Research on traffic channelization design of Urban viaduct on off ramp

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Abstract

The junction part of the expressway ramp and the ground road is the key point of the traffic flow transformation between the urban viaduct and the ground, which is also the key to improve the capacity of the urban road. Aiming at a series of traffic problems caused by the layout of the entrance ramp of urban expressway. Firstly, on the basis of field investigation, the characteristics of traffic flow in the junction between the ramp and the ground are analyzed, then, the channelization design method of the junction between the typical ramp and the ground road is put forward, which provides the theoretical basis for the design of the exit ramp and the intersection.

Keywords: urban Viaduct, traffic organization, ramp exit

1. INTRODUCTION

With the rapid development of the city and the rapid growth of traffic demand, more and more cities are building the expressway system to relieve the traffic pressure. Elevated road is the main form of urban expressway (Orge et al., 2014; Newl, 2011). Because of the small distance of Urban Elevated Road, it is closely related to the road network. The cross is closely connected with the exit ramp mouth also bear the viaduct and ground road traffic pressure, the traffic pressure or traffic organization methods are not suitable, extremely easy to become the city traffic flow and discontinuous transformation bottleneck. From the city viaduct interchange and long-term development, how to make continuous and ground road viaduct in the discontinuous connection of safety and smooth, make full use of space resources, for the construction and operation of city expressway and the road surface system has a special significance.

The structural characteristics of the urban elevated road determine that the traffic is restricted to the entrance ramp. When the outflow demand is greater than the capacity, the queue will appear on the exit ramp, or even extend to the main line, resulting in traffic congestion in the urban elevated road, but also seriously affect the quality of the road surface. The measures to solve the problem of the exit ramp and queue of the viaduct are divided into two aspects (Sun et al., 2015; Lee et al., 2015; Yanget al., 2016; Wang et al., 2015): traffic control and traffic organization. The inflow control method, which is implemented by the urban road traffic control system, is considered to be the most effective and feasible control measure. The means of traffic control is to focus on the measures taken from the macro point of view. At present, the technology of real-time traffic information collection in China needs to be further improved, and the effectiveness of traffic congestion control and congestion avoidance is limited by means of traffic control (Yang et al., 2009; Chen et al., 2000). According to the characteristics of the road and the traffic flow characteristics, the traffic managers adopt a lot of traffic organization methods. However, there are no systematic theoretical analysis and research on how to use different modes of traffic organization for different exit ramp. How to make a continuous and discontinuous organic convergence, make full use of space resources, to achieve the best system, for the construction and operation of viaduct and ground road system has a special significance.

2. TRAFFIC ORGANIZATION METHOD FOR CONNECTING SECTION OF EXIT RAMP

The interaction between the traffic flow is the core of the problem of traffic connection section, Chinese city road network density, traffic flow, interweave capacity can not meet the traffic demand, the traffic organization is taken to avoid or reduce the interleaving. The main task of the manager is to coordinate the left turn traffic...
flow and the straight traffic flow. A common practice is: one is the two stream of interleaved fully through the intersection; two is the physical separation of the two strands of traffic; three is to prohibit a traffic in the intersection right or the implementation of traffic control method.

### 2.1 Organization mode I

Organization mode I refers to the convergence of the road does not take measures, such as forbidden line and separation, the traffic flow on the ramp and the ground traffic flow can be fully crossed before passing through the intersection, see figure 1. In this case, the ramp and the ground traffic flow need to change lanes to reach the entrance of the parking lot, the link \( L_j \) is divided into the parking section \( L_p \) and the weaving section \( L_w \) of the vehicle due to the intersection of red light control, that is \( L_j = L_w + L_p \).

![Figure 1. Ground connection section of exit ramp - organization mode I](image)

### 2.2 Organization mode II

Organization mode II refers to the solid or the fence that separated the exit ramp ground left turn traffic and the traffic, as shown in figure 2.

![Figure 2. Ground connection section of exit ramp - organization mode II](image)

This kind of organization mode does not exist, so it can avoid the influence of interleaving on the link; Under the condition that the weaving section cannot meet the traffic demand, help to maintain the order of the system and improve the service level. From the situation of the ramp junction of many large cities in China, this is a common method of traffic organization.

### 3. ANALYSIS OF TRAFFIC FLOW CHARACTERISTICS IN THE CONVERGENCE SECTION OF THE RAMP

The existence of ramp is an important factor to restrict the operation of the entrance, according to the traffic supply and demand balance principle, should ensure that the exit ramp convergence road capacity and ramp and
ground traffic to match, so that the flow can be timely discharge, the system is maintained in a relatively stable state.

3.1 Traffic characteristics analysis of traffic organization mode I

The main difference between the organization mode I and the traffic flow at the intersection is in the weaving section. In order to ensure the convergence of the road to accommodate both the ground and exit ramp traffic, the capacity of the weaving section and the entrance road should be matched (Evans et al., 2011; Ngoduy et al., 2016). That is

\[
\begin{align*}
\alpha_1 C_w & \geq Q_g + Q_r \\
\alpha_2 C_A & \geq Q_g + Q_r
\end{align*}
\]

(1)

Type: \(Q_g\) for ground arrival traffic, \(Q_r\) for the next ramp flow, \(C_w\) for the weaving section, \(C_A\) capacity of the import channel, \(\alpha_1, \alpha_2\) as empirical coefficient, With the decrease of this value, the saturation of the weaving section decreases and the service level increases.

3.2 Traffic characteristics analysis of traffic organization mode II

Traffic organization II, That is "no weaving" design of the entrance of the road link, separated from the next Ramp Traffic and ground traffic. There is no weaving area in the connection section, which can alleviate the traffic disorder and obstruction caused by the interleaving. Due to the separation of down ramp traffic and ground traffic, compared with the general import road, the inlet channel will be affected by the uneven distribution of traffic flow in each lane. Flow imbalance coefficient \(\sigma\) is introduced, That is

\[
\sigma = \frac{Q_r}{Q_g}
\]

(2)

3.2.1 Inlet channel saturation

As shown in Figure 2 of the ramp junction section, assuming that the entrance road to turn left (or straight) the total flow of \(Q=Q_g+Q_r\), The corresponding saturation flow rate of single lane is \(S\), Green letter ratio is \(\lambda\), \(q\) is the unit green time through the traffic (In order to simplify the calculation, determine the objective function, do not consider the traffic to flow through the intersection of the green time).

\[
\begin{align*}
Q_r &= \frac{\sigma Q}{1+\sigma} \\
Q_g &= \frac{Q}{1+\sigma}
\end{align*}
\]

(3)

When the traffic organization is in figure 1, Then \(q_1=2S\).

In order to ensure the stability of the system, the saturation \(X_i \leq 0.9\) should be satisfied, that

\[
\begin{align*}
\left[ \frac{\sigma Q}{(1+\sigma)} \right] / \lambda \cdot S & \leq 0.9 \quad \sigma > 1 \\
\left[ \frac{Q}{(1+\sigma)} \right] / \lambda \cdot S & \leq 0.9 \quad 0 < \sigma < 1
\end{align*}
\]

(4)

Then \(\sigma\) should be satisfied
\[ \sigma \leq \begin{cases} \frac{0.9 \lambda}{y - 0.9 \lambda} & \sigma > 1 \\ \frac{0.9 \lambda - y}{0.9 \lambda} & 0 < \sigma < 1 \end{cases} \]

Type: \( y = \frac{Q}{S} \).

### 3.2.2 Lane Utilization Ratio

Figure 2 to take measures to separate the ramp and ground traffic, the number of vehicles arriving in the two lanes is not balanced. In order to investigate the relationship between the organization and the utilization ratio of road resources, with the same traffic flow of the unit green time \( q \) as the objective function, the effect of \( \sigma \) on \( q \) under the same flow rate was analyzed.

Figure 3 shows the curve of arrival and discharge. The abscissa is time, the ordinate is the cumulative arrival (emission) of the number of vehicles.

![Figure 3. Flow reach and discharge curve](image)

Figure 3: \( Q_r \) represents the arrival of traffic from the ramp; \( Q_g \) represents the flow from the ground to the vehicle; \( S \) curve represents the traffic flow of the entrance road. Time period \( r \) indicates an effective red light time; the time section \( g_1 \) represents the saturation green time of the ground traffic flow, and the time period \( g_2 \) represents the saturation green time of the down ramp traffic. The total number of vehicles arriving in a period of time is equal to the total number of vehicles, namely

\[ Q_{\text{arrive}} = Q_{\text{discharge}} \]

to investigate the value of \( \sigma \), can get

\[ \begin{align*}
q_1 g_2 &= S g_2 + S q_1 + Q_g (g_2 - g_1) & \sigma \geq 1 \\
q_1 g_1 &= S g_1 + S q_1 + Q_g (g_1 - g_2) & 0 < \sigma < 1
\end{align*} \]

In the formula: the time section \( g_1 \) represents the saturation green time of the ground traffic flow, and the time period \( g_2 \) represents the saturation green time of the down ramp traffic (Kerner et al., 2016; Li, 2016).

\[ g_1 = \frac{r Q_g}{S - Q_g}, \quad g_2 = \frac{r Q_r}{S - Q_r} \]

Through the formula (6) changes and finishing can be drawn.
The relationship curve between $q_{11}/q_1$ and $\sigma$ is shown in figure 4. From figure 4, which can be seen, when $\sigma=1, q_{11}=q_1$; the rest of the time is $q_{11}<q_1$.

\[
\begin{align*}
q_{11}/q_1 &= 0.5(1+1/\sigma) \quad \sigma \geq 1 \\
q_{11}/q_1 &= 0.5(1+\sigma) \quad 0 < \sigma \leq 1
\end{align*}
\]  
(7)

Figure 4. Relation curve $q_{11}/q_1$ and $\sigma$

3.3 Traffic characteristics analysis of traffic organization mode III

For the situation that the form of organization I and II cannot be satisfied, organizational form III can be considered, that is, the prohibition or implementation of traffic control scheme. For the forbidden line of the left turn vehicle way, consider making a U-turn in the road in front of the vehicle, or turn left at the downstream intersection. At present, there are quite a number of export ramp connecting sections in China, which can be used to avoid the left or right traffic organization, which is helpful to simplify the complicated traffic conditions and improve the traffic capacity and service level. The traffic organization at the expense of a direction of traffic rights, and will spread to the surrounding road of contradiction. In addition, for the saturated intersection, the intersection of the upper reaches of the intersection should be implemented to control the flow of the road system.

4. APPLICABILITY ANALYSIS OF TRAFFIC ORGANIZATION FORM ON THE EXIT RAMP

In order to ensure the convergence of the convergence section of the ramp, traffic managers choose the link road organization according to the actual situation of road traffic. The selection of reasonable traffic organization is the premise of implementing effective traffic control scheme.

4.1 Application of organizational mode I

4.1.1 Link road import channel traffic capacity

If allowed to exit ramp traffic convergence weaving operation, when the type (1) cannot be satisfied, the traffic capacity of weaving area is not large enough to hold the ground and the ramp, the critical state of system balance is broken, began queuing and congestion. Organizational mode I, the formula for calculating the capacity of the inlet passage is $C_A=\sum_i S_i (g/c)$, in the formula, $S_i$ is the saturation flow rate of the inlet channel; $g/c$ is the green ratio.

4.1.2 Service level of weaving area

On the basis of the capacity of the HCM weaving section on the highway, the traffic capacity of the weaving area of the joint section should be modified. The correction factor is affected not only by the length of weaving section, but also by the weaving form and the proportion of heavy vehicles. Therefore, it is not of great significance to consider the calculation of the capacity of some factors, which can be used in the planning and design of weaving section. According to the minimum average method to change lane speed, service level can be divided into A–F, among them, A, B level of service to meet the sufficient length of the segment, driving can be carried out smoothly; C, D, E level cannot meet the free weaving, the speed is gradually reduced, but the traffic...
flow basically stable operation; F level cannot meet the normal traffic flow. In order to ensure the stability of the system, the service level should not be less than C. The formula for change speed is as follows (Li et al., 2016):

\[ V_{\text{change}} = K\left( \frac{60}{1 + \exp(a - b \ln(L_j))} \right) - cQ_{\text{No-change}} - dQ_{\text{change}} + e \]  

(8)

Type: a, b, c, d, e were all positive, the value varies with the interweaving form; K is the coefficient of heavy truck; \( L_j \) is the length of the weaving section. \( Q_{\text{No-change}} \) is the traffic flow without changing lanes in the weaving section; \( Q_{\text{change}} \) is the traffic flow of lane changing lane.

For new or renovated intersection, traffic design should also meet the traffic capacity and service level requirements, it still can make the weaving section import and keep the good running order, continuous and discontinuous smooth conversion.

4.2 Application of organizational mode II

At the intersection of the intersection of the ramp, there is no weaving design to isolate the two vehicles which need to be crossed. This solves the contradiction between the pressure of traffic and the shortage of \( L_j \). However, due to the presence of an unbalanced coefficient \( \sigma \), the number of vehicles passing through the unit green time is reduced. When the unbalanced coefficient deviates from 1, the utilization rate of existing facilities is reduced. In the case of equal total traffic, the traffic flow in the direction needs longer green time. When \( \sigma \to 0 \) or \( +\infty \), it is equivalent to the waste of a lane capacity. If the discount 30% is used as a limiting condition, the formula (4) can be obtained. When \( \sigma < 0.4 \) or \( \sigma > 2.5 \), the applicability of this traffic organization is limited. The above analysis cannot meet the traffic demand of the weaving section. If the weaving section can meet the needs of traffic flow and can guarantee a certain level of service, whether to choose the traffic organization form without weaving design will not have a big impact on the traffic flow. At the same time, \( \sigma \) cannot always equal to 1. Therefore, when the length of the weaving section meets the requirements, the design of the link segment model without weaving is always a waste of road resources.

In addition to the impact of traffic imbalance coefficient on the vehicle driving, there is a potential conflict point when the vehicle passes through the parking line, as shown in figure 5. In general, the lane width is 3.5 m, the left turning radius is 30 m, and the left turning vehicle passing through the stop line is 8 m/s.

![Figure 5. Analysis of vehicle track at the intersection of the exit ramp](image)

The length of arc AB and the length of arc AC can be calculated as

\[ L_{\text{AB}} = 2 \cdot \pi \cdot 30 \cdot \cos^{-1}\left( \frac{30 - 3.5}{30} \right) = 14.64 m \]

\[ L_{\text{AC}} = 2 \cdot \pi \cdot 30 \cdot \cos^{-1}\left( \frac{30 - 3.5 \times 2}{30} \right) = 20.91 m \]

Then turn left across the car B point need time is 1.83 s, C points across the time required 20.91/8 = 2.61 s, that can be guaranteed in the yellow light 3S time. But when the left turn traffic at intervals of 3 straight lane above, the vehicle with the outer left turn lane is prone to conflict with the green direct traffic, so the left turn road should not be more than two straight lane interval.
5. MANAGEMENT MEASURES OF ADJACENT GROUND INTERSECTIONS

The exit ramp adjacent ground intersection to expressway traffic management ability, to a large extent determines the output capacity of expressway traffic, is the most significant bottleneck point in the process of expressway traffic distribution, measures should be taken to improve its capacity to adapt and ramp flow. It includes several aspects, such as interchange construction, flow limitation, intersection channelization and signal control.

Separation of lateral straight-going traffic. On the nodes of the lateral main road with large traffic flow, in the planning should be considered to build overpass or tunnel transverse, separate lateral road traffic, reduce cross port pressure.

Flow direction restriction. Limit some secondary flows, in order to reduce the conflict points within the intersection, is conducive to the mainstream of traffic to the vehicle. Flow restriction should be coordinated with the intersection channelization and signal control scheme, when the channelization and signal control method to deal with traffic pressure, to consider appropriate flow restrictions.

Traffic channel design. The main purpose of channelization design is to improve the traffic supply capacity and avoid the same phase traffic flow. Mainly include: (1) The design of the motorized vehicle channel is to widen the number of lanes and optimize the function of lanes. (2) Non motorized vehicle channelization design, the focus is to restrict the traffic space of non motorized vehicles, if necessary, can be set up isolation fence. (3) Pedestrian traffic channelization design, the focus is to optimize the pedestrian crosswalk location and setting of pedestrian protection area.

Traffic signal control. Intersection signal control optimization can improve the traffic supply capacity, and realize the order of traffic flow. The optimization methods include adjusting the signal period, optimizing the phase combination and so on. In order to improve the ability of evacuation and control the traffic volume on the ramp, the lane lights should be used to carry out separate signal control. Bus lanes should be individually controlled by the signal, in order to meet the bus lanes for public transport priority. In order to avoid traffic and slow traffic between conflict and interference, can take the right turn control, slow traffic signal lights and delayed early break etc. Aiming at the intersection of different traffic and special needs, should make flexible use of the two means of channelization and signal control, as far as possible from the time and space vehicles to avoid interleaving, improve the utilization rate of space intersection, expand its total capacity and ability to ease under the ramp.

Traffic sign cooperation. In order to realize the traffic organization design, the detailed design and function division of the channel, it is convenient for the driver to understand the design intention concisely and accurately, need to set clear signs in the right place.

6. CONCLUSION

In this paper, the import flow direction-ant methods of traffic organization in the convergence section of the ramp are analyzed, the characteristics of the traffic flow of the weaving design and the non interlaced design are analyzed, the important parameters such as traffic capacity, saturation flow rate and service level were investigated.

The unbalanced coefficient of ramp and ground arrival flow is introduced for the lower ramp convergence section, the mathematical model of the relationship between the unbalanced coefficient and the average unit green time is obtained, as an important index for quantitative calculation of the lane utilization ratio of non woven design, at the same time, according to the relational model, the lane utilization ratio is always less than or equal to the allowable traffic organization mode I.

Various types of traffic organization are compared, and their applicability and limitations are analyzed. It should be pointed out that every exit ramp and adjacent intersections have their own special situations and problems, and should be analyzed in detail. This paper only provides some basic ideas and methods, which can be used as reference for similar projects.
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REFERENCES


