Study on the minimum distance between three lane ramp continuous exits of stereoscopic structure highway

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Abstract—Under the design model of stereoscopic structure highway, conventional one-lane and two-lane ramps can no longer meet the traffic conversion requirements of interchange, so three-lane ramps should be designed in interchange. Due to the changing of design form, the existing single-lane and dual-lane design indicators cannot meet the design requirements of the three-lane ramp, especially in the continuous diversion area. Thus, according to the design requirements of the three-lane ramp in the stereoscopic structure highway, this paper discusses the distance between adjacent connecting parts when the main line and the ramp are continuously diverted. First, it analyzes the driving behavior on the continuous diversion section of the ramp. Then, based on the lane-changing theory, the formula of the vehicle lane-changing length, the driver's recognition of the signs, the driving behavior are used to establish the models, which calculate the main line to the ramp diverging stage and ramp again diverging stage. After that, the recommended value of the minimum distance between consecutive exits at different ramp design speeds can be calculated. Finally, a 360 ° full view driving simulation platform is used to verify the rationality and applicability of the model from the aspects of driving trajectory, speed running characteristics and driver's physiological index changes. The experimental results show that the value of the calculation model conforms to the driving habit, and all test drivers successfully completed the experiment, and the average driving distance in the experiment is less than the theoretical calculation value. Therefore, it can be considered that the theoretical model and relevant parameters established in this paper are reasonable and have certain engineering applicability.

1. INTRODUCTION

There are frequent lane changing phenomena in Interchange diversion area, which leads to traffic flow disorder and frequent traffic conflicts [1]. Relevant data show that over 30% of highway accidents occur in interchange diversion area and its impact area [2]. Most of the drivers can't carry out the ramp diversion normally because of the small distance between the continuous exits and the large traffic
flow on the ramp. Such problems have adverse effects on the traffic efficiency and traffic safety of the ramp. With the construction of three-dimensional composite highways, the engineering application demand for three-lane exit ramps has become stronger. Ramp continuous diversion refers to two or more diversions within a certain distance. In the case of continuous exits on the same side of the main line within the scope of a single interchange, the multiple setting of traffic guidance signs within a short range will affect the driver's judgment of the exit, and the vehicle will frequently change lanes and slow down. It usually adopts the way of combining multiple ramp exits. For the three-dimensional composite highway, the same turning direction of the three-dimensional composite interchange can be divided into three-dimensional layer and ground layer road. There are multiple diversions on the ramp of the main line one-way three lane ramp. All in all, the distance between the continuous diversion connection of the three-lane ramp is particularly important, which directly affects the driving safety of the driver.

Domestic and foreign researches have been conducted on basic highway sections, interchanges and their ramps, but there is a certain gap between the recommended values of various countries. The current Chinese route-related regulations stipulate that the continuous spacing of interchange ramps is only related to the design speed of the main line, and does not take into account the actual number of ramp lanes and the influence of different design speeds on the spacing, plus the three-dimensional composite highway interchange. The continuous diversion to the three-lane exit ramp is slightly different from the continuous diversion of the single and double-lane ramp. The frequent diverging and intertwined operation of vehicles in the continuous diverging area are more serious. Gao Jianping conducted an on-site survey on multiple interchanges in Chongqing, and used statistical methods to qualitatively divide lane changing behaviors into four types [3]. The research results show that more than 80% of drivers see the traffic guidance of the target exit The behavior of changing lanes is only taken after the sign, and the driver is not familiar with the setting of the exit, and the driver needs to change lanes several times to seek the exit. Shao yang et al. Analyzed the driving behavior of main line and ramp continuous separation and merging, and established the calculation model of continuous on ramp separation and merging by using vehicle lane changing model and driver sign recognition law. Jiang Fei established a calculation model for the minimum distance of continuous diverging of interchange ramps by analyzing the traffic characteristics and vehicle operating characteristics at the continuous exit of the ramp, the characteristics of the driver’s recognition sign, and the distribution of the headway time at the ramp, and established a calculation model for the minimum distance The minimum distance between continuous exits of the ramp at the design speed is recommended [4]. The above-mentioned research is mainly aimed at the continuous (twice) diverging of the two-lane exit ramp, which has certain reference significance for the calculation of the minimum distance between the multiple diversion junctions of the three-lane exit ramp in this paper. Based on the characteristics of the composite highway project, this paper analyzes the three-lane ramp continuous diverging driving behavior, establishes the calculation model of minimum distance between connecting parts of continuous diverging on three lane ramp, and carries out driving simulation for continuous diverging, verifies the rationality and applicability of the model from the aspects of driving track, speed operation characteristics and driver's physiological index changes.

2. DRIVING BEHAVIOR ANALYSIS OF CONTINUOUS DIVERGING ON RAMP

Regarding the traffic flow characteristics of the diversion area, in the upstream of the diversion area, the vehicles that need to leave are changed from the inner to the outer lane, and the vehicles that need to go straight change from the outer lane to the inner lane, and the lane traffic on the lane is redistributed to form an interweaving. Vehicles downstream of the diversion area will no longer change lanes. In the upstream of the diversion area, Zhao Xiaocui [5] and others found that the actual vehicle speed in the diversion area is often greater than the design speed of the ramp, and the characteristic of decelerating first and then accelerating in the deceleration lane is shown. In the downstream of the diversion area, the speed of the vehicle becoming steady.
Generally, a diverging on a ramp is a diversion in different turning directions. Therefore, the driver's lane change demand is the most during the diverging from the main line to the ramp diversion. The interweaving of this section is the most serious, and the traffic flow is turbulent. Under the guidance of the front guide signs, the vehicles leaving the three lane off ramp will change lanes to the inner lane and the secondary inner lane. This process often requires one or two lane changes. The secondary diversion or multiple diversions on the ramp are the diversions that drive into different road levels (facade layer and ground layer). After recognizing the information of guide signs, vehicles only need to change lanes once to smoothly enter the target ramp. However, the guidance for different road levels in the same direction is very complex, and it is often necessary to inform the driver of the information of the next exit of the main line for the driver to select the level. Therefore, the driving distance in the recognition and reaction time of the driver is relatively long. To sum up, the three-lane continuous ramp diversion can be divided into two stages for the study of the minimum spacing value respectively, that is, from the main line to the ramp diverging stage, and the ramp diverging stage again.

![Figure 1. the diagram of continuous diversion lane changing behavior of three-lane ramp](image)

3. CALCULATION MODEL OF CONTINUOUS EXIT SPACING OF THREE LANE RAMP

This stage refers to the diversion of three lane off ramp with other ramps at a certain distance from the main line. Considering the actual engineering demand, it is necessary to set up ETC non-stop toll station in this diverging stage. Therefore, it is necessary to calculate the distance between the outlets with and without toll stations.

3.1 Diversion from the main line to the ramp diverging stage

3.1.1 No toll station on ramp

According to the characteristics of the driver's driving process on the ramp, the minimum distance of continuous diverging on the ramp should include the driver's sign reading and action distance $L_1$, the driver's required distance $L_2$ to find the inserted gap, the driver's driving distance $L_3$, the exit confirmation distance $L_4$, the transition section $L_5$ of the second diverging connection and the length of the wedge-shaped end marking line $L_6$. Therefore, the minimum distance calculation model of ramp continuous exit is established.

$$ S = L_1 + L_2 + L_3 + \max \{L_4, L_5\} + L_6 $$

![Figure 2. the diagram of ramp continuous exit](image)
a) Recognition, discrimination and action distance of ramp continuous diversion signs $L_1$
Because the off ramp needs to meet the needs of smooth traffic flow conversion, it is usually set up in the form of two lanes and multi lanes. After the vehicles diverge from the main line into the ramp, and before the second diversion nose, the driver needs to identify the information expressed by the guide sign in front of the ramp diversion connection, and drive into the target ramp through lane change. Therefore, the reading and decision-making distance of guide signs refers to the distance that the driver can accurately recognize after seeing the guide sign and make the corresponding lane change decision in the whole time.

$$L_1 = \frac{V(t_r + t_d)}{3.6}$$  

(2)

Where $V$ is the ramp design speed, and $t_r$ is the time required to read the sign, $t_r$ is generally taken as 1-2s, and $t_d$ is the time required to respond to decision-making, $t_d$ is generally taken 2-2.5s [6]. Domestic scholars have studied the relationship between the number of names in traffic signs and cognitive time [7], as shown in the table below. Because there are no more than 5 place names in traffic signs and cognitive time, as shown in the table below. Because there are no more than 5 place names in two directions at the diverging area of ramps, $t_r$ and $t_d$ are taken as 2s and 2.5s respectively.

| Number of place names | 2   | 3   | 4   | 5   | 6   |
|-----------------------|-----|-----|-----|-----|-----|
| Time/s               | 1.32| 1.55| 1.63| 2.07| 2.72|

### TABLE 1 THE NUMBER OF PLACE NAMES AND DRIVERS’ COGNITIVE TIME

b) The driver finds the distance needed to insert the gap $L_2$
The driver observes the traffic conditions on the adjacent outer lanes and waits for the ideal insertable gap to appear. In this process, the distance traveled by the vehicle is $L_2$. Assuming that the vehicle speed of the basic section of the ramp is $V$ and the traffic flow is $Q$, the average arrival rate of vehicles is $\lambda = \frac{3600}{Q}$. The exit of the interchange adopts a three-level service level, the traffic flow is in a stable flow state, and the K-order Erlang distribution is suitable for the description of the steady flow of free flow and congested flow. Therefore, this paper uses the second-order Erlang shift distribution function to solve the average waiting time $t_w$ of the insertable gap:

$$t_w = \frac{2}{\lambda} + \frac{1}{\lambda} \left[ t_c + 1 \right]^2 + \frac{1}{\lambda} \left[ t_c + 1 \right] e^{-2(1+\tau)}$$

$$L_2 = \frac{V}{3.6} t_w$$

(3)

(4)

Where $t_c$ is the critical gap of vehicles, and $\lambda$ is the average arrival rate per unit time of the target lane, and $\tau$ is the minimum headway of the target lane. Through the statistical analysis of field survey data, $t_c$ is 2.0s, $\tau$ is 0.9s.

### TABLE 2 THE TIME OF READING THE LATIN LETTERS ON SIGN

| Number of words | 5   | 10  | 15  | 20  | 25  |
|-----------------|-----|-----|-----|-----|-----|
| Time/s          | 1.3 | 1.5 | 1.9 | 2.5 | 3.2 |

### TABLE 3 DESIGN CAPACITY OF BASIC SECTION ON RAMP

| Ramp design speed (km/h) | 80  | 70  | 60  | 50  | 40  | 35  | 30  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|
| Design capacity (pcu/h)  |     |     |     |     |     |     |     |
| Single lane              | 1500| 1400| 1300| 1200| 1000| 900 | 800 |
| Two-lane                 | 2900| 2600| 2300| 2000| 1700| 1500| 1300|
| Three-lane               | 3950| 3600| 3150| 2800| 2400| 2000| 1800|
c) Lane change distance $L_3$

Vehicles need to cross the width of a lane at an appropriate speed when changing lanes, so the lane change time is basically stable [8]. The driving distance of the vehicle during the lane change is $L_3$.

$$L_3 = \frac{V_w}{3.6\gamma}$$  \hspace{1cm} (5)

Where $w$ is the lane width, and $\gamma$ is the vehicle lateral movement rate, which is taken as 1m / s according to relevant research.

d) Exit confirmation distance $L_4$

Drivers observe the geometric alignment of the road after ramp diversion to determine whether deceleration measures are needed. The deceleration distance is related to the passing speed of the off ramp nose end of the main line and the ramp design speed after the diversion.

$$L_4 = \frac{V}{3.6\gamma}$$ \hspace{1cm} (6)

Where $t_4$ is the driver's confirmation time (s), according to relevant research, the value is generally 2.5s [9].

e) Length of transition section of diversion junction $L_5$

The length of the transition section of the diverging junction refers to the length of the road surface from the normal width to the diverging point (where one lane width is added). According to the Detailed design rules for highway interchange (JTG/T D21-2014) [10], the alignment design of ramp diversion connection is shown in Figure 3.

![Figure 3. Line design drawing of ramp diversion connection](image)

The minimum length of the transition section of the ramp mutual diversion junction is determined according to the maximum transition rate of the diversion junction. The calculation results are shown in Table 4.

| Diverging velocity (km/h) | 80  | 70  | 60  | 50  | 40  | 35  | 30  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|
| Maximum transition rate of junction | 1/22.5 | 1/20 | 1/17.5 | 1/15 | 1/15 | 1/15 | 1/15 |
| Minimum length of transition section (m) | 80  | 70  | 60  | 55  | 50  | 50  | 50  |

f) Triangle length of zebra crossing at diversion junction $L_6$

The triangle length of zebra crossing refers to the distance from the diverging point to the diversion nose. Chen Jin et al. Carried out modeling and calculation on the length of the triangle area of zebra crossing, mainly including two cases of the ramp alignment deviation after the diversion is reverse and the same direction [11].
In Figure 4, M is the diverging point, n is the small nose point, \( O_a \) and \( O_b \) are the center of the circular curve of the assumed ramp alignment, and the straight line \( l_{MN} \) is the length of the triangle area. The position of the small nose point can be determined by the offset widening value of the connecting part. The offset circle in the figure represents the edge line formed by the sum of the offset widened hard shoulder width value and the chamfer radius value.

According to the geometric relationship in Figure 5 (b):

\[
l_{0,0a} = \sqrt{l_{0,0a}^2 + l_{0,0b}^2 - 2l_{0,0a}l_{0,0b}\cos(\pi - \alpha)} \quad \text{(REVERSE DIRECTION)}
\]

\[
l_{0,0a} = \sqrt{l_{0,0a}^2 + l_{0,0b}^2 - 2l_{0,0a}l_{0,0b}\cos(\alpha)} \quad \text{(SAME DIRECTION)}
\]

\[
\angle MO_A N = \arccos\left(\frac{l_{0,N}^2 + l_{0,0}^2 - l_{0,N}^2}{2l_{0,0a}l_{0,0b}}\right) - \arcsin\left(\frac{l_{0,0a}}{l_{0,0b}}\sin(\alpha)\right)
\]

\[
l_{SN} = \sqrt{l_{0,0a}^2 + l_{0,0b}^2 - 2l_{0,0a}l_{0,0b}\cos\angle MO_A N}
\]

Where \( l_{MN} \) is the triangle length (m); \( \alpha \) is the tangent angle between the design line of two ramps at the diverging point, which is approximately equal to the gradual change rate of the diversion transition section; \( R_A \) and \( R_B \) are respectively the radius of circular curve of the two ramps in the triangle area after the diverging (m); \( R_A + C_1 \) and \( R_B + C_2 \) are the radius of the circular curve after the offset of the hard shoulder side line at the nose end (m); \( C_1 \) and \( C_2 \) are the sum of the right and left hard shoulder after bias broadening and the chamfer radius of the small nose point, respectively 3.1m and 1.95m.

According to the above analysis and calculation, the continuous exit distance \( s \) of ramp is determined. Among them, the wedge-shaped marking length of the junction is the longer one under
different conditions of the two alignments of the ramp after the diverging, that is, the calculated value when the alignment is reversed.

TABLE 5 THE MINIMUM LENGTH OF CONNECTING PART ON THE ZEBRA CROSSING TRIANGLE (REVERSE DIRECTION)

| Diverging velocity (km/h) | 80  | 70  | 60  | 50  | 40  | 35  | 30  |
|---------------------------|-----|-----|-----|-----|-----|-----|-----|
| Maximum gradient rate of diversion section | 1/22.5 | 1/20 | 1/17.5 | 1/15 | 1/15 | 1/15 | 1/12.5 |
| Minimum length of triangle end (m) | 57.51 | 52.17 | 45.02 | 37.54 | 32.46 | 29.30 | 24.37 |
| Triangle end value (m) | 60  | 55  | 45  | 40  | 35  | 30  | 25  |

The three lane ramp diverts from the main line to the ramp. Considering the most unfavorable situation, it needs two lane diversions. However, if the driver needs one lane change, he can also diverge into the next ramp. Therefore, considering the most unfavorable situation, the calculated spacing value of two diversions is taken as the general value, and the calculated spacing value of one lane change is taken as the limit value. According to the above formula, the minimum distance from main line diversion to ramp diversion exit can be calculated.

TABLE 6 THE CALCULATION RESULT OF DISTANCE BETWEEN MAIN LINE AND RAMP DIVERSION EXIT

| Distance (m) | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ | Minimum Value Limit value | General value |
|--------------|-------|-------|-------|-------|-------|-------|-------------------------|---------------|
| Ramp design speed (km/h) | 80    | 100   | 63.74 | 77.78 | 55.56 | 80    | 380  | 525            |
|               | 70    | 87.5  | 46.26 | 68.06 | 48.61 | 70    | 55    | 330  | 445        |
|               | 60    | 75    | 30.54 | 58.33 | 41.67 | 60    | 45    | 270  | 360        |
|               | 50    | 62.5  | 20.34 | 48.61 | 34.72 | 55    | 40    | 230  | 295        |
|               | 40    | 50    | 10.39 | 38.89 | 27.78 | 50    | 35    | 190  | 240        |
|               | 35    | 43.75 | 7.64  | 34.03 | 24.31 | 50    | 30    | 165  | 210        |
|               | 30    | 37.5  | 5.41  | 29.17 | 20.83 | 50    | 25    | 150  | 185        |

Note: The minimum spacing value can be adjusted according to the actual length of the wedge-shaped end marking line during design.

3.1.2 Toll station on ramp
Ramp toll stations will affect the normal driving and diverging of vehicles. The spacing should at least meet the requirements for deceleration and one lane change between the first diverging nose and the toll station, and the functional requirements for acceleration and one lane change between the toll station and the second diverging nose. As shown in Figure 6, the length of this section can be divided into three parts, namely the distance from the first diversion nose to the toll station S1, the toll island S2, and the distance from the toll station to the second diversion nose S3. Based on the above analysis, a calculation model for the minimum distance between continuous ramp exits is established.
Figure 6. the diagram of ramp continuous exit (Toll station on ramp)

\[ S_1 = L_4 + L_5 + L_6 + L_d \]  \hspace{1cm} (8)
\[ S_2 = L_4 + L_6 + \max \{L_{1'}, L_5'\} + L_6 \]  \hspace{1cm} (9)
\[ S = S_1 + S_2 \]  \hspace{1cm} (10)

Where \( S_T \) is the length of the toll island, and \( L_d \) is the vehicle deceleration distance (m). At present, the speed limit of ETC lane is 20km / h, so \( L_d \) is the driving distance from ramp design speed to 20km / h. The average deceleration value of brake is shown in the table 7.

**TABLE 7 THE ADOPTED AVERAGE DECELERATION OF BRAKE**

| Initial velocity of diverging point (km/h) | 90 | 80 | 70 | ≤60 |
|------------------------------------------|----|----|----|-----|
| Brake deceleration \( a \) (m/s²)        | 2  | 1.8| 1.6| 1.2 |

The ramp re-diversion phase specifically refers to the continuous diversion of vehicles from the ramp. Compared with the previous diversion process, the number of lanes is reduced from three lanes to two lanes. For a composite three-dimensional highway, although the driver can obtain the diversion guidance information from the last ramp diversion guidance sign, the ramp diversion again determines the vehicle to go to the ground layer or the three-dimensional layer, where the road sign indicates the direction. The information is more complicated, and the driver's recognition and reaction time to the sign is longer. Based on the aforementioned research on the driver's recognition and reaction time of signs, the mid-sign recognition time \( t_r \) and decision-making reaction time \( t_d \) are calculated as 2s and 2.72s respectively when the ramp is diverted again. In the same way, the minimum distance value from the main line diversion to the ramp diversion exit is calculated. When calculating the limit value, the driver's lane-changing distance and the gradual length of the connection are combined.

**TABLE 8 CALCULATION RESULT OF DISTANCE BETWEEN THE RAMP AND THE SECOND DIVERSION**

| Distance (m) | \( L_1 \) | \( L_2 \) | \( L_3 \) | \( L_4 \) | \( L_5 \) | \( L_6 \) | \( L_d \) | Minimum Value |
|--------------|--------|--------|--------|--------|--------|--------|--------|--------------|
| Ramp design speed (km/h) |   |        |        |        |        |        |        |              |
| 80           | 100.00 | 63.74  | 77.78  | 55.56  | 80     | 60     | 128.60 | 140          | 285          |
| 70           | 87.50  | 46.26  | 68.06  | 48.61  | 70     | 55     | 108.51 | 125          | 240          |
| 60           | 75.00  | 30.54  | 58.33  | 41.67  | 60     | 45     | 102.88 | 105          | 195          |
| 50           | 62.50  | 20.34  | 48.61  | 34.72  | 55     | 40     | 67.52  | 95           | 165          |
| 40           | 50.00  | 12.20  | 38.89  | 27.78  | 50     | 35     | 38.58  | 85           | 140          |
| 35           | 43.75  | 7.64   | 34.03  | 24.31  | 50     | 30     | 26.52  | 80           | 125          |
| 30           | 37.50  | 5.41   | 29.17  | 20.83  | 50     | 25     | 16.08  | 75           | 110          |

Note: The minimum spacing value can be adjusted according to the actual length of the wedge-shaped end marking line during design. Because the longitudinal slope of toll plaza should not be greater than 2%, when restricted by terrain or other special conditions, it should not be greater than 3%. Therefore, there is no need to modify the distance between the main line diversion and the ramp diversion exit in the longitudinal slope section.
3.2 Ramp re-diverging stage

![Figure 7. the calculation diagram of the second diversion distance on the ramp](image)

The ramp re-diversion phase specifically refers to the continuous diversion of vehicles from the ramp. Compared with the previous diversion process, the number of lanes is reduced from three lanes to two lanes. For a composite three-dimensional highway, although the driver can obtain the diversion guidance information from the last ramp diversion guidance sign, the ramp diversion again determines the vehicle to go to the ground layer or the three-dimensional layer, where the road sign indicates the direction. The information is more complicated, and the driver's recognition and reaction time to the sign is longer. Based on the aforementioned research on the driver's recognition and reaction time of signs, the mid-sign recognition time $t_r$ and decision-making reaction time $t_d$ are calculated as $2s$ and $2.72s$ respectively when the ramp is diverted again. In the same way, the minimum distance value from the main line diversion to the ramp diversion exit is calculated. When calculating the limit value, the driver's lane-changing distance and the gradual length of the connection are combined.

| TABLE 9 CALCULATION RESULT OF DISTANCE BETWEEN THE RAMP AND THE SECOND DIVERSION |
|---------------------------------|-----|-----|-----|-----|-----|-----|
| Distance (m)                  | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ |
|--------------------------------|-------|-------|-------|-------|-------|-------|
| Ramp design speed (km/h)     |       |       |       |       |       |       |
| 80                            | 66.67 | 63.74 | 77.78 | 55.56 | 80    | 60    |
| 70                            | 58.33 | 46.26 | 68.06 | 48.61 | 70    | 55    | 265   | 335   |
| 60                            | 50.00 | 30.54 | 58.33 | 41.67 | 60    | 45    | 215   | 275   |
| 50                            | 41.67 | 20.34 | 48.61 | 34.72 | 55    | 40    | 180   | 230   |
| 40                            | 33.33 | 12.20 | 38.89 | 27.78 | 50    | 35    | 150   | 190   |
| 35                            | 29.17 | 7.64  | 34.03 | 24.31 | 50    | 30    | 135   | 170   |
| 30                            | 25.00 | 5.41  | 29.17 | 20.83 | 50    | 25    | 120   | 150   |
| Minimum Value                 |       |       |       |       |       |       |
| Limit value                   |       |       |       |       |       |       |
| General value                 |       |       |       |       |       |       |

Note: The minimum spacing value can be adjusted according to the actual length of the marking line at the end of the diversion wedge during design.

4. SIMULATION VERIFICATION

4.1 Simulation modeling

According to the calculation results of minimum distance between continuous exits of three lane ramp in this paper, a three-dimensional simulation road model of continuous diversion of main line + three lane ramp exit with design speed of 100km/h and ramp design speed of 60km/h is established, as shown in Figure 8. The main line is 5km long, connected to the direct three lane ramp exit, and the continuous off ramp spacing is 360m and 235m respectively. Warning signs of 2km, 1km, 0.5km and 0 exit are set at the exit of the main line, the stop signs of speed limit of 80km/h and 60km/h are set at the starting point of deceleration section and the end of diversion nose, and the location direction sign is set at the diversion nose of ramp.
The 360 ° full view driving simulation platform was used to carry out simulation verification experiment. Nine male and three female subjects with corrected visual acuity above 4.5 were selected. The data of vehicle movement, driver's eye movement and heart rate were collected by driving simulation cabin, SMI eye tracking system and mp150 wireless physiological recording and analyzing system. The distance was evaluated by the vehicle trajectory and velocity distribution. The heart rate growth rate (GR), eye movement fixation times and fixation time were used to characterize the effects of distance on drivers' heart and physiology.
4.2 Simulation result analysis
The rationality and applicability of setting the continuous distance between the entrance and exit of the three lane ramp in the experimental section were analyzed through 12 drivers' driving simulation subjective feeling, driving speed and track data, traffic sign observation time, heart rate change and so on.

(1) It can be seen from the test driver’s trajectory graph (Figure 10) and speed change graph (Figure 11) that the driver has a certain visual recognition and discrimination reaction process to the road signs after entering the diversion area twice, and then starts to change Lane diversion; the driver is affected by the vehicle in the target lane during the lane change, and the driver will adjust the speed to advance or delay the lane change operation; the driver continuously diverts the ramp to drive, and the driving speed will gradually decrease. The experimental results show that all test drivers have successfully diverted lanes, and the actual lane-changing distance (148.5m in the first lane-changing twice, 72.5m in the second lane-changing lane) is less than the theoretical calculation The value (the distance between two lane changes is 177.74m, and the distance between one lane change is 88.87m) indicates that the calculated value of the minimum distance between continuous exits proposed in this paper can well satisfy the driver’s visual recognition of road signs, finding and determining the insertable gap, The demand for continuous lane change.

Figure 10. the first diversion vehicle trajectory and speed distribution diagram

Figure 11. the second diversion vehicle trajectory and speed distribution diagram

(2) According to the eye movement statistics chart, it can be seen that the driver's gaze time for the exit notice sign is between 1.5 and 2.0s, and the gaze time for the direction sign of the exit location at the diversion nose is between 0.9 and 2.0. With the increase of the number of ramp diversion, the driver's fixation time on the signboard decreases, and the fixation frequency also decreases, which indicates that the driver can compensate for obtaining the direction information of the back ramp exit location because of the warning of the direction sign information at the ramp exit. However, in the last
diversion of ramp, when the driver decides to drive into the three-dimensional layer or the ground layer, due to the complexity of the sign guidance and the amount of information, the test driver's visual recognition and reaction time is longer. The average time interval between turning on the turn signal and looking at the rear-view mirror was 1.6 ~ 2.6 s for the last diversion on the ramp. The response time of male drivers was shorter than that of female drivers. The experimental results show that in the distance calculation model in this paper, the visual recognition and response decision time of the road signs of the driver are taken as 2s and 2.5s respectively, and the calculation of the off-ramp diversion calculation takes 2s and 2.72s respectively, which is reasonable and feasible.

![Figure 12. statistic diagram of the time and number of driver looked at the signpost](image1)

![Figure 13. statistic diagram of the time interval between the driver's end of watching the sign/road surface and turning on turn signal](image2)

(3) According to the curve chart of the driver's instantaneous heart rate growth rate, it can be seen that the driver's tension is certain due to the continuous diversion of the exit and ramp, and the driver's tension increases slightly near the exit, and the driver's instantaneous heart rate growth rate is less than 0.10; The results show that the tension of drivers on the ramp is increased to a certain extent, and the instantaneous heart rate growth rate of drivers is less than 0.150, and the driver's heart rate is generally stable. Compared with female drivers, the change rate of heart rate interval of male drivers is smaller, which indicates that male drivers are more leisurely in continuous Lane diversion. The experimental results show that the minimum distance of continuous diverging corresponding to the design speed of 60km/h does not significantly increase the driver's psychological pressure and driving load, and the driver has good adaptability to the minimum distance value of continuous diverging.
Figure 14. statistic diagram of the time interval between the driver's end of watching the sign/road surface and turning on turn signal

To sum up, the calculation value of the minimum distance of continuous diverging of three lane ramp proposed in this study can better meet the driver's demand of lane change and speed change, with high safety and comfort. The theoretical model and related parameters are reasonable and feasible, and have certain engineering applicability.

5. CONCLUSION
(1) The results of driving simulation experiment show that the parameters of driver's guide sign recognition and reaction decision-making time are reasonable, which are in line with the driver's normal driving behavior, and the recommended minimum distance can well meet the driver's requirements for seeing, finding and determining the insertable gap and continuous lane changing, which has certain engineering applicability and design reference.

(2) In practical application, the setting of continuous exit will increase the amount of driver's information acquisition in a short time. When the distance between continuous diverging points of ramp is small, speed limit signs can be set in advance in front of continuous diverging section of ramp, and engineering measures such as road deceleration marking can be used to ensure the safety of continuous ramp diversion section.

(3) In the calculation of the minimum distance in this paper, the speed is taken from the ramp design speed, without considering the actual operating speed. For the change of the vehicle speed during the three-lane ramp change process, further actual measurement and analysis are needed, and then the calculated value of the minimum distance in this paper needs to be corrected according to the analysis results.

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REFERENCES
[1] Zheng Zhanji, Xiang Qiaojun, Li Han, et al. Traffic conflict prediction model of interchange diversion area [J]. Chinese Journal of safety science, 2018, 028 (006): 85-90
[2] Xu Hongtao. Research on safety service level of Highway diversion area based on speed consistency [D]. Harbin Institute of technology, 2011
[3] Gao Jianping, Liao Li. Study on the minimum spacing of continuous diverging points on interchange ramp [J]. Journal of Chongqing Jiaotong University (NATURAL SCIENCE EDITION), 2014, 33 (2): 103-107
[4] Jiang Fei, Yang Shaowei. Study on minimum distance between continuous exits of highway interchange ramp [J]. Journal of Railway Science and engineering, 2017, 014 (009): 2026-2032
[5] Zhao Xiaocui, Yang Feng, Zhao Nina. Driving behavior in Highway Interchange diversion zone [J]. Highway transportation technology, 2012, 29 (2): 143 − 145
[6] AASHTO. A Policy on geometric design of highways and streets[J]. American Association of State Highway and Transportation Officials, Washington, DC, 2011, 1(990): 158.
[7] Shaoyang, pan Binghong, Wang Yunze. Study on continuous exit and entrance spacing of highway interchanges [J]. Journal of Railway Science and engineering, 2016, 013 (008): 1642-1651
[8] Japan Road Corporation. Design essentials of Japanese Highway [M]. Xi'an: Shaanxi Tourism Press, 1991:125-155
[9] Ren Futian, Liu Xiaoming, Rong Jian. Traffic engineering [m]. Beijing: People's Communications Press, 2008
[10] Industrial standard of the people's Republic of China. JTG / T D21-2014 Detailed design rules for highway interchange [S]. Beijing: People's Communications Press Co., Ltd., 2014
[11] Chen Jin. Study on relevant technical indexes of Highway Interchange exit and entrance setting [D]