Study on Long-distance Turn-around at Non-Signal Control Intersection of First-Class Highway

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Abstract: Long-distance turn-around is a traffic organization method to guide and improve left-turn vehicles at intersections. In this paper, the non-signal control intersection of the first-class highway is taken as the research object. The influence of different road conditions, traffic flow size and traffic control on the selection of long-distance turn is analyzed, and the location of long-distance turn is preliminarily determined by calculating the length of interlaced section. Through VISSIM simulation, the position of telemetry turn is finally determined.

1. Introduction

In road traffic system, intersection is the junction and hub of road network, but it is often the bottleneck of road capacity and the frequent point of traffic accidents. According to the investigation and analysis, in the plane intersection conflict, the left-turn traffic conflict has the greatest impact on the main line traffic and the largest number of accidents. Therefore, reducing left-turn traffic conflicts at intersections is the key to improve road capacity and traffic safety. According to the research of American scholars in recent years, it is shown that the left-turn vehicle turn-around can effectively reduce traffic conflicts and average vehicle delays at intersections with large traffic volume[1].

2. An overview of the Long-distance Turn-around

Long-distance heading refers to forbidding vehicles to turn left directly at the level intersection, opening the central partition belt at an appropriate distance from the level intersection, and setting turning signs for vehicles to turn around. It can effectively transfer traffic delays at intersections to sections, reduce traffic conflicts at intersections, improve traffic safety and efficiency at intersections, and achieve a certain balance between the efficiency of intersections and downstream sections. [2].

![Figure 1. Left-turning Vehicle Long-distance Turn-around Trajectory Map.](image-url)
2.1. Advantages of Long-distance Turn-around

From the aspect of driving safety level. Replacing direct left turn with Long-distance Turn-around can change the intersection conflict point into confluence and diversion point, simplify driver's driving behavior, and reduce the malignant degree of the accident[3].

From the aspect of traffic efficiency. Vehicles turning left into the main road usually have to wait for the main road traffic flow to have a pluggable workshop gap before they can enter the intersection and complete the left turn process. During the rush hour, the number of interchangeable workshops in the secondary road decreases, which will lead to a large delay of the secondary vehicles. At this time, if the method of long-distance turn-around is adopted, not only the interference of the secondary road to the main road vehicle operation can be reduced, but also the difficulty of the secondary road vehicle operation can be reduced and the traffic efficiency can be improved[4].

2.2. Applicability of Long-distance Turn-around

The typical application environments of this method are as follows: the distance between the distant approach intersection and the upstream and downstream intersection is large, so that the turnaround position of the distant approach is neither in the functional area of the intersection nor in the functional area of the upstream and downstream intersection; the active traffic flow is large, the secondary traffic flow is appropriate; the secondary lane is not more than two-way four lanes, and the main road is horizontal. The cross-section should be at least four lanes in two directions, but not more than eight lanes in two directions, so as to avoid insufficient lane-changing distance for vehicle turning around. Meanwhile, the main road should be equipped with a certain width of the central dividing zone to meet the requirements of expanding the turning queue lane[5].

2.3. Consideration Points for Choosing the Position of long-distance turn-around

The factors affecting the location of long-distance turn-around at non-signal control intersections are the length of the interlaced section of the long turn vehicle, the width of the central partition band and the length of the opening at the turn, the size of the traffic volume on the main road, the proportion of left turn vehicles and the speed of the vehicle.

Yang Xiao-kuan used simulation software to compare the advantages and disadvantages of direct left turn and long-distance turn-around, and concluded that the value of interleaving length has a significant impact on the evaluation results[6]. If the interleaving length is insufficient, the vehicle can not complete the lane change in time, and there may be potential safety hazards; if the interleaving length is too long, additional traffic delays will be increased and travel efficiency will be reduced. Therefore, the determination of the length of the interleaving segment has a vital impact on the application of tele-turn.

3. Calculating the Length of the Interlaced Section of the long-distance turn-around

Interleaving refers to the crossing behavior of two or more traffic flows with the same driving direction along a fairly long road section without the aid of traffic control facilities. It is also called interleaving operation[7].

3.1. Calculation Method of Evaluation Index of Interlaced Segment

The length of interleaving section required for long-distance turn of vehicles at intersections is a decisive factor affecting the opening position of the central dividing belt of long-distance turn. This paper mainly evaluates the rationality of the length of the interlaced section by using the average vehicle density of the interlaced section as the evaluation index through the manual method of highway capacity in China.

(1) Calculation of peak hourly flow rate

The operation of the interleaving segment is based on the 15-minute flow rate (pcu/h). The conversion formula is as follows:

\[ v_i = \frac{V_i}{PHF \times f_{HV} \times f_p} \]  \hspace{1cm} (3.1)
Calculation of Interlacing Strength Coefficient

The interleaving strength coefficient ($W_w$ and $W_{nw}$) is an index describing the influence of interleaving behavior on the average speed of interleaving and non-interleaving vehicles. The calculation formulas are as follows:

$$W_i = \frac{a(1 + VR)^b \left(\frac{V}{N}\right)^c}{(3.28L)^d} \quad (3.2)$$

Table 1. Calculating Constant Value of Interlacing Strength Coefficient in C-type Interlacing.

| Structural types | Constraint type | Calculating the Constant of Interleaving Velocity $S_w$ | Calculating the Constant of Non-interleaving Speed $S_{nw}$ |
|------------------|----------------|--------------------------------------------------------|----------------------------------------------------------|
|                  | a  | b  | c  | d  | a  | b  | c  | d  |
| Type C           | 0.08 | 2.3 | 0.80 | 0.60 | 0.0020 | 6.0 | 1.1 | 0.60 |
|                  | 0.14 | 2.3 | 0.80 | 0.60 | 0.0010 | 6.0 | 1.1 | 0.60 |

(3) Calculating Interleaved Average Vehicle Speed and Non-Interleaved Average Vehicle Speed

Average Vehicle Speed of Interlaced Vehicles:

$$S_i = S_{\min} + \frac{S_{\max} - S_{\min}}{1 + W_i} \quad (3.3)$$

(4) Determine operational status

Before calculating the speed of interleaving section, it is necessary to determine whether the operation type is constrained or unconstrained. $N_w$ refers to the number of lanes used by interleaving vehicles to achieve balanced or unconstrained operation of vehicles; $N_w (max)$ refers to the maximum number of lanes used by interleaving vehicles for specified interleaving section. When $N_w < N_w (max)$, the number of lanes needed for balanced operation of interwoven vehicles is non-constrained; when $N_w (> N_w (max))$, the number of lanes used by interwoven vehicles is limited by the maximum number of lanes available, so the number of roads needed for balanced operation of vehicles can not be used as constrained type.

When the C-type interleaving coefficient is used for the first time, the average interleaving speed and average non-interleaving speed are calculated under the assumption that the interleaving operation is in an unconstrained state, and then the number of lanes required for the unconstrained operation of the C-type interleaving in Table 3-2 is checked. If it is satisfied, the interleaving operation is proved to be unconstrained; if it is not satisfied, the equation coefficients corresponding to the constraint type are brought into the calculation, and the interleaving strength is calculated by re-selecting the interleaving coefficients.

Table 2. Determining Operating Type Criteria.

| Interlacing Section Configuration | Number of lanes required for unconstrained operation $N_w$ | $N_w (max)$ |
|----------------------------------|----------------------------------------------------------|-------------|
| Type A                           | 1.21(N)VR0.571L0.234/Sw0.438                              | 1.4         |
| Type B                           | N[0.085+0.703VR+(71.57/L)-0.0112(S_{nw}-Sw)]               | 3.5         |
| Type C                           | N[0.761+0.047VR-0.00036L-0.0031(S_{nw}-Sw)]               | 3.0         |

(5) Calculating Vehicle Speed in Interlacing Section
\[
S = \frac{V_W + V_{NW}}{S_W + S_{NW}}
\]  
(3.4)

(6) Calculate spatial average density:
\[
D = \frac{\left( \frac{V}{N} \right)}{S}
\]  
(3.5)

### 3.2. Calculation of Interlaced Section Length under Different Traffic Volumes

According to the provisions of the General Introduction to Traffic Engineering (Xu Jiqian), the length of the interlaced section should be 50 m–600 M. Therefore, the length of the interlaced section should be 10 m in the range of 50 m–600 M. According to the above method, the average vehicle density is calculated to evaluate whether the length of the interlaced section meets the requirements. Taking the two-way four-lane first-class highway as an example, the design speed of the first-class highway is 60 km/h, the width of the lane is 3.75 m, the width of the central partition is 2 m, and the intersecting branches along the first-class highway are ordinary two-lane highways. So, take \( N = 2 \). The Code for Design of Urban Road Engineering stipulates that the design speed of intersection section is 0.5-0.7 times that of normal section, \( S_{min}=0.5*60=30 \text{ km/h}, \quad S_{max}=0.7*60=42 \text{ km/h} \).

If the main line traffic volume \( V_F = \) main line direct vehicle \( V_{FF} + V_{FR} \) with mid-band opening, branch traffic volume \( V_R = \) branch direct vehicle \( V_{RF} + \) mid-band opening long-distance turn-around vehicle \( V_{RR} \), and branch traffic volume ratio \( R = V_{RR} / V_R \), then the main line traffic volume \( V_F = \) main line direct vehicle \( V_{FF} + \) mid-band opening remote turning vehicle \( V_{RR} \).

\[
V_W = V_{RR} = R \cdot V_R  \quad (3.6)
\]
\[
V_{NW} = V_{FF} + V_{FR} + V_{RF} = V_F + (1-R)V_R  \quad (3.7)
\]
\[
V_R = V_W / (V_W + V_{NW})  \quad (3.8)
\]

Highway Route Design Code (JTGD20-2006) stipulates the design capacity of one lane of the first-class highway (Table 3-3). From the table, it can be seen that when the design speed of the first-class highway is 60 km/h, the design capacity of one lane of the first-class highway with trunk function is 900 pcu/h/ln, and one of the first-class highways with distribution function. The design capacity of the lane is 550-700 pcu/h/ln. Therefore, in the calculation process, the value of the first-class highway traffic flow is 1000-1800 pcu/h. According to the design capacity of the second, third and fourth-class highways, the value range of the branch traffic flow is 200-800 pcu/h/ln.

**Table 3. Design Capacity of Single Lane on Grade I Highway.**

| Actual speed (km/h) | 100  | 80   | 60   |
|---------------------|------|------|------|
| Design Capacity of First-Class Highway with Main Line Function (pcu/h/ln) | 1300 | 1100 | 900  |
| Design Capacity of First-Class Highway with Distribution Function (pcu/h/ln) | 85~1000 | 700~900 | 550~700 |

### 4. A Method for Determining the Position of long-distance turn-around

The determination of the turning position of long-distance heading not only needs to consider the interleaving length required for crossing with the main line vehicles before turning, but also needs to consider the road alignment conditions comprehensively. The method for determining the turning position of telemetry is as follows:

1. Forecast the proportion of traffic flow and left-turn vehicles between the main and branch roads of the new project, and convert it into equivalent traffic volume.
2. According to the forecasting results, the minimum length of the interleaving segment is
calculated according to the calculation method of the length of the interleaving segment under the different traffic volume mentioned above.

(3) In order to avoid the complex driving conditions and new hidden dangers of driving safety caused by the change of road alignment, the remote heading should be set at the straight line position to avoid the curve or longitudinal slope section.

(4) In order to ensure that the vehicle can be found directly after turning to the opposite lane in time to avoid traffic accidents, it is necessary to ensure that there is no line-of-sight occlusion within the parking sight range of upstream and downstream directions at the far-heading turning position and to ensure the sight distance.

5. Conclusion
In order to reduce the traffic conflict caused by direct left-turn of vehicles at non-signalized intersections, two methods, theoretical calculation and simulation analysis, are used to determine the required interleaving length of vehicle turning at two-way four-lane first-class highway, and the average vehicle in the interleaving section of long-lead turning is taken as an example. Density is the evaluation index and three-level service level is the evaluation criterion. The minimum calculation method of vehicle turning interleaving length under different traffic flow and different turning vehicle proportion is given. The appropriate location of the opening of the central dividing zone of the long-distance turning is determined according to road conditions.

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