Traffic Safety Evaluation Approach for Reconstructed Freeway Medium Strip Opening Area

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Abstract: The remaining of the medium strip of the freeway in reconstruction and widening project reduces the cost of renovation, however brings potential driving risks. In this study, the characteristics of traffic flow changes caused by the opening of the medium strip were analyzed. The safety of the opening length of the medium strip was evaluated based on the interweaving and conflicting driving behavior characteristics, and the opening length of the interweaving area of the medium strip was calculated. In addition, the location of the exit traffic sign was advised for this new traffic flow characteristic. Appropriate opening length of the medium strip and the optimized traffic signs can effectively guide drivers to enter and exit the closed area of the central separation zone safely and comfortably.

1. Introduction
With the rapid development of the economy and the rapid growth of transportation demand, the early construction of freeways gradually faced problems such as insufficient capacity and reduced service levels. Reconstruction and widening have become the preferred method to solve the above problems. Commonly used forms of freeways widening and widening include two-side integral widening, one-side integral widening and separate subgrade widening\textsuperscript{[1]}. Due to the limitation of terrain condition, the freeway reconstruction and widening project in mountainous heavy hill area usually adopts the form of one-side integral widening, such as Zhengzhou-Luoyang and Luoyang-Sanmenxia freeway in China.

From an economic point of view, the reservation of the medium strip is money saving for the one-side widening of the freeway reconstruction and widening project. However, medium strip reservation does not conform to the driver's driving habits. When the vehicle enters and exits the medium strip, the traffic flow will be intertwined. Increased diversion and confluence driving behavior can result in increased driving workload. To enable the driver to make the necessary transitions between the inner and outer lanes, it is necessary to set openings in vicinity of the freeway entrance and exit ramps. The length of the opening is a compromise between economy and safety, which requires special attention.

When determining the length of the opening in the one-side widening project, the longer length of the medium strip opening promotes vehicles from the central dividing lane to the adjacent lane to select the ideal safety clearance for lane change and guarantee the safer lane change behavior. However, from the perspective of economic cost, it is expected that shorter medium strip of the central divider is more economical\textsuperscript{[2]}. Considering that previous studies on interleaving zone are mainly aimed at the capacity of interleaving zone\textsuperscript{[3]}, there are few studies on the interweaving, conflict and driving behavior of the road safety in the interweaving area. Therefore, this paper analyzes the relevant interlacing theory, acceptable interval theory, queuing theory and other related theories, aiming at setting the economical and reliable medium strip opening length to meet the driver's safety and comfort. In addition, reasonable
traffic sign settings can also guide the driver's behavior and deserve further study.

This paper studies the safety of retaining the original medium strip in the project of freeway reconstruction and widening with one-side integral widening scenario. Research on the length of the opening of the medium strip considering the traffic factors before or after the interchange of the reconstructed section and the speed limit condition was carried out to ensure the safety of driving under the one side widening form, as well as the impact on the safety and comfort of driving for drivers.

2. Entrance and exit sections traffic flow characteristics on one-side widening

In the one-side widening of the freeway that retains the medium strip of the present road, the medium strip is opened at the entrance and exit section for the inner lane driver to enter and exit the freeway. Due to the existence of the medium strip opening, the driving behavior of the one-side widening project entrance and exit section is different from that of the conventional two-side widening project. The driving trajectory of the entrance and exit section of the one-side widening project is shown in figure 1.

![Figure 1](image1.png)

a) Exit segment driving trajectory

b) Entrance segment driving trajectory

Figure 1. The trajectory in interweaving area of the one side widening project

From the analysis of the trajectory of the vehicle exiting the freeway, it indicates that although the vehicle driving out of the freeway needs to change five lanes during the process of driving from the inner lane to the deceleration lane, generally, it is possible to decide whether or not to change the lane according to the possibility of changing lanes. Lane change is optional and does not cause traffic conflicts. Only in the process of driving the vehicle to change lanes, if the distance between the vehicles is less than the critical distance, collisions and conflicts may occur. It is the same when vehicle entering the freeway, only in the process of driving the vehicle to change lanes, if the distance between the vehicles is less than the critical distance, collisions and conflicts may occur.

In the medium strip opening sections, fast vehicles enter or exit the highway exit from the medium strip with open lanes and merge into adjacent lanes, as shown in figure 2. In this process, the straight traffic of the adjacent lanes is preferentially circulated, and the fast vehicles driving out of the open lane of the medium strip must yield to adjacent straight-through vehicles, looking for a traversable critical interval to be inserted into the target lane.
Critical clearance is the shortest time interval in which continuous traffic can be interspersed by other vehicles and performed for specific operations. Assuming that the straight-through vehicle has priority, when the interval is greater than the critical interval $t_0$ (the interval can be inserted), the vehicle to be driven out can be inserted into the straight traffic flow. When the straight traffic is relatively large, the probability of occurrence of the insertable interval is reduced. When the vehicle cannot find the interval into the object lane, it is necessary to wait for the insertable gap section to ensure that the vehicle travels at a certain speed to find the gap to enter the main lane.

The duration of the critical interval $t_0$ plays a key role in the process of the vehicle entering the target lane. Factors affecting the critical interval value include vehicle speed, safety clearance between hybrid vehicle type, and the acceptability of different drivers for clearance.

3. Safety Analysis of Opening Length of Medium Strip

Analysis of possible driving risk factors in the one-side widened construction should consider drivers’ cognition in the time or space constraints. The medium strip opening length that meets the driver's safety and comfort requirements is required to achieve safe driving comfort for normal driving behavior.

According to the driving behavior requirement of the opening of the medium strip, the length of the opening of the medium strip can be divided into three sections: the length of the opening beginning $L_1$, the length of the opening intermediate section $L_2$, and the length of the opening end $L_3$, as shown in figure 2. This section will focus on the problem of setting the length of the medium strip. The length is minimal length to ensure the necessary safety.

In the zone of the opening of the medium strip, the fast vehicle to be driven out and the slow vehicle to be driven out of the outer lane form an interleaving zone. The length of the interleaving zone can be determined by interleaving theory. When there are a large number of fast vehicles waiting to drive out from the inner side, fast vehicles waiting to drive out of the opening of the medium strip queue up in the lane of the opening of the medium strip to wait for the appearance of the crossing gap of slow traffic flow on the outer side. The middle area of the opening of the medium strip can be determined by the crossing gap theory and queuing theory. The setting method based on interleaving theory is as follows.

In the middle zone of the opening of the medium strip, the fast vehicles to be driven out and the slow vehicles in the outer lane form the interleaving zone, and the interleaving zone configuration belongs to type B [4]. The operation diagram of vehicles in the interleaving area is shown in figure 3.

Figure 3. Operation diagram of interleaving area

The length of the middle zone of the medium strip is the length of the interweaving. According to the formula of the running speed of the vehicle in the theory of interlacing, the calculation formula of
the interweaving length is obtained. \cite{4,5}

\begin{align}
L &= \left( \frac{a(1+V_R)b(V_N)^c}{W_w} \right)^{1/3.28} \\
L &= \left( \frac{a(1+V_R)b(V_N)^c}{W_{nw}} \right)^{1/3.28}
\end{align}

where:  
- $L$—Interlace length (m);  
- $a, b, c, d$—Interlaced zone constant value, the value is related to the form of interleaving and constraint;  
- $W_w, W_{nw}$—Interlacing intensity coefficient of interlaced traffic and non-interlaced traffic in interleaved segments;  
- $V_R$—Ratio of total interwoven vehicles to total traffic volume in the interlaced segment;  
- $V$—Total traffic volume in the interlaced segment (pcu/h);  
- $N$—Number of intersecting lanes.

Referring to the definition of traffic capacity in traffic engineering, it can be concluded that the interleaving area of the entrance and exit sections of freeways is a secondary service level with the minimum average interleaving speed of 72km/h and the minimum average non-interleaving speed of 77km/h. The values of the interleaving parameters are also available. After determining the parameter value, the length $L$ of the middle zone of the opening of the medium strip can be obtained.

4. Traffic Sign Setting for Opening Area of Medium Strip

Considering the access needs and structural obstacles of drivers in the entrance or exit area, the setting of traffic sign facilities should be able to timely and effectively inform drivers of the closure information of the medium strip zone and guide drivers to safely and comfortably reach the medium strip zone for lane selection. At the same time, the setting of traffic sign facilities should be able to meet the cognitive expectations of drivers when they enter or exit the openings of the medium strip \cite{5}. Optimized traffic signs can reduce the difficulty of obtaining traffic information, reserve reaction operation time, and ensure safe and comfortable access to the freeway from the openings of the medium strip \cite{6}.

After the widening of the existing two-lane freeway to synthetic four-lane highway, drivers in a closed place to find acceptable gap by third lane and change lanes into median, lane changing again into the outside lane. The driving process of a vehicle entering the inner lane of the freeway is similar. In response to the need for lane change before and after the closure of the vehicle, two sets of special signs were designed, to inform and induce the driver to enter and close the medium strip.

4.1 Entrance and Exit Points Merge Flow Notice

In order for the driver to confirm the closed information, it is necessary to set up the diverging indicator signs of straight and right turns before the exit closure, and the diverging indicator signs of left and right turns before the entrance closure to ensure the safety of vehicles and the normal operation of traffic order. The form of the sign is shown in the figure 4.

![Points confluence notice sign](image_url)

Figure 4. Points confluence notice signs

This type of sign strives to simplify and clearly express the road traffic information at the closed area ahead, so that the driver can clearly and understand the road situation in the shortest time. Specifically, a four-level exit warning sign is set 2km ahead of the closure.
4.2 Medium Strip Closed Notice Sign of Entrance and Exit

In order to ensure the safety and comfort of drivers driving in the closed area of the medium strip, it is necessary to provide drivers with the closed position information of the medium strip and set up the indicator signs of slow and fast lanes to ensure that drivers have a complete grasp of the road ahead and traffic conditions. The content of the warning exit information is mainly reflected in adding left-right bypass signs into the warning signs to enable drivers to understand the road information ahead in the fastest time with concise symbols. The layout of the sign board is shown in figure 5.

![Figure 5. Median strip closure notice signs before exit area](image)

The closed warning signs of the medium strip are respectively set above the inner and outer lanes in the form of door frames. The specific location is 2km, 1km, and 500m away from the closed end of the central separation belt. When the closed length of the medium strip is greater than 3km, a 3km warning sign is required.

5. Conclusions

In this study, the traffic safety problems faced by the medium strip are analyzed. Based on the driving characteristics of the interweaving zone, the length calculating approach of the interweaving area of the medium strip is proposed, and the setting of the new traffic sign is discussed. The main research conclusions are summarized.

（1）Based on the interweaving theory, the driving behavior characteristics, traffic flow characteristics and the interweaving and conflict points of drivers entering and leaving the opening of medium strip are systematically analyzed and studied.

（2）Through the analysis of driving behavior characteristics and conflict point, and from the perspective of driver safety and comfort, the opening length of the medium strip in the freeway widening project is determined.

（3）Based on the traffic control demand and driver's visual recognition, the applicability evaluation of new traffic signs is analyzed and studied, and the problem of traffic signs setting in the opening area of the medium strip of freeway.

This paper evaluates the safety risk of the opening of the medium strip on one-side widening situation of freeway. At present, the interference of different weather, environment and other factors on drivers' visual recognition process has not been considered. Further research on this aspect can be carried out in the future.

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