Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2022, 9(8):51-58

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Intersection Turnaround Selection Based on Optimal Inlet Lane Access Efficiency

Yuan Fu*, Shulong Dong, Benxing Liu, Pengsheng Zhao, Xiaoqing Wang, Qian Cao

School of Transportation and Vehicle Engineering, Shandong University of Technology, Zibo 255000, China

Abstract Turning vehicles account for a large proportion of urban road signal intersection sections. At present, there are many problems in the design of turning area and facilities, and there is no corresponding specification to guide the setting of turning area. Designers usually set turning area based on experience, and the traffic capacity and safety level of roads are significantly reduced. The traditional four phase signalized intersection is selected as the research object. Based on the minimum impact of turning vehicles on the safety and traffic capacity of the entrance lane of the intersection, the selection method of the best turning position of the intersection is proposed. This method establishes the speed model of different points at the exit of the intersection, reveals the loss of driving time caused by the probability of meeting the turning vehicles on the driving lane, and then reduces the capacity, and establishes the location selection model of the turning point with the maximum capacity. Finally, the paper takes Zibo City Center as an example. The experimental results show that this method can improve the capacity of the opposite lane by 17.82%.

Keywords Passage capacity; Traffic safety; Lost time

Introduction

In recent years, in order to divide the traffic, maintain the order of traffic flow and improve road traffic safety, more and more urban trunk roads have been added to the road central isolation facilities, which causes trouble for the vehicle turnaround behavior on the road section. In order to solve this problem, the far lead turnaround organization is increasingly used, and vehicle turnaround to a large extent affects the efficiency and safety of the intersection traffic flow. In the urban road network, road intersections as the key nodes of urban road network traffic, its capacity affects the level of service of the entire traffic network. Reasonable allocation of intersection space resources, especially the quality of the turnaround area settings have also become an important factor affecting the level of service at intersections. China's current design specifications lack of turnaround location setting specifications, road organization designers can only rely on experience to turnaround settings, which leads to not well meet the vehicle turnaround needs, but also to ensure the safety and efficiency of traffic flow. Therefore, to improve the capacity and safety of signalized intersections, it is necessary to carry out scientific research on the location of turnarounds.

Research Status

There are relatively few studies on the location selection of turnaround openings, and not many can establish a clear motion model for the selection of turnaround openings. Sun Feng et al [1] established a turnaround opening location selection model based on the optimal capacity, analyzed the mechanism of mutual influence between left-turning vehicles and turnaround vehicles, and the result improved the operation efficiency of turnaround openings; Sun Li et al [2] studied the influence mechanism of single left-turn lane turnaround openings and double left-turn lane turnaround openings, constructed a signal intersection total and capacity calculation model on this basis, and determined the optimal efficiency of traffic as the goal of the The intersection turnaround selection method; Kagayin [3] analyzed the safer travel sight distance for guiding traffic; Wang Tao [4] analyzed and optimized the current turnaround setting principle based on the vehicle operation characteristics and influencing factors to improve the utilization of space-time resources; Liu Renwen [5] used the queuing model to theoretically discuss the queuing nature and queuing parameters of the turnaround, which is an inspiration for the research method selection in this paper It is useful for the selection of research methods in this paper.

Research Subjects

The object of this study is a signal-controlled intersection with a central barrier.

The distance from the inlet road stop line to the opposite stop line is L_1, the distance from the stop line to the inlet road where the vehicle sees a turnaround vehicle ahead and takes the brake is L_2, and the distance from this position to the turnaround opening is L_3 (stopping sight distance). Assume that the vehicle from the import road to take the braking point when the uniform acceleration motion, the acceleration is a_1; take the braking uniform deceleration motion, the acceleration is a_2, the process can reach the maximum travel speed for v.

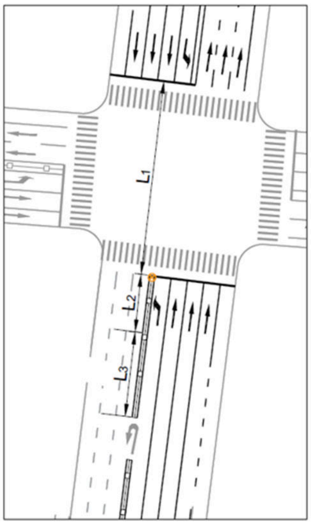

Figure 1: Intersection plan

Inlet lane and opposing turnaround traffic impact mechanism

(1) Vehicle movement description

Vehicles in the inlet lane stop in the inlet lane stop line. The intersection is open to traffic and the vehicle is in uniform acceleration motion. At a certain point see the opposite exit lane is making a U-turn movement of vehicles and braking, until stopping in front of the turnaround vehicles, resulting in the loss of movement time. During peak periods the import lane is close to saturation and the import lane is affected by the turnaround vehicles often evolve into a queue waiting to pass the convoy of turnaround vehicles, which generates queue loss time.

(2) Movement assumptions

To set the safest turnaround location as the ultimate goal, only the most congested situation that is the import lane traffic due to the opposite direction has a turnaround action completely stop when the loss of travel time and queuing time loss.

Assume the vehicle does uniform acceleration motion in the acceleration section $L_1 + L_2$ and uniform deceleration motion in the braking section L_3.

Turning vehicle blocking the import road vehicle travel loss time analysis

Due to the turnaround movement of the vehicle turnaround is not controlled by the signal, turnaround movement on the opposite direction of the blocking impact of vehicles and can not be known in advance, so the opposite direction of the incoming traffic only when you see the turnaround movement in front of the turnaround to take the brake to avoid, which often evolves into a brake stop to avoid during peak periods. This produces a loss of time and thus causes a reduction in capacity. General turnaround vehicle turning movement will affect the normal movement of vehicles in the two lanes of the import road, so the capacity reduction only occurs in the two lanes.

(1) Accelerated movement of vehicles in the inlet lane

When the green light at the intersection is on, the vehicles in the queue in the import lane are in uniform acceleration. The relationship between the distance L_1 and the maximum speed is as follows.

$$v^2 = 2a_1(L_1 + L_2) \tag{1}$$

where: v is the maximum speed that can be achieved when the opposite turning vehicle is seen to take the brake;

a_1 is the acceleration during the uniform acceleration phase.

Figure 2: Stage 1 diagram

(2) Traffic to take the brake

The inlet lane traffic to see the opposite direction turning vehicles and take the brake, its movement is as shown in the figure, the relationship between the distance L_3 traveled by the process and the travel time, the maximum speed is:

$$v^2 = 2a_2L_3 \tag{2}$$

$$v = a_2t \tag{3}$$

where: t is the time of the braking phase movement.

a_2 is the acceleration of the braking phase, determined by the relation between stopping sight distance and speed.

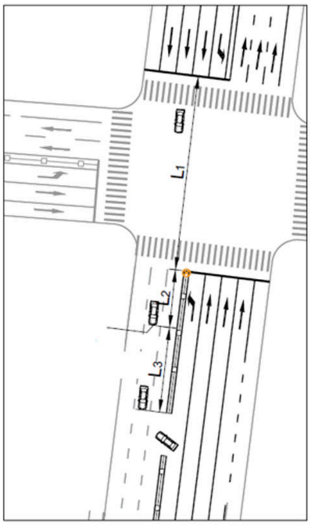

Figure 3: Stage 2 diagram

The stopping sight distance is used to determine the shortest distance needed to brake when an oncoming vehicle sees a turning vehicle on the inlet road. The table 1 shows the comparison table of stopping sight distance on Chinese highways, and the expression of the relationship between stopping sight distance and vehicle speed is fitted.

Table 1: Chinese road parking sight distance comparison table

Country	Stopping sight distance(m) at the following design speed (km/h)				
	120	**100**	**80**	**60**	**40**
China	210	160	110	75	40

$$L_3 = 0.008v^2 + 0.8393v - 6 \quad (4)$$

Combining equations (2) and (4) yields the acceleration expression:

$$a_2 = v^2/(0.016v^2 + 1.6786v + 12) \quad (5)$$

Combining equations (3) and (5) yields the travel time expression:

$$t = 0.016v + \frac{12}{v} + 1.6786 \quad (6)$$

(3) Queuing loss

The time lost by vehicles stopping in front of the turnaround queue is shown in Fig. According to the theory of traversable gap, it can be deduced that the number of vehicles in the queue that can cross the traffic flow of the turnaround vehicle per hour is:

$$Q = \frac{ke^{(-qt_0)}}{1-e^{(-qt_a)}} \quad (7)$$

$$q = \frac{Q}{3600} \quad (8)$$

where: Q is the amount of traffic that can cross the turnaround vehicles in the queue in the inlet lane (pcu/h).

k is the number of vehicles turning around during the counting interval (pcu/h).

t_0 is the critical gap time, t_0=7~9s for those stopping to pass.

t_a for the import road vehicles with the headway of the headway distance. Generally take t_a = 3s.

Figure 4: Parking queue section diagram

The time lost per vehicle in the import lane while waiting in the queue is the sum of the waiting time and the start-up loss time:

$$t_g = t_0 + L_g \tag{9}$$

Then the lost time due to queuing through in one cycle is:

$$t_{2mod} = Qt_g \tag{10}$$

Turning vehicle affects the import road capacity calculation

(1) Capacity calculation model

Single-vehicle travel time minus single-vehicle travel time in the loss of time to get single-vehicle effective travel time, and then single-vehicle effective travel time divided by the traffic saturation headway to get a single-vehicle unit of travel time in the actual capacity of the lane. From this, the capacity of an inlet lane where traffic encounters a turnaround vehicle obstructing traffic is calculated as

$$C_s = \frac{3600}{T_c}\left(\frac{T_g - T_{1\text{mod}} - T_{2\text{mod}}}{t_b}\right) \tag{11}$$

where: C_s is the capacity of a straight lane (pcu/h).

T_c is the signal period (s).

t_b is the saturation headway of continuous traffic in the inlet lane (s).

T_g is the green light time for passable import lanes.

(2) Motion process loss time

Due to the intersection traffic characteristics, the vehicle before leaving the intersection are not up to the design speed of the road, assuming that the vehicle has been doing uniform acceleration before arriving at the turnaround, the inlet road traffic in the normal driving time required to meet the turnaround vehicle is

$$t_1 = \sqrt{\frac{L_1+L_2+L_3}{a}} \tag{12}$$

Then the lost time caused by the turning vehicle blocking the traffic flow movement is

$$t_{1\text{mod}} = t_1 - t = \sqrt{\frac{L_1+L_2+L_3}{a}} - 0.016v + \frac{12}{v} + 1.6786 \tag{13}$$

According to the current research results, the vehicle arrivals in the import lane obey the Poisson distribution, then the probability that the number of vehicles arriving in a green light cycle is k_2 is

$$P(k_1) = \frac{(\alpha T_g)^k e^{-\alpha T_g}}{k!}, k = 0,1,2,... \quad (14)$$

where: α the average arrival rate per unit time interval (pcu/s).

T_g is the passable green light time of the import lane.

Then the lost time due to vehicle movement is

$$T_{1\text{mod}} = \frac{\sum_{t=0}^{T_g}\left(P(k_1)t_{1\text{mod}}(t)\right)}{\sum_{t=0}^{T_g}(k_1)} \quad (15)$$

(3) Queuing process loss time

In practice, not all cases will occur queuing phenomenon, there are not affected by the turnaround vehicle normal movement of the import lane vehicles, need to calculate the probability of the turnaround vehicle affect the import lane traffic flow.

Before the start of the queue, the number of turnaround vehicles k $k(k = 1,2, \dots\dots)$take a range of values from 0 to x, then the probability of turnaround vehicles blocking the flow of traffic in the import lane calculation formula is

$$P(k_2) = \frac{1}{\lambda+1}\left(\frac{\lambda}{\lambda+1}\right)^k \quad (16)$$

Where: λ is the proportion of turnaround vehicles.

Then the queue loss time generated by the turnaround vehicle blocking the inlet lane traffic is calculated as

$$T_{2\text{mod}} = \frac{\sum_{k=0}^{x}\left(t_{2\text{mod}}(k_2)P(k_2)\right)}{\sum_{k=0}^{x}P(k_2)} \quad (17)$$

The best way to determine the location of the turnaround port

In the turnaround car in the lane traffic flow characteristics and intersection design parameters are known, calculate the capacity of the inlet lane traffic with the maximum speed change function, draw the inlet lane capacity and the maximum speed corresponding change curve, find the maximum capacity speed value, use the speed value to calculate the stopping sight distance, according to the basic parameters of the intersection to calculate the distance between the turnaround opening and the intersection stop line.

Parameter acquisition

(1) Determining the proportion of turning vehicles λ in the turnaround lane.

(2) Determine the basic parameters of the intersection, including the two-way stop line distance L_1, signal period T_c, and green light time T_g in the inlet lane.

(3) Determine the inlet lane traffic flow characteristics, including uniform acceleration section acceleration a_1, following headway time distance t_a, and single green light cycle arrival rate α.

Passage capacity calculation

(1) Calculate the inlet lane traffic movement time loss T_{1mod}, and bring the known data into equation (15) to derive the expression for the loss time of vehicles due to braking.

(2) Calculate the inlet lane traffic queuing waiting time loss T_{2mod}, and bring the known data into equation (17) to derive the expression for the loss time of vehicles due to queuing.
(3) Import the intersection and traffic flow characteristics data into equation (11), bring the expression for the loss of motion time and the expression for the loss of queuing time into equation (11), and derive the expression for the capacity C regarding the maximum travel speed v. According to the range of values taken by the expression and the extreme value characteristics, find the value of the maximum speed when the capacity is maximum.

The best turnaround position is determined

(1) Bring the value of speed v into equation (4) and find the stopping sight distance L_3 at the maximum capacity.
(2) Bring the speed value v into equation (1) to find $L_1 + L_2$.
(3) the location of the turnaround point is derived from the intersection lane stop line distance $L_2 + L_3$.

Instance Verification

This paper takes the intersection of Century Road and Gongqingtuan Road in Zhangdian District of Zibo City as an example to optimize the design of its turnaround location and compare the capacity before and after optimization to verify the effectiveness of the above method.

(1) Parameter survey

Table 2: Intersections and traffic flow parameters

Data Category	Data Name	Numerical value
Left-turning car	λ	6
Intersection lane properties	L_1/m	75
	T_c/s	156
	T_g/s	54
	$a_1/m \cdot s^{-2}$	3
Traffic flow characteristics	t_a/s	2.5
	α	0.5

(2) Passage capacity calculation

When d = 6, using equations (11), (4) and (1) to calculate the capacity and the location of the turnaround port $L_2 + L_3$, as shown in Figure 5.

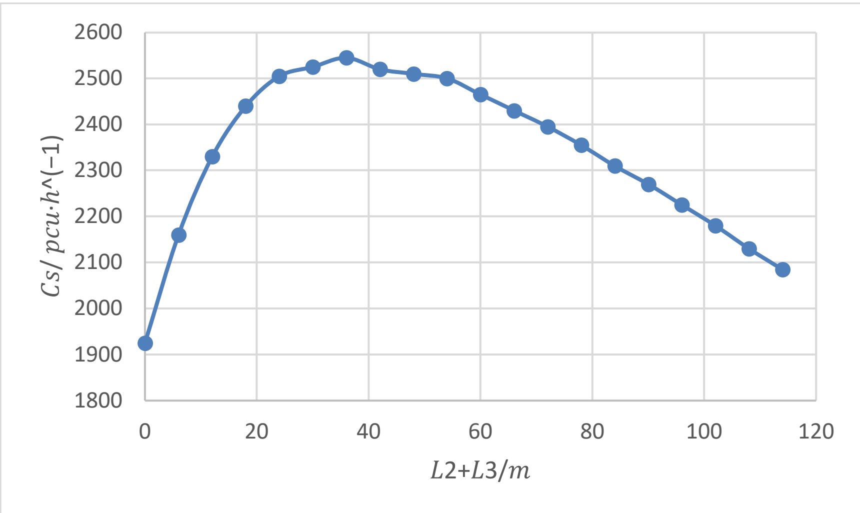

Figure 5: Correspondence between traffic capacity and turnaround location

(3) Program evaluation

As can be seen from Figure 5, for similar intersections with the same parameters, the capacity of different locations varies considerably, up to 32. 21%. The actual turnaround position of the intersection is at 6 m, and the optimal position is at 36 m using the method proposed in this paper, with a capacity improvement of 17. 82% over the status quo.

Conclusion

The intersection turnaround selection method proposed in this paper is proposed after theoretical analysis and mathematical modeling with full consideration of key factors such as intersection size, vehicle arrival rate, and the ratio of left-turn to turnaround vehicles, and the effectiveness of the method is verified by examples, and the following conclusions are drawn: (1) the method can effectively improve the capacity of the left-turn and turnaround shared lane and give full play to the benefits of intersection turnaround organization; (2) (2) Considering the safety of intersection operation, it is recommended to set warning signs before the conflict point between turnaround and right-turn vehicle merging to warn right-turning vehicles to avoid turnaround vehicles; (3) the research idea of this paper is also applicable to the intersection turnaround selection position with central green belt, and the influence of green belt width on the turnaround traffic operation will be considered in the subsequent research.

References

[1]. Feng Sun, Li Sun, Qingyin Li, Location of U-Turn Openings at Signalized Intersections Based on Opti mal Traffic Capacity [J]. Journal of Southwest Jiaotong University, 2017,52(02):334-339.

[2]. Li Sun. Research on urban signal intersection turnaround location selection method [D]. Shandong Uni versity of Technology, 2017.

[3]. Jiayin Ke. Analysis of highway sight distance safety based on the comparison of Chinese and foreign n orms [J]. Transportation Science & Technology, 2021(01):108-110+115.

[4]. Tao Wang. Analysis and optimization of traffic impact factors of intersection turnaround [J]. Constructi on Science and Technology, 2014(14):89-91.

[5]. Renwen Liu. Queuing Model for U-Turn Mouth of Bi-directional Streets [J]. Journal of Chongqing Uni versity (Social Science Edition), 2009, 28(05): 921-925.