Study on the Opening Position of the Same Median Strip at the Exit of the Passenger and Truck Separation Integrated Subgrade Interchange

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Abstract. In order to avoid the traffic disorder and traffic accident caused by the weaving from the same median strip openings to the interchange exit segment, this paper analyzes the structure from the same median strip openings to the interchange exit, and explores the influencing factors of the opening position. By analyzing the configuration, operating state and volume to capacity ratio, the calculation model of the minimum length of the weaving segment is established. Based on the number of lanes and design speed, the proposed value of the opening position of the same median strip at the exit of the passenger and truck separation integrated subgrade interchange is proposed.

1. Introduction
As a node of the highway network, the complex mixed traffic flow leads to frequent accidents at the interchange exit. It is difficult to meet the requirements of future highway traffic safety with passenger and truck mixed driving, therefore the design method of passenger and truck separated driving comes into being.

At present, the main line of the separate interchange of passenger and truck (hereinafter referred to as the interchange) mainly adopts the integrated subgrade form of forced separation of passenger cars and trucks. In other words, the road is divided into inner road only for cars and outer road only for trucks. In the middle, a physical separation belt is set, namely, the same direction separation belt (referred to as the same median strip) (Figure 1). At the exit of the interchange, the cars driving on the inner road must cross the same median strip opening and the outer road before entering the ramp. That is to say, the weaving will occur in the truck lane, which is easy to cause traffic disorder and traffic accidents. Therefore, the opening position of the same median strip will have a great impact on the drivers of the exit segment. If the opening position is too close to the exit, the drivers may not operate in time and miss the exit. If the opening position is too far away from the interchange exit, the driver will spend too much time weaving in the truck lane, which will affect the capacity of the truck. Therefore, it is necessary to study the opening position of the same median strip between car and truck to ensure the operational efficiency and safety of the exit section and the entire road network.

At present, scholars at home and abroad have studied the length of weaving segment a lot. In the Road Capacity Manual (HCM2010), the United States regressed the calculation method of the capacity and length of weaving segment through a large number of measured data [1]. The German Road Capacity Manual (HBX2015) also systematically studies the overall capacity and service level of diversion, confluence and weaving segment [2]. Domestic such as Jian Sun et al based on a large number of measured data to simulate a new model for calculating the capacity of weaving segments
[3]; Hongjun Cui et al established a calculation method for safe lane change based on the length of weaving segment by applying probability theory and traffic flow theory [4]. However, there are few researches on the exit of the passenger and truck separation integrated subgrade interchange. Thanks to many engineering examples of separation of passenger and truck highways in the United States, such as the New Jersey toll road I-95, it can provide valuable experience for the study of the opening position of the same median strip. Domestic scholars mainly focus on the necessity and setting conditions of the separation of passenger and truck, and the study of the separation belt mainly focuses on the length of median strip openings.

In summary, there are few studies on the opening position of the same median strip at home and abroad. When setting the same median strip, designers choose the position without reference which may have potential safety risks. Therefore, it need to be further studied. Based on the weaving theory, this paper establishes the calculation model of the opening position of the same median strip that satisfies the driving safety and comfort of the driver, and gives its suggested value.
2.2. Length of weaving segment
The length of the weaving segment refers to the length from the end of the transition section of the same median strip to the starting point of the transition section of the deceleration lane. In this paper, the length of weaving segment is calculated by the method given by the American capacity manual (HCM2010), which has certain limitations and can only calculate the length of weaving segment within the range of 150~750m [1]. When the length is more than 750m, the degree of turbulence in the weaving segment is roughly the same as that in the basic road section. And when the length is less than 150m, it can be studied according to the intersection without signal [7].

2.3. Weaving segment level of service
The traffic density is used as the division standard of the level of service of the weaving segment, as shown in table 1.

| Level of service | Traffic density in weaving segment [ pcu/(km·ln) ] |
|------------------|--------------------------------------------------|
| A                | 0~7                                              |
| B                | >7~12                                            |
| C                | >12~18                                           |
| D                | >18~25                                           |
| E                | >25~35                                           |
| F                | >35                                              |

2.4. Weaving segment parameters and configuration
The relevant parameters of traffic flow in the weaving segment are shown in table 2.

| Parameter | Meaning | Parameter | Meaning |
|-----------|---------|-----------|---------|
| L(或Lw)  | length of weaving segment | VR | Flow ratio Qw / Q |
| N        | total number of lanes in the weaving segment | R | Ratio of smaller weaving flow rate to total weaving flow rate |
| Nw       | Number of lanes occupied by non-constrained weaving vehicles | V | Average speed of all vehicles in the weaving segment |
| Nnw      | Number of lanes occupied by non-weaving vehicles | Vw | Average speed of weaving vehicles |
| Q        | Total flow rate in the weaving segment | Vnw | Average speed of non-weaving vehicles |
| Qw       | Total weaving flow rate | Qw1 | Higher weaving flow rate |
| Qnw      | Total non-weaving flow rate | Qw2 | Lower weaving flow rate |

2.5. Weaving operation type
Weaving operation types can be classified into constrained and non-constrained. The specific basis is: when Nw < Nw(max), it is the non-constrained; When Nw ≥ Nw(max), it is the constrained.

2.6. Weaving speed and non-weaving speed
The average speed and expected speed in the weaving (non-weaving) segment of weaving (non-weaving) vehicles is related to the weaving strength coefficient. HCM2000 gives the prediction formula of the average speed, as shown in formula 1.

\[ V_i = 24 + \frac{V_{FE} - 16}{1 + W_i} \]  \hspace{1cm} (1)
In the formula: \( V_i \) - Average speed of weaving (non-weaving) vehicles; \( V_{ff} \) - Average free flow speed; \( W_i \) - Weaving strength coefficient

And the weaving strength coefficient \((W_i, or \ W_{ni})\) is determined by the following formula 2.

\[
W_i = \frac{a(1+VR)^b}{(3.28L)^d} \left( \frac{Q}{N} \right)^c
\]

where \( a, b, c, \) and \( d \) are the calibration constants respectively, which can be found according to table 3 below.

### Table 3. Calculation constant of intensity coefficient

| Weaving strength constant | Non-weaving strength constant |
|---------------------------|-----------------------------|
| a  | b  | c  | d  | a  | b  | c  | d  |
| Non-constrained | 0.15 | 2.2 | 0.97 | 0.80 | 0.0035 | 4.0 | 1.3 | 0.75 |
| Constrained   | 0.35 | 2.2 | 0.97 | 0.80 | 0.0020 | 4.0 | 1.3 | 0.75 |
| Non-constrained | 0.08 | 2.2 | 0.70 | 0.50 | 0.0020 | 6.0 | 1.0 | 0.50 |
| Constrained   | 0.15 | 2.2 | 0.70 | 0.50 | 0.0010 | 6.0 | 1.0 | 0.50 |
| Non-constrained | 0.08 | 2.3 | 0.80 | 0.60 | 0.0020 | 6.0 | 1.1 | 0.60 |
| Constrained   | 0.14 | 2.3 | 0.80 | 0.60 | 0.0010 | 6.0 | 1.1 | 0.60 |

### 2.7. Average speed of weaving segment

Average speed of all vehicles in the weaving segment is determined by the following formula 3.

\[
V = \frac{Q}{\frac{Q_{\text{we}}}{V_{\text{we}}} + \frac{Q}{V}}
\]

### 2.8. Length of weaving segment

Considering five subgrade forms and two kinds of speed-change lanes, the minimum length of weaving segment required for the D-class level is calculated according to formula 4. And the average traffic flow density at the level of D-class service is 25pcu/(km\(\cdot\)h). This paper uses Mathematic software to solve the problem.

When the subgrade of the main line is 2T+2C+2C+2T, 2T+3C+3C+2T or 2T+4C+4C+2T, and the exit ramp is a single-lane deceleration lane, the car needs to change one lane to get off the ramp. Thus, this weaving configuration is type B, volume to capacity ratio is 0.4. When the capacity of car lane reaches ramp capacity, the weaving length is the longest, and volume to capacity ratio is 0.4. What’s more, weaving operation type is non-constrained.

The length of weaving segment is shown in table 4.

### Table 4. Single-exit two-lane ramp weaving length

| Type B | Design speed of main line (km/h) | 120 | 100 | 80  | 60  |
|--------|---------------------------------|-----|-----|-----|-----|
| Design | 80                              | (750) | (750) | ___ | ___ |
speed of ramp (km/h) | 70 | 625 | (750) | — | — | 60 | 325 | 585 | (750) | — | 50 | 170 | 305 | 515 | — | 40 | (150) | 155 | 265 | (750) | 30 | (150) | (150) | (150) | 450

Note: 750m (150m) in brackets in the above table represents the maximum (minimum) length of interleave section calculated by this model, which is not applicable (the same below).

② When the subgrade of main line is 2T+2C+2C+2T, 2T+3C+3C+2T or 2T+4C+4C+2T, and the exit ramp is a two-lane deceleration lane, the car needs to change one lane to get off the ramp. Thus, this weaving configuration is type B, and volume to capacity ratio is 0.5. What’s more, weaving operation type is non-constrained.

The length of weaving segment is shown in table 5.

| Type B | Design speed of main line (km/h) | 120 | 100 | 80 | 60 |
|--------|-------------------------------|-----|-----|----|----|
|        | Design speed of ramp (km/h)    |     |     |    |    |
| 80     | (750)                         | (750) | — | — | — |
| 70     | (750)                         | (750) | — | — | — |
| 60     | 705                           | (750) | (750) | — | — |
| 50     | 235                           | 656   | (750) | — | — |
| 40     | (150)                         | 170   | 555 | (750) | — |
| 30     | (150)                         | (150) | (150) | — | 430 |

③ When the subgrade of main line is 3T+2C+2C+3T or 3T+3C+3C+3T, and the exit ramp is a single-lane deceleration lane, the car needs to change two lanes to get off the ramp. Thus, this weaving configuration is type C, and volume to capacity ratio is 0.4. What is more, weaving operation type is non-constrained.

The length of weaving segment is shown in table 6.

| Type C | Design speed of main line (km/h) | 120 | 100 | 80 | 60 |
|--------|-------------------------------|-----|-----|----|----|
|        | Design speed of ramp (km/h)    |     |     |    |    |
| 80     | (750)                         | (750) | — | — | — |
| 70     | (750)                         | (750) | — | — | — |
| 60     | 490                           | (750) | (750) | — | — |
| 50     | 320                           | 430   | (750) | — | — |
| 40     | (150)                         | 290   | 380 | (750) | — |
| 30     | (150)                         | (150) | (150) | — | 305 |

④ When the subgrade of main line is 3T+2C+2C+3T or 3T+3C+3C+3T, and the exit ramp is a two-lane deceleration lane, the car needs to change two lanes to get off the ramp. Thus, this weaving configuration is type C, and volume to capacity ratio is 0.4. What is more, weaving operation type is non-constrained.

The length of weaving segment is shown in table 7.
Table 7. Two-exit three-lane ramp weaving length

| Type C | Design speed of main line (km/h) | 120     | 100     | 80      | 60      |
|--------|---------------------------------|---------|---------|---------|---------|
|        |                                 | 80      | (750)   | (750)   | —       | —       |
|        | Design speed of ramp (km/h)     | 70      | (750)   | (750)   | —       | —       |
|        |                                 | 60      | (750)   | (750)   | (750)   | —       |
|        |                                 | 50      | 680     | 565     | (750)   | —       |
|        |                                 | 40      | 235     | 160     | (750)   | (750)   |
|        |                                 | 30      | (150)   | (150)   | 430     | (750)   |

3. Conclusion

This paper analyzes the structure from the same median strip openings to the interchange exit, and explores the influencing factors of the opening position of the same median strip. By analyzing the number of lanes, the configuration, operating state and volume to capacity ratio, the calculation model of the minimum length of the weaving segment is established. Based on the number of lanes and design speed, the proposed value of the opening position of the same median strip at the exit of the passenger and truck separation integrated subgrade interchange is proposed.

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