Study on Design Parameters Setting for the Jug-handle-type Far-leading Intersection

Hu Tao¹, Jingsheng Chen¹*¹
¹ School of Automotive and Transportation Engineering, Hefei University of Technology, Hefei, Anhui, 230009, China
*Corresponding author’s e-mail: 1518993909@qq.com

Abstract. The left-turn traffic on the sub-arterial road at the intersection has a greater impact on the intersection traffic, the collision of vehicles can be reduced and the efficiency of the intersection will be improved by setting the Jug-handle-type far-leading (JHTFL) on the left-turn traffic flow through the sub-arterial road. In this paper, the applicable conditions and traffic flow organization method of the horizontal JHTFL intersection is analysed. Taking the minimum delay as the goal, several calculation models of the key geometric parameters are built, such as the length of the speed-change lane in front the ramp entrance, the distance between the ramp entrance and the main intersection, the queue length of the far-leading vehicles on the ramp and the length of the ramp, etc. The calculation methods for the delay and capacity of the JHTFL intersection are also presented. The feasibility of the above methods is verified by an example. Under certain conditions, we can find the left-turning traffic flow at the intersections can effectively reduce the number of signal phases and the average delay of the vehicle through the simulation. The results indicate the horizontal JHTFL intersection method has a good application value for optimizing the design of urban intersections.

1. Introduction
In the urban transport system, as the node of the road network, intersection is where all traffic flows converge, generating complex traffic behaviours such as diverting, crossing, merging and so on. In the traffic flow entering the intersection, the number of conflict points generated by left-turn traffic flow is the most, which is a key factor to affect the efficiency and safety of the intersection[1]. In recent years, domestic and international research shows that, at an intersection with a large volume of traffic, setting the far-leading of left-turning is an effectively way to reduce traffic conflicts and intersection traffic delays. The current research on the methods of setting the far-leading of left-turning mainly focuses on the “U-turn of far-leading left-turning”, which has high requirements on the central partition and limited application scope[2-3]. When the width of the medial divider of the road is insufficient, it is a better measure to use the method of setting the Jug-handle-type far-leading (JHTFL) to realize vehicles turning left at the sub-arterial road. The model of JHTFL is the method of turning left-turning traffic at sub-arterial road of intersection into the direct traffic flow at arterial road by means of the ramp of Jug-handle-type far-leading (as shown in Figure 1). Md. Shoaib Chowdhury used CORSIM to simulate the four ramps at the Jug-handle-type far-leading intersection of the New Jersey, adopting signal control and no signal control. Results show that under the low traffic volume condition, the effect of no control at the JHTFL intersections is better than the situations of signal control; on the contrary, in the case of large traffic flow at the Jug-handle-type far-leading intersection, the performance of signal control is better, and the traffic capacity is increased by about 45% compared
with the traditional signalized intersection[4]. At present, only the American Transportation Research Commission stipulates that the distance between the starting point of the main road at the JHTFL and the intersections should be at least 100 feet, while other relevant design parameters have not been stipulated; however, there is no relevant design specification in China, and the application practice is even less[5].

In a word, there are few studies on the design parameters of the JHTFL intersection, such as the parameters about spatial and signal control, and the practical application of the JHTFL mainly depends on the experience of traffic engineers; and that, the calculation method for the analysis of the traffic capacity and delay of the JHTFL left-turning intersection is insufficient. According to the traffic organization and operation characteristics of the JHTFL left-turning intersection, it is undoubtedly of great theoretical significance and engineering application value to discuss and construct the calculation method of key parameters, signal coordination control methods, capacity and delay calculation methods of the JHTFL intersections.

2. The analysis of traffic flow organization

The organization model of JHTFL is applicable to the intersection which intersecting roads have much difference on road hierarchy, such as the intersection of arterial road and sub-arterial road, or the intersection of arterial road and branch way. Another requirement is that the traffic volume of arterial road is large enough and the traffic volume of sub-arterial road is also large, while the traffic volume of left-turning at sub-arterial road is comparably small.

As shown in Figure 1, the off-ramp entrance of the JHTFL intersection is set up with a certain distance behind the stop line on the right side of the driving direction of the sub-arterial road approach lane, and the off-ramp exit is set up on the right of the driving direction of the arterial road exit-lane. At the intersection, left-turning vehicles change lanes behind the sign of detours to turning left, entering the ramp of the JHTFL along with right-turning vehicles, when arriving at the exit of ramp, these vehicles will wait for a left-turning release signal, then turning left onto the straight approach of the arterial road and go straight through the intersection; the traffic decelerating and yielding control method is adopted to realize the right-turning vehicles from sub-arterial road turn right at the exit of the ramp. The left-turning conflict of the sub-arterial road at the intersection is transferred to the sub-intersection formed by the ramp and the arterial road, while it is not necessary to consider the left-turn traffic flow at the approach of sub-arterial road entrance of the main intersection. The straight flow from sub-arterial road and the flow from arterial road could be organized by three-phase signal control method at the main intersection, which can reduce one phase compared with the conventional signal control intersection. Based on the fact that the left-turning and right-turning flows of sub-arterial roads are usually less than the capacity of single lane, the on-ramp can be set as a single lane, and the entrance road at the sub-intersection can be set as lanes of left and right separation lanes, namely the right-turning lane and the left-turning far-leading queue lane. In addition, in order to reduce the interference of left-turning traffic flow on the arterial road straight flow when far-leading vehicle
turning left at the main ramp exit, the following measures can be taken such as one or more special straight lanes for far-leading vehicles. After channelizing, the approach lanes of arterial road from inside to outside are straight lane, left-turn lane, straight lane and right-turn lane.

3. The research of spatial geometric parameters and the analysis of signal control

3.1. The research of spatial geometric parameters

3.1.1. The length of the speed-change lane. As shown in Figure 1, the speed-change lane consists of a tapered section \( L_A \) and a deceleration lane \( L_B \) [6]:

\[
L_A = \frac{\nu_{\text{sub}} t_A}{6},
\]

\[
L_B = \frac{1}{2} a^{-1} \left( \left( \frac{\nu_{\text{sub}}}{3.6} \right)^2 - \left( \frac{\nu_{\text{ramp}}}{3.6} \right)^2 \right)
\]

Where: \( \nu_{\text{sub}} \) represents the sub-arterial design speed of the JHTFL intersection, km/h. According to the Urban Road Engineering Design Specification[7], \( \nu_{\text{sub}} \) can be taken from 30 km/h to 50 km/h, generally 40 km/h. \( \nu_{\text{ramp}} \) represents the design speed of the ramp, km/h, 0.4 ~ 0.7 times of the arterial road velocity in general, the value can be 25 km/h. \( t_A \) represents the time that vehicle move a lane horizontally, which is calculated as 1 meter per second. And \( a \) represents the decelerate of the vehicle driving on the speed-change lane.

3.1.2. The space between the exit of ramp and the stopping line of the main intersection. As shown in Figure 1, the travelling track of the far-leading left-turning vehicle is similar to the arc of a quarter circle. \( R \) is the turning radius of the vehicle, which can be calculated by the formula (3):

\[
R = (n_{\text{main}} + 1) \cdot L_{\text{lane}}
\]

Where: \( L_{\text{lane}} \) represents the width of a driveway, which can be taken 3.5m; \( n_{\text{main}} \) is the number of main exit lanes, generally the value is taken as 3 or more.

When the arterial road has three exit lanes, the turning radius of vehicles can be obtained from formula (3) to be about 14m, which meets the requirements of the minimum turning radius of general large vehicles. That is to say, a straight lane, which is added on the innermost side of the main intersection, should meet the requirements of turning radius for all far-leading vehicles to turn left. The space \( L_c \) between the exit of ramp and the main intersection have to meet the maximum queue length of far-leading vehicle in straight lane of the main intersection, or far-leading vehicles on the ramp will not able to turn left into the straight lanes of the arterial road. If the exit of ramp is too far away from the main intersection, the detouring distance of left-turning vehicles will be increased, which will increase the detouring traffic delay and the engineering construction cost.

\[
L_c \geq \lambda_{\text{sub}} \times r_m \times h
\]

Where: \( \lambda_{\text{sub}} \) represents the arrival rate of sub-arterial road traffic flow, pcu/s; \( r_m \) is the red light time of the arterial road straight signal phase at the main intersection, s; \( h \) means the average headspace of vehicle parking, m.

Similarly, the space \( L_c \) between the exit of ramp and the stopping line of the main intersection should be no less than the maximum queue length of sub-arterial road straight vehicles and the length of far-leading vehicles queue lane. To avoiding affecting the right-turning traffic flow on the sub-
arterial road, \( L_d \) on the ramp should be no less than the maximum queue length of far-leading vehicles at the exit of ramp during the red light. Therefore, \( L_s \) and \( L_d \) can also be calculated by formula (4), which will not be repeated here.

![Figure 2. The relation between the composition of the ramp and the spacing of the intersection.](image)

**3.1.3. The ramp length of the JHTFL.** The ramp of the JHTFL as a special case of right-turning ramp, the ramp of JHTFL can be designed with simple horizontal alignment. For example, the combined form of circular curve - straight line - circular curve - straight line can be used. As shown in Figure 2, \( L_{ramp} \) is set as the length of ramp, so \( L_{ramp} \) can be calculated by the formula (5):

\[
L_{ramp} = L_{S1} + L_E + L_{S2} + L_D
\]  

(5)

Where, \( L_{S1} \) and \( L_{S2} \) represent the arc length, m; \( L_e \) is the middle straight lane length of the ramp.

As can be seen from Figure 2, the tangent line at the starting point D of the ramp entrance's circular curve is not parallel to the arterial road. The steering angle \( \theta \) and \( \beta \) of the two circular curves are not equal. According to the arc length theorem, the relationship between arc length \( L_{S1} \) and the steering angle \( \beta \) of the circular curve as follows:

\[
L_{S1} = \frac{\pi \beta R_{S1}}{180}
\]  

(6)

Where: \( R_{S1} \) represents the radius of the circle curve, m.

From formula (6), it can be known that the steering angle \( \theta \) of a circular curve has the following relationship with arc length \( L_{S2} \):

\[
\theta = \frac{L_{S2} \times 180}{\pi R_{S2}}
\]  

(7)

In Figure 2, the straight lane of the ramp \( L_E \), the values of the radius \( R_{S1} \), \( R_{S2} \) and the arc length \( L_{S2} \) are related to the design speed of the ramp, which can be taken according to the Urban Road Engineering Design Specification. In the same way, the length of the straight line of the ramp of JHTFL \( L_E \), the radius \( R_{S1} \), \( R_{S2} \) and the arc length \( L_{S2} \) can also be determined by referring to the specifications. \( L_E \) is generally no less than 2 times of the design speed of the ramp, usually can be taken no less than 50 m.

According to Figure 2, the distance between the exit of ramp and intersection \( L_{sub} \) satisfies the formula (8):
\[ L_{\text{sub}} = L_c + \phi = R_{y2} - R_{y2} \cdot \cos \theta + L_{DE} \cdot \sin \theta + L_{DE} \]  

(8)

Where: \( \phi \) represents the distance between the tangent of the sub-arterial road direction circular to the stopping line of the arterial road, which is related to the setting of stopping line and pedestrian crossing at intersections, usually take as 10 m. \( L_{DE} \) represents the height on the sides BC of the triangle BCD, m.

The length \( L_{DE} \) can be obtained from formula (8). According to the geometric relations in Figure 2, the length of BC side can be obtained, and the area of the triangle ADC equals to the area of the triangle ABC plus the area of the triangle BCD.

\[
0.5 \frac{R_{y1} \cdot \sin \beta}{\sin(90^\circ - \beta + \theta)} \cdot L_{DE} + 0.5 \frac{(R_{y1} \cdot \sin \beta)^2}{\sin(90^\circ - \beta + \theta)} = 0.5R_{y1}^2 \cdot \sin \beta
\]

(9)

According to the formula (9), the angle \( \beta \) can be obtained. \( L_{y1} \) can also be calculated by substituting \( \beta \) into formula (6) and if \( L_{y1} \) conforms to the specification, substitute it into formula (5) can get the length of ramp; if not, then increase the length to meet the specification.

3.2. The analysis of the coordinated signal control

The main intersection of the JHTFL is controlled by the ordinary three-phase signal method, and the exit of the ramp can be regarded as a sub-intersection. At the sub-arterial road, the right-turning vehicles are controlled by the method of decelerating and yielding, while, as for left-turning of far-leading vehicles, the signal control coordinated with the main intersection is employed. The Webster method can be used to obtain the best signal timing scheme with minimum delay:

\[
C_{\text{main}} = \frac{1.5 \times L_{\text{max}}}{1 - (\gamma_{\text{sub}} + \gamma_{\text{main-l}} + \gamma_{\text{main-s}})}
\]

(10)

Where: \( C_{\text{main}} \) represents the best signal cycle of the main intersection. \( \gamma_{\text{sub}} \), \( \gamma_{\text{main-l}} \) and \( \gamma_{\text{main-s}} \) represent the maximum flow rate of the sub-arterial road straight phase, arterial road left-turning phase and arterial road straight phase respectively. \( L_{\text{max}} \) means the total damage time, s. The left-turning of far-leading vehicles of the sub-arterial road need to be considered when the maximum flow rate of the arterial road straight phase be calculated.

The left-turning of far-leading vehicles of arterial road are controlled by signal control method. The signal at the sub-intersection should be green when the main intersection signal is sub-arterial road straight green phase and arterial road left-turning green phase. But in order to avoid the conflicts between left-turning of far-leading vehicles of the sub-arterial road and the straight vehicles at the exit lanes of the arterial road, the starting time of the green light at the ramp should be delayed after \( t_{\text{delay}} \):

\[
t_{\text{delay}} = \frac{3.6 \times L_{\text{sub}}}{\delta v}
\]

(11)

Where: \( \delta \) represents the velocity reduction coefficient of vehicles passing through the intersection, according to the Urban Road Engineering Design Specification, usually taking 0.5 ~ 0.7 times of the design velocity, we take 0.6 times here. \( v \) represents the design velocity of the arterial road at the intersection, km/h.

The signal at the exit of ramp should be red when the main intersection signal is arterial road straight green phase. In order to increase the traffic efficiency of the intersection, the red phase of the sub-intersection should start later than the straight green phase of the arterial road. So, the \( t_{\text{ds}} \):

\[
t_{\text{ds}} = 3.6 \times \left[ \frac{L_{\text{sub}} + m_{\text{sub}} \cdot L_{\text{lane}}}{\delta v} - \frac{\pi(n_{\text{main}} + 1) L_{\text{lane}}}{2 \delta v_{\text{ramp}}} \right]
\]

(12)
Where: $t_{ds}$ represents delay start time, equals to the time lag between the start time of straight green phase at arterial road with the start time of the red phase at sub-intersection, $s$. $m_{sub}$ represents the number of lanes on sub-arterial roads.

4. The research of intersection delay

4.1. The signal control delay of main intersection

The signal control delay of the main intersection can be calculated by Webster delay model. So:

$$D_{main} = \sum Q_i \left( C_{main} \left(1-\lambda_i\right) + \frac{x_{i2}^2}{2Q_i(1-x_i)} - 0.65 \left(C_{main}^2 \frac{x_{i1}}{Q_i} + \delta_{i}\right) \right)$$  \hspace{1cm} (13)

Where, $D_{main}$ represents signal control delay of the main intersection, $s$, and the left-turning of far-leading vehicles should be counted as straight vehicles of arterial road. $Q_i$ represents the modified traffic flow during the phase $i$. $\lambda_i$ represents the green split of phase $i$. $x_i$ means the saturation flow of phase $i$.

4.2. The deceleration delay of far-leading vehicle

The design speed of the ramp is lower than that of the sub-arterial road, far-leading vehicles need to decelerate before entering the ramp. Therefore, deceleration delay is caused when far-leading vehicles drive on the deceleration lane.

$$D_{dec} = \sum (q_{isub-r} + q_{isub-l}) \cdot \left( \frac{v_{sub} - v_{ramp}}{3.6a} - \frac{3.6L_g}{v_{sub}} \right)$$  \hspace{1cm} (14)

Where, $q_{isub-r}$ and $q_{isub-l}$ represents the right-turning flow and the left-turning flow of the approach $i$ of sub-arterial road respectively, pcu/h. $v_{sub}$ and $v_{ramp}$ means the design velocity of the sub-arterial road and the ramp, km/h. And $a$ means the deceleration, km/h$^2$.

4.3. The detour delay of far-leading vehicle

Far-leading vehicles travel longer distances than conventional left-turning vehicles, which led to the detour delay. At the same time, the operating speed of the vehicle when entering the functional area of intersection is lower than section design speed. The detour delay of far-leading vehicle can be calculated by the formula (15):

$$D_{detour} = \sum q_{isub-l} \cdot 3.6 \left( \frac{L_{ramp}}{v_{ramp}} + \frac{L_{sub}}{\delta v_{ramp}} - \frac{L_g}{\delta v_{ramp}} \right)$$  \hspace{1cm} (15)

Where: $\delta$ means velocity reduction coefficient and can be taken as the formula (11).

4.4. The signal control delay of sub-intersection

The vehicles on the sub-intersection are controlled by the signal control coordinated with the main intersection, the far-leading vehicles will queue up for the green light when them arrive at the sub-intersection during the red light. the signal control delay is generated. For the JHTFL intersection, the left-turning of far-leading flow usually small, and the arrive rate is less than the traffic capacity of the ramp, so signal control delay of the left-turning of far-leading vehicles can be calculated by vehicle delay model under the unsaturation condition:

$$D_{sub} = \sum q_{isub-l} \cdot \frac{S_{ramp} \cdot q_{isub-l} \cdot R^2}{2(S_{ramp} - q_{isub-l}) \cdot 3600}$$  \hspace{1cm} (16)
Where: $q_{\text{sub-r}}$ represents the traffic capacity of the ramp, pcu/h, the calculation method of $S_{\text{ramp}}$ is described below. $R_f$ means the red time corresponding to the sub-intersection signal cycle of $q_{\text{sub-l}}$, s.

5. The research of intersection traffic capacity

The traffic capacity of the JHTFL intersection is equal to the sum of each flow of the approach at the intersection. Conventional signal control method is adopted at the straight sub-arterial road and the arterial road, so the capacity can be obtained by the calculation formula of the signal control intersection combining the signal timing scheme of the main intersection:

$$S_{\text{main+sub-r}} = \left(\frac{C_{\text{main}} - L_{\text{main}}}{K_{\text{main}}} \cdot S_{\text{sub-r}} \cdot \gamma_{\text{sub-r}} + K_{\text{main}} \cdot S_{\text{main-l}} \cdot \gamma_{\text{main-l}} + K_{\text{main}} \cdot S_{\text{main-s}} \cdot \gamma_{\text{main-s}} + K_{\text{sub}} \cdot S_{\text{sub-l}}\right) / C_{\text{main}}$$

(17)

Where: $S_{\text{main+sub-r}}$ represents the traffic capacity of sub-arterial road straight flow and arterial road, pcu/h. $C_{\text{main}}$ represents signal cycle of main intersection, s. $K$ means the number of the approach lane. And $S$ means the designed saturation flow of an approach lane, pcu/h.

The traffic capacity of left-turning and right-turning flow of sub-arterial road related to the capacity of ramp. And the capacity of ramp $S_{\text{ramp}}$ can be calculated by the minimum average time headway when the vehicles on the ramp reach equilibrium state:

$$S_{\text{ramp}} = \frac{3600}{h_{\text{min}}}$$

(18)

Where: $h_{\text{min}}$ represents the minimum average time headway when the vehicles on the ramp reach equilibrium state, s[8].

The ramp width and the mixed rate of heavy vehicles have a large effect on the capacity of ramp, so the capacity need to be modified:

$$S_{\text{ramp-actual}} = S_{\text{ramp}} \cdot \frac{C_{\text{ramp}}}{1 + \sum P(E_i - 1)}$$

(19)

Where: $S_{\text{ramp-actual}}$ represents the actual capacity of the JHTFL ramp, pcu/h. $P_i$ represents the proportion of vehicle type $i$ to the total traffic volume of the ramp, $E_i$ means the conversion coefficient of the vehicle type $i$ and $C_{\text{ramp}}$ means the influence coefficient of ramp width.

The right-turning traffic capacity of sub-arterial road equals to the proportion of right-turning traffic on the ramp in actual capacity of the JHTFL ramp. So:

$$S_{\text{sub-r}} = S_{\text{ramp-actual}} \cdot \frac{q_{\text{sub-r}}}{q_{\text{sub-r}} + q_{\text{sub-l}}}$$

(20)

Where: $S_{\text{sub-r}}$ represents right-turning traffic capacity of the sub-arterial road, pcu/h.

The left-turning of far-leading traffic capacity is not only limited by the capacity of ramp, but also affected by the green ratio of the straight phase of the arterial road.

$$S_{\text{sub-l}} = \min \left( S_{\text{ramp-actual}} \cdot \frac{q_{\text{sub-l}}}{q_{\text{sub-r}} + q_{\text{sub-l}}} \cdot C_{\text{main}} \cdot \left( C_{\text{main}} - L_{\text{main}} \right) \cdot \gamma_{\text{sub-l}} + \gamma_{\text{sub-r}} + \gamma_{\text{main-s}} + t_{\text{delay}} + t_{\text{dr}} \right) / C_{\text{main}}$$

(21)

The total traffic capacity of the JHTFL intersection $S_{\text{JHTFL}}$ can be calculated by the formula (22):

$$S_{\text{JHTFL}} = S_{\text{main+sub-r}} + S_{\text{sub-r}} + S_{\text{sub-l}}$$

(22)
6. Example verification
Take the intersection of JiuLong avenue and NanCang road in a certain city as an example. JiuLong avenue is positioned as the urban arterial north-south road, with a 2.5 m wide central isolation belt. And NanCang road is positioned as the urban sun-arterial east-west road with a central isolation guardrail. The north-south road at the intersection has 4 approach lanes (including 2 straight lanes, 1 left-turning lane and 1 right-turning lane) and 4 exit lanes, and the east-west road has 3 approach lanes (including 1 straight lane, 1 left-turning lane and 1 right-turning lane) and 2 exit lanes. The survey results of peak hour traffic volume at the intersections are shown in Table 1.

| Left-turning peak flow | Straight peak flow | Right-turning peak flow |
|------------------------|--------------------|-------------------------|
| East approach lane     | 149                | 203                     | 217                     |
| West approach lane     | 164                | 257                     | 192                     |
| South approach lane    | 325                | 926                     | 244                     |
| North approach lane    | 278                | 850                     | 315                     |

The JiuLong avenue-NanCang road intersection is channelized by the aforementioned method combining the spatial parameter and timing of the intersection. The average vehicle delay and the total traffic capacity of the channelized JHTFL intersection are calculated by the JHTFL delay and traffic capacity model. Comparing with results of current situation intersection and that of adopting the Webster best timing method, the average vehicle delay of the intersection channelized by the JHTFL method can be reduced by 37% (as shown in Table 2), and the total traffic capacity only reduced by 4%. The phenomenon illustrate that it is reasonable to implement the JHTFL organization method.

The above three different traffic organization modes at the intersection was also simulated by VISSIM. The average vehicle delay of these modes can be obtained. As show in Table 2, the differences of computation value and the simulation value within 4.4 s. The results verify the accuracy of the aforementioned delay calculation method, and also show that the left-turning of far-leading channelization can effectively reduce the intersection delay.

| Different modes | Current situation | Webster timing | The JHTFL method |
|-----------------|------------------|----------------|------------------|
|                 | Total average delay | Far-leading delay | Other flow delay | Total average delay | Far-leading delay | Other flow delay | Total average delay | Far-leading delay | Other flow delay | Total average delay | Far-leading delay | Other flow delay |
| Calculation value | 51.1              | 44.5            | 51.7             | 6997              | 43.2             | 54.0            | 42.0             | 7300              | 26.4             | 46.4            | 24.2             | 7008 |
| Simulation value | 53.9              | 42.9            | 54.9             | —                 | 45.7             | 56.1            | 44.6             | —                 | 22.8             | 49.5            | 19.8             | —               |
| Difference      | -2.8              | 1.6             | -3.2             | —                 | -2.5             | -2.1            | -2.6             | —                 | 3.6              | -3.1            | 4.4              | —               |

7. Conclusion
By analyzing the traffic organization method of the JHTFL intersection, the calculation parameters and control method of the main intersection and sub-intersection are studied; the methods of signal control of main intersection, vehicle deceleration delay, detour delay and signal control of sub-intersection are presented; and the traffic capacity model of the JHTFL intersection is derived. According to the simulation data of the JiuLong avenue-NanCang road intersection, the theoretical calculation model is verified. Simulation results show that the calculated value of theoretical method is basically consistent with that of simulation, indicating the effectiveness of the theoretical method. At the same time, it also shows that under certain conditions, the operation efficiency of the JHTFL...
intersection organization method is higher than that of the traditional multi-phase signal control method, which can greatly reduce the average vehicle delay at the intersection.

Acknowledgments
This work was supported by the National Natural Science Foundation of China [grant No. 51878236].

References
[1] Xu, L.J., Wang, W. (2006) Analysis of Influence of Left-Turn Non-motors in Signalized Intersection[J]. China Journal of Highway and Transport, 19(1): 89-92.
[2] Hildebrand, T.E. (2007) Unconventional Intersection Designs for Improving Through Traffic along the Arterial Road[D]. Tallahassee: Florida State University.
[3] Zhang, W.H., Chen, J.S., Dong, R.J. (2017) Study on Geometrical Parameter Setup and Efficiency of Secondary Road in Intersection[J]. China Civil Engineering Journal, 50(10): 121-128.
[4] Chowdhury, M.D. (2011) An Evaluation of New Jersey Jug-handle Intersection (NJJII) with and without Pre-Signals[J]. 2011: 1245-1254.
[5] Maze, T.H., Hochstein, J.L., Souleyrette, R.R., et al. (2010) Median Intersection Design for Rural High-Speed Divided Highways. In: Transportation Research Board. Washington, D.C.
[6] Pei, Y.L., Zhou, S.S., You, R.W. (2009) Road Surveying Design[M]. China Communication Press, Beijing.
[7] Ministry of Housing and Urban-Rural Development of the People’s Republic of China. CJJ37—2012. Urban Road Engineering Design Specification[S]. China Building Industry Press, Beijing.
[8] Chen, K.M., Yan, B.J. (2011) Analysis of Road Capacity[M]. China Communication Press, Beijing.