

Research on service capacity of widened intersection based on traffic simulation

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Abstract: Delay analysis method is adopted to study the service capacity of a widened intersection. Traffic simulation software VISSIM is used for microscopic simulation of a widened intersection so as to obtain a delay curve. The delay-volume model of a widened intersection is established based on traffic simulation. The suggested value of basic service capacity of the widened left-turn lane is given along with how to determine correction factors and practical service capacity.

Key words: traffic simulation; widened intersection; service capacity; average delay

Capacity is a critical parameter in the signal timing of intersection and road design. The relative arithmetic has been studied before. However, there is little research on the calculation of capacity of a widened intersection. It is necessary to contrast existing calculation methods and find a point of reference. After the approach is widened, the delay at the intersection will change so that the service capacity alters with it. So a delay analysis method^[1] is adopted to calculate the service capacity of a widened signalized intersection.

1 Basic Thought of Delay Analysis Method

Several researches indicate that the traffic flow at an intersection is related to the average delay. Average delay will increase rapidly with the augmentation of traffic volume and its increasing trend is nonlinear. Therefore, the traffic volume and capacity of an intersection can be calculated by the relationship between traffic volume and delay at an intersection. And service level of the intersection can be determined by the average delay, then corresponding traffic volume can be obtained under different service levels.

There are three ways to gain the relation curve between average delay and traffic volume of a widened intersection. They are spot observation, mathematical model and computer simulation. Using a computer simulation method, a fake random number with the same distribution character of traffic flow can be produced by computer. Then a random variable can be formed through the compositor of the random number^[2]. The random variable can be used for

simulating running behaviors, queuing and delay of intersections through a numerical value calculation and logical test. Finally the delay-traffic volume curve is formed.

A computer simulation method is adopted to obtain the relation curve between the average delay and traffic volume of a widened intersection and service capacity corresponding to each service level of the widening intersection.

VISSIM is adopted to conduct microscopic simulation of traffic flow at a widened intersection. It is a discrete and random microscopic simulation model whose time step is 1/10 s. Longitudinal movement of vehicles adopts a psychology-physiology following model, while transverse movement (lane change) adopts a rule-based algorithm. A driver behavioral model classifies drivers as either a conservative type or a hazardous type. And vehicles move according to data that are defined by users or input by VISSIM. VISSIM provides a graphic interface and shows intuitionistic vehicular movements by 2-D or 3-D compacted cartoon. Dynamic traffic assignment is used for route choice.

2 Establishment of Relation Model between Average Delay and Traffic Volume

2.1 Conditions needed by VISSIM

Conditions needed by VISSIM when simulating widened intersection include road conditions and traffic conditions. Road conditions include the number of widened lanes, lane width, lane length, longitudinal slope and grade length, etc. And traffic conditions include traffic composition, traffic volume, ratio of turning vehicles and signal timing, and so on.

Standard road conditions and traffic conditions are adopted to simulate a widened intersection. Standard

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conditions include vehicle type (compact car), lane width (3.25 m), longitudinal slope (0%), grade length (0 m) and non-motorized vehicle influence (nonexistence).

A widened lane is defined as a road containing exclusive left-turn or right-turn lanes which are obtained by means of widening the intersection such as reducing the medium strip or side walk. The standard widened lane length value can be calculated as the following equation^[2] and adopts 70 m.

$$L = 0.75 QSl / 3600 \tag{1}$$

where L is the widened lane length (m); Q denotes the saturation flow of approach (veh/h), suggestion value is 1 200 to 1 440 veh/h; S is the effective green time in one cycle (s); l is the average space headway (m), suggested value is 7 to 9 m.

In addition, signal timing adopts two phases and cycle length is 80 s and amber period is 5 s. Considering an intersection with two main roads crossed, the green period of two directions is equal. The standard value of left-turn volume adopts $1/n$ of approach volume when n is the lane number of approach.

2.2 Simulation results analysis and establishment of model

It is regulated in HCM^[3] that an exclusive left-turn lane should be setup if left-turn volume exceeds 100 veh/h and two exclusive left-turn lanes should be setup if left-turn volume exceeds 300 veh/h. Therefore the traffic volume value which is input to widened approach ranges from 100 to 300 veh/h and input step is 10 veh/h. Then the corresponding average delay value of left-turn vehicle is obtained. Finally the delay curve of the widened lane is gained and the relation model between the average delay and the traffic volume is established. Fig.1 is a plane sketch map of

the simulated intersection. Simulation results are shown in Tab.1.

It can be seen from the data of Tab.1 that the average delay increases with the increase of left-turn volume. When left-turn volume is 100 pcu/h, the average delay is 15.2 s being close to 15.1 s which is the delay lower limit value of level C. Moreover, when left-turn volume is 300 pcu/h, the average delay is 48.9 s being close to 50.0 s which is the delay upper limit value of level D. Levels C and D represent normal running conditions, so it is shown that the setting gist of exclusive left-turn lane accords with the facts on one hand and the average delay value obtained by simulation is believable on the other hand.

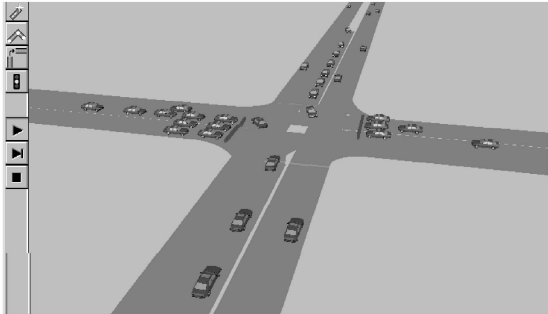


Fig.1 Plane sketch map of simulation intersection

Regression analysis is conducted to the data of left-turn volume and average delay in Tab.1 and the delay-volume curve of the widened left-turn lane can be obtained which meets the above road conditions and traffic conditions (see Fig.2).

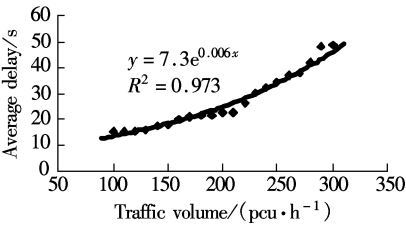


Fig.2 Relation curve between delay and traffic volume of a widened left-turn lane

Tab.1 Simulation results

Total volume/ (pcu · h ⁻¹)	Left-turn volume/(pcu · h ⁻¹)	Average delay/s	Total volume/ (pcu · h ⁻¹)	Left-turn volume/(pcu · h ⁻¹)	Average delay/s
300	100	15.2	630	210	22.8
330	110	15.2	660	220	26.4
360	120	15.4	690	230	30.4
390	130	16.0	720	240	32.2
420	140	17.6	750	250	34.3
450	150	17.9	780	260	37.0
480	160	20.1	810	270	38.1
510	170	20.9	840	280	41.9
540	180	21.4	870	290	48.2
570	190	21.6	900	300	48.9
600	200	22.6			

It can be seen from Fig.2 that the relation between average delay and traffic volume is an exponential relation with high relativity ($R^2 = 0.937$). The relation model is

$$d = 7.3e^{0.0061Q} \quad (2)$$

where d is the average delay (s); Q is the traffic volume (pcu/h).

The above model also can be expressed as the form in which the average delay is an independent variable as the following:

$$Q = 164(\ln AR - 1.99) \quad (3)$$

Using this model, basic service capacity of a widened left-turn lane corresponding to each level can be calculated under standard road and traffic conditions and above signal timing. Basic service capacity under normal running conditions, namely, basic service capacity corresponding to levels C and D are calculated and the suggested values can be seen in Tab.2.

Tab.2 Suggested value of basic service capacity of widened left-turn lane

Service level	Average delay upper limit/s	Basic service capacity/(pcu · h ⁻¹)
C	30	231
D	50	315

Through the above simulation course, delay-volume curves of through lane, widened right-turn lane and protective widened left-turn lane under standard road and traffic conditions can be obtained. And the basic service capacity of a widened intersection corresponding to each level can be determined finally.

3 Calculation of Practical Service Capacity

3.1 Calculation of correction factors

The above service capacity is calculated according to the delay-volume curve under standard road and traffic conditions. When conditions change, basic service capacity needs to be corrected.

3.1.1 Correction factors of traffic composition

When traffic flow is heterogeneous, the traffic load caused by different vehicle types is not equal nor is the influence of different vehicle types on a delay curve because of different running characters. The correction of traffic composition based on a delay curve is not simply the determination of equivalent factors but a determination of the influence of non-standard vehicles on the delay curve.

Regarding the compact car as the standard

vehicle, heterogeneous degree can be calculated according to the following equation:

$$P = \frac{\sum Q_i K_i}{\sum Q_i} \quad (4)$$

where P denotes the heterogeneous degree of a non-standard vehicle; Q_i is the traffic volume of i vehicle type (veh/h); K_i is the equivalence factor of i vehicle type.

$P = 1$ is the delay curve of standard flow. The delay curve of heterogeneous flow, i.e. P is more than 1, can be obtained by the above simulation course. The correction factor is calculated by the following equation:

$$n_{1K} = \frac{Q_{1Ki}}{Q_{1Ki}} \quad (5)$$

where n_{1K} denotes the correction factor of heterogeneous flow on service capacity of level K; Q_{1Ki} is the heterogeneous traffic volume corresponding standard delay under level K (veh/h); Q_{1Ki} is the service capacity of level K of standard flow (veh/h).

3.1.2 Correction factor of signal timing

The above delay curve is obtained under the conditions of standard signal timing, namely, cycle length is 80 s and the green periods of two directions are equal. The delay curve of a widened lane will change to another signal timing and the service capacity should be corrected. Analogously, the delay curve under different signal timings can be gained by the above simulation course and corresponding service capacity can be calculated. The correction factor is calculated as the following equation:

$$n_{2K} = \frac{Q_{2Ki}}{Q_{2Ki}} \quad (6)$$

where n_{2K} denotes the correction factor of signal timing on service capacity of level K; Q_{2Ki} is the traffic volume corresponding to the standard delay on non-standard signal timing delay curve under level K (veh/h); Q_{2Ki} is the service capacity of level K of standard signal timing (veh/h).

3.1.3 Correction factor of the number of a widened lane

Two exclusive left-turn lanes should be set up when left-turn traffic volume is more than 300 veh/h. Research indicates that the capacities of two left-turn lanes aren't equal and the capacity of the inner lane is lower than that of the outer lane. Moreover, both left-turn correction factors of two lanes have a certain

range^[4]. The standard number of a widened lane is regulated as 1. So the correction factor of the number of widened lanes can be calculated as the following equation:

$$n_{3K} = \frac{Q_{3Ki}}{Q_{3Ki}} \quad (7)$$

where n_{3K} is the correction factor of the number of widened lanes on service capacity of level K; Q_{3Ki} is the traffic volume corresponding to the standard delay on non-standard delay curve under level K when the number of widened lanes is more than 1 (veh/h); Q_{3Ki} is the service capacity of level K when the number of widened lanes is equal to 1 (veh/h).

3.1.4 Correction factor of widened lane width

The correction factor of widened lane width, n_{4K} , can adopt values in Tab.3^[5]. When lane width is standard width, 3.25 m, $n_{4K} = 1$. When lane width is less than standard width, n_{4K} is less than 1. When lane width is more than standard width, n_{4K} is more than 1.

Tab.3 Correction factor of exclusive left-turn lane width

Lane width/m	Saturation flow/(veh · h ⁻¹)	Correction factor
2.90	1 193	0.81
2.95	1 215	0.83
3.00	1 243	0.85
3.05	1 277	0.87
3.10	1 317	0.90
3.15	1 363	0.93
3.20	1 414	0.96
3.25	1 471	1.00
3.30	1 534	1.04
3.35	1 603	1.09
3.40	1 678	1.14
3.45	1 758	1.20
3.50	1 845	1.25

3.1.5 Correction factor of widened lane length

Standard widened lane length is regulated as 70 m, namely, eight standard vehicles. N is defined as the number of vehicles that can be accommodated. According to the relation model^[5] between widened left-turn lane length and capacity, the capacity of widened left-turn lane can be gained when the proportion of left-turn vehicles is $1/n$ (n is the number of approach lanes) and $N = 8$. When N is equal to others, the capacity of widened left-turn lane can also be gained. The ratio of the two capacity values can be regarded as the correction factor of the widened lane length.

$$n_{5K} = \frac{c_m}{c_8} \quad (8)$$

where n_{5K} is the correction factor of the widened lane length on service capacity of level K; c_8 is the capacity of widened left-turn lane when $N = 8$ (veh/h); c_m is the capacity of widened left-turn lane when $N = m$ (veh/h).

3.1.6 Others correction factors

Using similars methods of calculating correction factors of traffic composition, the effects of longitudinal slop, grade length and non-motorized vehicles on service capacity of widened lane can be determined.

3.2 Calculation of practical service capacity

The service capacity needed is that of each level under practical road and traffic conditions in planning, design and evaluation of intersections. It is called “practical service capacity”. The practical service capacity of each level should be gained through correcting corresponding basic service capacity obtained from the curve under standard road and traffic conditions.

$$C_K = C_{SK} \prod_i n_{iK} \quad (9)$$

where C_K is the service capacity of level K under practical road and traffic conditions (veh/h); C_{SK} is the service capacity of level K under standard road and traffic conditions (veh/h); n_{iK} is the correction factor of level K.

Service capacity of level D is often adopted as the evaluation gist in planning and design of urban road intersections.

4 Conclusion

Widening the approach is an effective measure to improving the capacity of an intersection. And the determination of service capacity of a widened intersection is very important in the planning, design and evaluation of that intersection. A simulation is adopted to acquire a delay curve of widened intersection so that a simple and accurate method to calculate the service capacity is provided. However, it is impossible that all delay curves of each intersection can be established to calculate its service capacity in a practical project. Spot observation method, mathematical model method and computer simulation method can be combined to establish each type of delay curve; correlative road conditions and a traffic condition correction factor are provided in the form of table or curve.

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基于交通仿真的拓宽交叉口服务通行能力研究

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摘 要 采用延误分析法研究路口拓宽后信号交叉口的服务通行能力,利用交通仿真软件 VISSIM 对拓宽交叉口进行交通流微观仿真,从而得到拓宽车道的延误曲线,建立了基于交通仿真的拓宽交叉口延误-流量模型.依据该模型提出了拓宽左转车道的基本服务通行能力的建议值,并给出了各修正系数以及实用服务通行能力的确定方法.

关键词 交通仿真; 拓宽交叉口; 服务通行能力; 平均延误

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