in the acceleration change of the vehicle [8], so it should also be analysed in combination with the acceleration of the vehicle. The variation trends of operating speed and acceleration are shown in Figure. 2 and Figure. 3 respectively.

From the change of speed and acceleration, it can be seen that the overall trend of truck speed change is deceleration, but the whole deceleration process can be divided into two obvious stages: the first stage has lower deceleration degree and slower speed decline; The deceleration value in the second stage is larger and lasts longer. According to the analysis of the driving conditions of the vehicles exiting from the actual interchange exit, when the drivers leave the main line and enter the variable speed lane, due to the driving inertia and the wide range of the variable speed lane, most drivers will choose to release the accelerator and use the engine to brake and decelerate, so the vehicles will keep running at a higher speed, and the braking acceleration at this time is smaller and the speed reduction range is lower. However, when the driver sees the narrow road surface at the end of the deceleration lane and the smaller exit radius of the ramp (compared with the lane change range and the main line), and also sees the speed limit sign of the ramp, in order to ensure driving safety, the driver will use the main brake to brake, and at this time the braking acceleration is larger and the speed drop is larger.

4. Deceleration lane length

4.1. Theory of Passenger and Freight Separation and Deceleration Lane

In this paper, the truck is taken as the research object, the running speed data of the single lane deceleration lane at the exit of the interchange is measured, the length of the deceleration lane is calculated based on the secondary deceleration theory [9], and the key parameters are calibrated.
4.2. Length of transition section

The research results of Binghong Pan [10] show that sideslip precedes rollover, the higher the vehicle speed is, the smaller the outflow angle is required, and the higher the center of mass is, the greater the possibility of overturning is. Therefore, in order to reduce the occurrence of accidents, the outflow angle of the special ramp for trucks should not be too large. According to the Detailed Rules, the gradual change rate at the exit of the single lane deceleration lane ranges from 1/25 to 1/17.5. The calculation of the gradual change rate is determined by the ratio of the road width change value between the start and end points of the deceleration section to the length of the deceleration section, as shown in equation (2). The formula for calculating the length of the gradual change section is shown in formula (3).

$$K = \frac{d_1 - d_2}{L_1 + L_2} = \frac{d_1}{L_0}$$

$$L_0 = \frac{d_1}{d_1 - d_2} (L_1 + L_2)$$

(2)

(3)

Where: $K$ is the export gradient rate; $d_1$ is the transverse shift value of the diversion point (m); $d_2$ is the lateral displacement value of shunt nose (m); Other symbols have the same meaning as above.

4.3. Length of deceleration section

4.3.1 First deceleration section $L_1$

In this paper, for the running speed of vehicle diversion points, SPSS software is used to process the exit speed data of four interchanges with design speeds of 120km/h and 100km/h, and the 85th percentile running speed value of truck traffic flow at sample interchange diversion points is obtained. The speed values of truck diversion points are shown in Table 2.

| Main line design speed (km/h) | 120  | 100  | 80   | 60   |
|-------------------------------|------|------|------|------|
| Shunt point velocity (km/h)   | 85   | 75   | 65   | 60   |

The analysis shows that 85% of the truck acceleration changes in the range of -0.8~0m/s$^2$ during engine braking deceleration. On the basis of test data and referring to the values of Japanese code [17], the deceleration values of truck engines in this paper are shown in table 3.

| Shunt point velocity (km/h) | 85   | 75   | 65   | 60   |
|----------------------------|------|------|------|------|
| Engine deceleration a1 (m/s$^2$) | 0.8  | 0.7  | 0.6  | 0.55 |

4.3.2 Second deceleration section $L_2$

The corresponding relationship between the speed of the truck's splitter nose and the design speed of the main line obtained from the measured speed data is shown in Table 4.
Table 4. Corresponding table of main line design speed and shunt nose speed

| Main line design speed (km/h) | 120 | 100 | 80 | 60 |
|-------------------------------|-----|-----|----|----|
| Shunt nose speed (km/h)       | 65  | 60  | 55 | 45 |

It can be seen that compared with the design speed of the main line, the running speed of the truck at the splitter nose is smaller. According to the analysis of the change of truck braking acceleration in the above 2.1, 85% of the truck acceleration change range is -1.5~0m/s² during deceleration by the brake. As the speed of the shunting point changes in the range of 90~80km/h, the braking acceleration value changes in the range of -1.5~1.2m/s² (85% percentile). Referring to the braking acceleration value range of 1~1.5m/s² in China's "Automobile Driver's Manual", on the basis of analysing the test data of braking acceleration, the braking acceleration of freight cars as shown in Table 5.

Table 5. Brake deceleration values

| Running speed (km / h) | 85 | 75 | 65 | 60 |
|------------------------|----|----|----|----|
| Brake deceleration a₂ (m/s²) | 1.5 | 1.2 | 1 | 0.8 |

The parameters calibrated in this test are brought into the formula for calculation, and the deceleration section length is corrected according to the gradient rate, so as to obtain the deceleration lane length (rounded 5m) and the recommended gradient rate value of the single lane of the truck ramp as shown in Table 6.

Table 6. Recommended value of deceleration lane on special ramp for freight cars (m)

| Main line design speed (km/h) | 80 | 70 | 60 | 50 | 40 | 30 |
|-------------------------------|----|----|----|----|----|----|
| Deceleration section          | 95 | 100 | 135 | 165 | 185 | 205 |
| Gradual change ratio          | 1/17.5 | 1/18.9 | 1/25.5 | 1/31.2 | 1/34.9 | 1/38.7 |
| Transition section            | 45 | 45 | 65 | 75 | 85 | 95 |
| Deceleration section          | 95 | 95 | 100 | 135 | 165 | 185 |
| Gradual change ratio          | 1/17.5 | 1/17.5 | 1/18.9 | 1/25.5 | 1/31.2 | 1/34.9 |
| Transition section            | 45 | 45 | 45 | 65 | 75 | 85 |
| Deceleration section          | - | 95 | 95 | 95 | 130 | 155 |
| Gradual change ratio          | - | 1/17.5 | 1/17.5 | 1/17.9 | 1/24.6 | 1/29.3 |
| Transition section            | - | 45 | 45 | 45 | 60 | 70 |
| Deceleration section          | - | - | - | 95 | 115 | 150 |
| Gradual change ratio          | - | - | - | 1/17.5 | 1/21.7 | 1/28.3 |
| Transition section            | - | - | - | 45 | 55 | 70 |

The study in this paper considered the influence of different ramp design speeds, and compared the recommended values in Table 6 with the specified values in the current specification. It was found that the specified value of the length of the gradual change section in the specification was close to the recommended value obtained when the ramp design speed was 30km/h; The specified length of deceleration section is close to the recommended length when the ramp design speed is 50km/h.

5. Conclusions
(1) This paper collects the vehicle running speed data through experiments, analyzes the braking characteristics of trucks at the interchange exit, and calculates the deceleration lane length index of special ramp for trucks by using the parameters in the recalibrated secondary deceleration theory.
(2) When collecting data, the sample size meets the requirements of statistical principles, the collected data meets the requirements of normal distribution, and the data is valid.
(3) By analysing the test data and vehicle running characteristics, the truck braking deceleration process is in good agreement with the secondary deceleration theory. Therefore, the method of calibrating parameters and calculating the length through measured data is feasible in this paper.

(4) This paper gives the recommended length index value of the deceleration lane of the special ramp for trucks with separated section, which further improves the specifications and provides guidance for the construction of the interchange of the passenger and freight separation expressway.

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