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Study on Capacity of Urban Expressway Weaving Segments

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Abstract

For the shortage of previous studies on urban expressway weaving segments, the capacity of them is studied using traffic simulation method. It is indicated and verified that the capacity of urban expressway weaving segments has a great relationship with the source and distribution of weaving and non-weaving flows. Subsequently, using the calibrated simulation model, capacity values of urban expressway weaving segments have been estimated, in which capacity values of weaving segments shorter than 150 m that it is not considered in the Highway Capacity Manual (HCM) 2000 are also included. In addition, it is demonstrated that the proposed model capacity estimates are consistent with field data while the HCM procedures tend to overestimate the capacity of weaving segments significantly.

Keywords: expressway; weaving segments; capacity; simulation model; VISSIM

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1. Introduction

As the expansion of cities and rapid growth of urban vehicle population, major cities in China have started to build or improve the urban expressway network system to mitigate the increasing traffic pressure. The purpose of constructing urban expressway in China is to improve the urban traffic operating efficiency by improving operating conditions of long-distance transportation and also to service for the collector-distributor traffic of the land along the road (Guisheng Liu 2003). However, due to lack of studies on weaving segment which is a bottleneck of urban expressway, the setting of weaving segment and entrance and exit of urban expressway is not very reasonable. Thus, the role of urban expressway

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cannot play very well, which greatly reduces its economic benefits.

In reviewing the literature, existing studies on the capacity of weaving segments are mainly for freeway weaving segments, and literatures on urban expressway weaving segments are not many. The most systematic study on weaving segment is Highway Capacity Manual (HCM). The freeway weaving analysis procedures in the HCM 2000 are based on research conducted in the early 1970s through the early 1980s. It provides values for capacity on various weaving segments (Exhibit 24-8) based on sets of conditions (configuration, speed, length, volume ratio, and number of lanes). Subsequent researches have shown that the method's ability to predict the operation of a weaving section is limited (Lertworawanich and Eleferiadou 2004, 2007; Rakha and Zhang 2004), which is most probably due to the outdated and limited database that was utilized to develop these models. To estimate capacity of freeway weaving sections, some other methods have been used as alternatives. Lertworawanich and Elefteriadou (2004, 2007) proposed a methodology to estimate the capacities of Type B weaving areas based on gap acceptance and linear optimization. Vermijs (1998) developed a microscopic simulation approach for estimating weaving section capacities that evaluate capacity for several Type A major weaves and ramp weaves. Awad (2003, 2004) mentioned two capacity prediction models using linear regression (LR) and neural network (NNT) for estimating capacity on weaving segments.

Most existing design and analysis procedures of weaving segments are based on limited empirical data collected at a certain number of weaving segments, while previous studies have found significant differences between the actual traffic performance of weaving sections and the estimates from the analytical procedures (Alexander Skabardonis 2002). Simulation is an alternative approach to evaluate the operation of weaving segments, provided that the model employed is capable of reasonably replicating known field conditions.

This paper utilizes the VISSIM microscopic simulation model to estimate the capacity of urban expressway weaving segments. Initially, the paper describes the characteristics of urban expressway weaving segments. Subsequently, the model is calibrated and validated. Afterwards, a wide range of weaving segment traffic demands is modeled using the VISSIM software. Finally, the paper presents findings and conclusions of the study.

2. Characteristics of urban expressway weaving segments

Weaving is defined as the crossing of two or more traffic streams traveling in the same general direction along a significant length of the roadway without the aid of traffic control devices. Weaving segments are formed when a merge area is closely followed by a diverge area, or when a one-lane on-ramp is closely followed by a one-lane off-ramp and the two are joined by an auxiliary lane. In interchanges, such as between the on- and off-ramps of rotary and cloverleaf interchanges, there are typical weaving segments.

Based on the number of lane changes required of each weaving movement, the HCM (2000) identifies three categories of weaving configurations: Type A, Type B and Type C. Among them, the characteristic of a Type A weaving segment is that each weaving vehicle must make one lane change at least to successfully complete a weaving maneuver. Type A weaving segment can be identified into ramp-weave segment and major-weave segment shown in Fig. 1. The form of urban expressway weaving segments in China generally belongs to Type A, and mostly is ramp-weave segment. So, this paper only studies the ramp-weave segment in Type A.

As a part of urban road network, urban expressway also services for the collector-distributor traffic of the land along the road. So, main and side roads are generally set to take the traffic functions of different characteristics. The main road takes on the long-distance and high-capacity thorough traffic; the side road mainly services for the collector-distributor traffic of middle and short distance in areas along the road, moreover, it also services for public transportation (Youjun Xu 2007). It needs setting exit and entrance between main and side roads to vehicles travelling in and out. Due to this relationship of main and side roads, they are set in parallel. Therefore, there are no vehicles travelling from the side road to the main road and then coming back the side road through the weaving segment. This way of traffic operation is different clearly from that of freeway weaving segments, as shown in Fig.2. However, there are no special studies on this case in existing capacity studies on weaving segments.

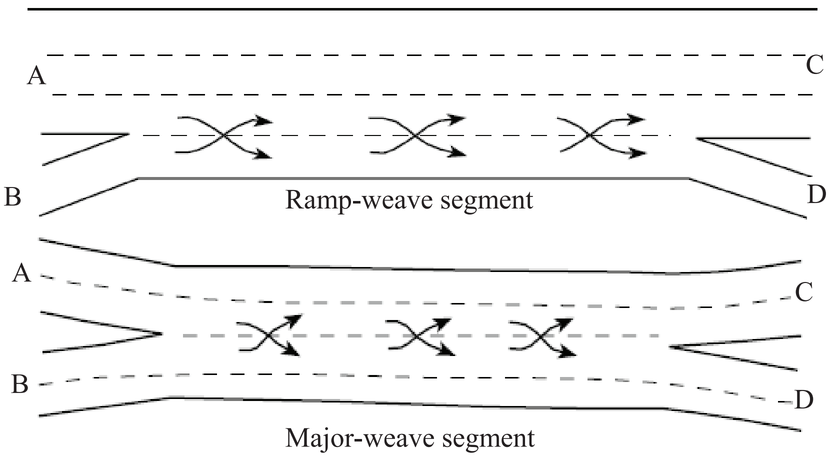

Fig. 1. Weaving segments of Type A

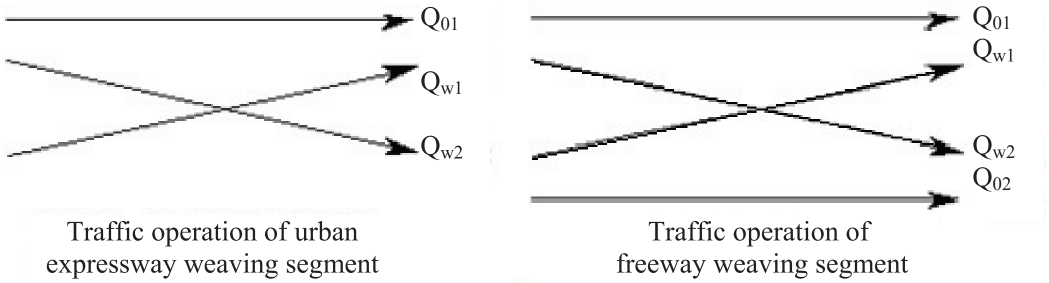

Fig. 2. Differences of the two weaving segments' traffic operation

In addition, after surveying weaving segments of the third and fourth ring roads in Beijing, it is found that urban expressway weaving segment lengths are generally short, in which weaving segments short than 150m take a large ratio. The proportions of various lengths of weaving segments on the third and fourth ring roads are shown in Tables 1 and 2. From the two tables, it is known that weaving segments short than 150m on the third ring road account for 60.3%, and weaving segments short than 150m on the fourth ring road also account for 20.8%. Because the HCM (2000) and other literatures on weaving segments don't consider capacities of weaving segments short than 150m, they only think weaving segments short than 150m dealt with as unsignalized intersections. Considering the shortage of that study, this paper also studies weaving segments short than 150 m.

Table 1. Statistics of weaving segment lengths of the third ring road in Beijing

Weaving segment lengths	<150	150-300	<300	Total
Total	44	24	5	73
Percentage	60.3%	32.9%	6.8%	100%

Table 2. Statistics of weaving segment lengths of the fourth ring road in Beijing

Weaving segment lengths	<150	150-300	300-400	400-500	500-600	Total
Total	10	20	7	6	5	48
Percentage	20.8%	41.7%	14.6%	12.5%	10.4%	100%

3. Simulation model calibration

The objective of the model calibration is to determine a combination of the model parameter values that can replicate field conditions as accurately as possible. The calibration process involved multiple simulation runs with different values of the model parameters. The results from the simulation runs were compared with field data to determine if the parameter combination produces the best match between predicted speed and traffic volumes and observed ones across all test sites.

This paper has calibrated key parameters of road, characteristics of vehicles and driving behavior, and established the corresponding simulation model based on the main traffic characteristics in Beijing. According to field data of the third and forth ring roads in Beijing, this paper has conducted simulation model calibration.

a. The geometry of the road: There are three lanes on the main road and an auxiliary lane on the weaving segment. Each lane width is 3.75m.

b. Driving behavior of vehicle: Vehicles are considered to travel at anywhere in the lane and allowed to overtake other cars in one lane when the width is enough and the safe distance meet the requirement.

c. Desired speed: Desired speed is the speed that vehicles free travelling will take without interference from other vehicles under certain road conditions. It is mainly affected by drivers' characteristics, the performance of vehicles and road conditions. As desired speed is a critical parameter, it will directly affect the obtained capacities and operating speed of vehicles by means of the simulation model. This paper adopts the speed collected in off-peak periods as the basis of calibrating desired speed. Considering the speed limited requirements of the third and forth ring roads in Beijing, the simulation model adopts the average field speed values of the free flow as the desired speed. In the model, the maximum desired speed value of the main road is 80 km/h, the minimum value is 60 km/h; the maximum desired speed value of the side road is 70 km/h, the minimum value is 40 km/h. Each simulation model parameter calibrated in this paper is show in Table 3.

Table 3. Calibrated parameters

Following parameters	Average standstill distance /m	2
	Additive part of safely distance /m	2.65
	Multiplicative Part of safely distance /m	3.65
Lane change parameters	Maximum deceleration /m · s^{-2}	-4.4/-4
	Waiting time before diffusion /s	30
	Minimum headway /m	1.75
	Safety distance reduction	0.67
	Maximum deceleration for cooperative braking /m · s^{-2}	-4
Car following model	Wiedemann74	

Thus, the paper conducted a number of simulation experiments and tested simulation results in aspects of the flow of weaving segment lanes and the speed of vehicles. Two hours' measured traffic flow when it runs stably and simulation data are compared. As shown in Figs. 3 and 4, the simulation data of the second lane basically coincides with the field data. And other lanes' compared figures are also coincident.

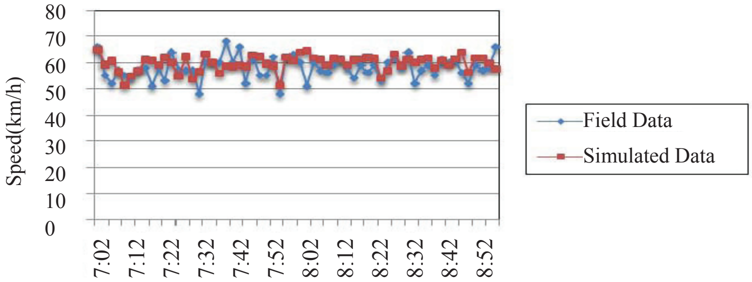

Fig. 3. Comparison of field and simulated average speed of the second lane

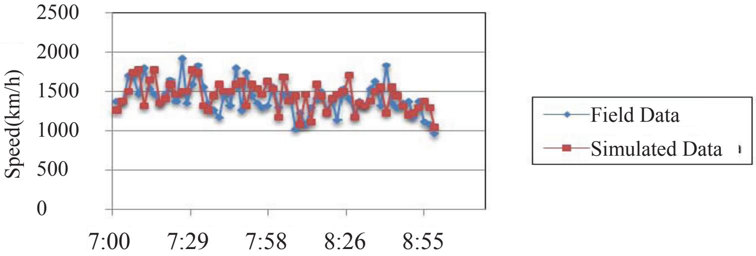

Fig. 4. Comparison of field and simulated flow rate of the second lane

So, the comparison of simulated and measured data indicates that the simulation model is very accurate. From measured and simulated values, the paper selects a number of average speed and flow values of the weaving segment and conducts t test respectively (Sheng Zhou 2005). Taking n pairs of measured and simulated values, the hypothesis testing problems is established as follow:

The null hypothesis H_0: $\mu_D=0$.

The alternative hypothesis H_1: $\mu_D\neq 0$.

where μ_D is the average differential value between the measured sample and simulated sample. Taking the significance level $\alpha=0.01$, test results can be calculated as shown in Table 4.

Table 4. T-test result

	Sample size	T value	Rejection region
Measured average speed	40	2.5289	|t|≥2.7079
Simulated average speed	40		
Measured flow	40	0.9060	|t|≥2.7969
Simulated flow	40		

After the test, it is considered that there is no significant difference between measured result and simulated result and the simulation model is valid.

4. Simulation results and verification

Capacity is defined as the maximum 15-min throughput (summation of mainline and off-ramp flows) that is measured downstream of a merge, diverge, or weaving section prior to traffic stream breakdown (Hesham Rakha et al. 2006). According to this definition of weaving segment capacity, using the calibrated and validated VISSM simulation model, it constantly increases the input traffic demand of main line and on-ramp in the case of each weaving length and volume ratio. When the traffic flow overflows, the summation of flow rate of main line and on-ramp can be considered as the capacity of weaving segment in the condition of certain volume ratio and weaving length. In order to avoid the error that the traffic flow doesn't match with the actual situation in the beginning and end of the simulation phase, we set the simulation time as 4500s and take the data of 600s to 4200s as the research data. Using this simulation method, values for capacity of various weaving segments can be obtained.

4.1. Effect of non-weaving vehicles on the capacity of weaving segments

Due to weaving and non-weaving vehicles share some lanes, fractional values for lane use requirements of weaving vehicles may occur. That is to say, non-weaving vehicles have some restriction on the operation of weaving vehicles. However, the effect of non-weaving vehicles on the capacity of weaving segments is not considered in the HCM (2000). By doing simulation experiments of four-lane weaving segments of highway, we can obtain capacities in different proportions of traffic flow participating in weaving which travels from on-ramp to weaving segment, as shown in Table 5.

Table 5. Capacities of four-lane weaving segment on general highway

Volume ratio		Weaving segment length，m			
		300 m	450 m	600 m	750 m
0.1	80%weaving[a]	7300	7400	7400	7600
	60%weaving	6800	7400	7400	7600
	40%weaving	6800	7500	7700	7700
	20%weaving	7800	8000	8150	8400
0.2	80%weaving	6800	6950	7150	7600
	60%weaving	6900	7250	7500	7800
	40%weaving	7100	7450	7700	8050

Notes: a. 80% of the traffic flow travelling from the ramp to weaving segment conducts weaving.

From Table 5, it is shown that there are some differences in obtained capacities under the condition of different proportions of weaving traffic flow coming from the ramp. That is because non-weaving vehicles on the auxiliary lane reduce the accepted gaps which can be used by weaving vehicles to change lanes to the auxiliary lane. Meanwhile, the results also indicate that the effect of non-weaving vehicles on the capacity of weaving segments is smaller than that of weaving vehicles.

4.2. Capacity values of weaving segments

From the above analysis, the capacity of expressway weaving segment is equal to that of highway weaving segment with the same configuration when the traffic flow entering from ramps participates in weaving completely. That is actually a special case of general weaving segments. Based on the method of traffic flow loaded mentioned above, simulation experiments of expressway weaving segments have been done, and the traffic flow-speed scatter diagram has been plotted according to the simulation results, whereby the capacity of expressway weaving segments can be determined. Tables 6 and 7 are capacity values of weaving segments obtained by the simulation model.

Table 6. Capacity for various expressway weaving segments (short than 150m)

VR	Length of weaving segment (m)				
	50	75	100	125	150
4-lane segments, pcu/h					
0.1	4750	5000	5040	5050	5200
0.2	3570	4000	4200	4260	4700
0.3	2790	3240	3270	3730	4080
0.4	2480	3100	3120	3250	3700
5-lane segments, pcu/h					
0.1	6930	6940	7020	7180	7420
0.2	5230	5380	5580	5820	6110
0.25	4620	4860	5110	5260	5320

Table 7. Capacity for various expressway weaving segments (long than 150m)

VR	Length of weaving segment (m)											
	200	250	300	350	400	450	500	550	600	650	700	750
4-lane segments, pcu/h												
0.1	5250	5470	5580	5700	5870	6200	6310	6390	6500	6550	6600	6680
0.2	4950	5310	5360	5500	5730	5950	6010	6080	6190	6320	6430	6520
0.3	4300	4670	4840	5140	5340	5790	5920	6030	6100	6150	6210	6260
0.4	4010	4400	4500	4810	4970	5150	5390	5530	5600	5660	5870	5890
5-lane segments, pcu/h												
0.1	7480	7600	7630	7720	7880	8110	8400	8570	8680	8740	8860	9020
0.2	6520	7090	7080	7160	7330	7890	7930	8160	8340	8470	8620	8750
0.25	5760	6470	6960	6990	7030	7200	7360	7570	7820	8090	8140	8220

4.3. Simulated results verification

In order to verify the accuracy of simulated results, the observed maximum traffic flow of the third ring road of Beijing in the peak time, the model and the HCM (2000) validation against field data capacity measurements are compared, as shown in Table 8. It is can be found that the model capacity estimates are closer to measured maximum values than ones estimated by in the HCM (2000). Thus, capacity values of expressway weaving segments obtained from the calibrated VISSIM software are more accurate.

Table 8. Model and HCM (2000) validation against field data capacity measurements

Weaving segment length (m)	Volume ratio	Field data (pcu/h)	Simulation model (pcu/h)	HCM (2000) (pcu/h)	Relative error of simulation model and field data (%)	Relative error of HCM (2000) and field data (%)
667m	0.34	5680	5990	6590	5.2	13.8
655m	0.37	5420	5820	6410	6.9	15.4
300m	0.22	5170	5250	6520	1.5	20.7
540m	0.36	5600	5700	6320	1.8	11.4

5. Conclusions

Because the traffic operation of weaving segments is very complex, the capacity of weaving segments has been always the difficulty of studies. Although the HCM (2000) has estimated the capacity of weaving segments based on field data, these weaving segments appear on freeway and their capacity values are not suitable for urban expressway weaving segments. The paper introduces methods and procedures to estimate the capacity of expressway weaving segments by VISSIM simulation model. It points out and verifies that the capacity of weaving segments has not only a relationship with volume ratio and length of weaving segments but also with the source and distribution of weaving flow and non-weaving flow. Subsequently, using the calibrated simulation model, capacity values of urban expressway weaving segments have been estimated, in which capacity values of weaving segments shorter than 150m that the Highway Capacity Manual (HCM) 2000 doesn't consider are included. Through comparing with field data of maximum traffic flow, it is verified that capacity values estimated by the simulation method are reliable.

Acknowledgements

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