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RESEARCH PAPER

Gap Acceptance Capacity Model for On-Ramp Junction of Urban Freeway

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Abstract: The commonly-used capacity calculation approaches for ramp junctions are mostly based on the American Highway Capacity Manual method. It had been approved that the headways for vehicles following the Weibull distribution function at on-ramp junctions in urban freeway system. The paper examined the critical headway and following time by the modified drew method and the survey traffic flow data on-site. The gap-acceptance capacity calculating model was developed for on-ramp junctions of urban freeway, and the numerical integration method was used to solve the model. Finally, the capacity values were obtained in condition of different mainline design speeds and different acceleration lane lengths. The results indicated that the capacity value would grow with the increase of the acceleration length and mainline design speed, and the capacity values for on-ramp junctions would approach basic freeway segments capacity values while the acceleration lengths beyond 400 meters.

Key Words: urban freeway; on-ramp junction; headway; numerical integration method; capacity

1 Introduction

In the urban freeway system of China, the influences from inflow vehicles on those on-ramp mainline vehicles are always omitted when the actual traffic volume of on-ramp junction is not large enough. However, with the increase of the inflow rate, the extrusion interference gradually gets worse, which even causes the traffic disturbance of on-ramp junctions. Thus, the on-ramp junction areas are often considered as the bottlenecks of urban freeway in China, which seriously restrict the function of the whole road network. Because urban freeway holds a relatively short developing history in China, there are many subjects which should be further studied, namely, capacity, level of service (LOS), and so on. Meanwhile, the construction scale, ramp settings, etc., are always determined by the capacity and the LOS of urban freeways. At present, the American Highway Capacity Manual (HCM) was widely used to determine the urban freeway capacity in China, and many problems were met in practical application. Therefore, this study investigates relevant factors from China's actual situation.

2 Basic theory

On-ramp junction capacity of urban freeway was defined as the maximum number of vehicles from on-ramp merging the mainline plus the passing vehicles number of middle lane and shoulder lane in each time unit. The gap-acceptance theory had been widely used to calculate the capacity of crossings, weaving zones and others, and also many calculating models were given correspondingly[1–4].

The gap-acceptance capacity calculating model of on-ramp junction of urban freeways was actually the ability of on-ramp vehicles accepting the gaps of mainline traffic flow in any section of a point x of acceleration lane with the intersectant traffic flow between on-ramp and shoulder lanes of mainlines.

In this paper, $Q_1(x)$ was the traffic volume of shoulder lanes corresponding the point x of acceleration lanes, and $Q_2(x)$ was the traffic volume of on-ramp. Vehicles from on-ramp could merge the mainline while it had a critical gap t_c in the mainline traffic flow, that is to say, $h \geq t_c$. Furthermore, if the headway of shoulder lanes satisfied $h \geq t_c + t_f$, double vehicles were allowed to merge the mainline. And also, if the headway

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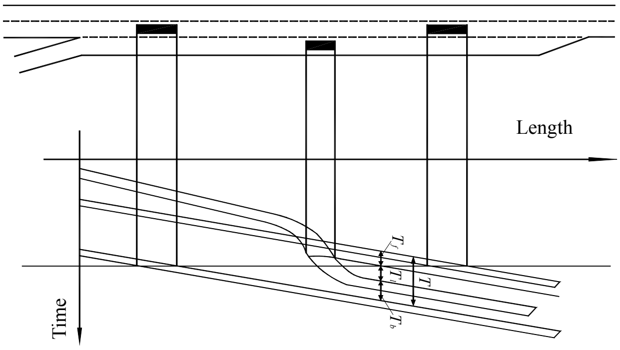

Fig. Critical headway for on-ramp junction

of shoulder lanes satisfied $h \geq t_c + nt_f$, $n+1$ vehicles were allowed to merge the mainline. Therefore, the capacity calculating model of any point from acceleration lanes of on-ramp junctions could be transformed to the capacity calculating model of mainline priority crossing with no signal.

3 Calculating model

$Q(t, x)$ was the inflow traffic flow acceleration lane to mainline shoulder lanes at the location x at the time of t, and $f(t, x)$ was the probability density function for the headway correspondingly. Thus, the maximum inflow volume at the location x from acceleration lanes was calculated by integration:

$$C(x) = Q_1(x)\int_0^{\infty} Q(t,x) f(t,x) dt \tag{1}$$

where $C(x)$ was the maximum inflow volume at the location x of acceleration lane (pcu/h).

The traffic flow from on-ramp $Q(t)$ merging mainlines could be described with discrete and continuous models, and in this paper, $Q(t)$ was described as the following continuous model:

$$Q(t) = \begin{cases} 0, & t < t_0 \\ \dfrac{t - t_0}{t_f}, & t \geqslant t_0 \end{cases} \tag{2}$$

$$t_0 = t_c - \frac{t_f}{2} \tag{3}$$

where t_c was the critical headway(s), and t_f was the following time (s).

From former studies, headways of shoulder lanes of on-ramp junctions followed Weibull distributions[5]. Therefore, inflow traffic volume of acceleration location x of on-ramp junctions was calculated by Eq. (4):

$$C(x) = \int_{t_0}^{\infty} Q_1(x)(\frac{t - t_0}{t_f})(\beta/\eta)[(t-\gamma)/\eta]^{\beta-1} \exp\{-[(t-\gamma)/\eta]^{\beta}\} dt \tag{4}$$

where β, η, and γ were respectively parameters of shape, dimension, and location.

The relationship between section volume of shoulder lane Q_1 and on-ramp volume Q_r, length from location x to triangular zone was expressed by Eq. (5), which was based on the mutiple regression analysis on the on-site survey urban freeway on-ramp junction data from seven domestic big cities, for instance, Beijing, Shanghai, Guangzhou, Shenzhen, etc.

$$Q_1 = 0.12Q_r + 0.012x - 40 \quad (R^2 = 0.82) \tag{5}$$

Hence, the possible capacity of on-ramp junction C was calculated by Eq. (6):

$$C = \int_0^L C(x)dx + Q_1 + C_m \tag{6}$$

where L was the length of acceleration lane (m); Q_1 was the passing volume of shoulder lanes of on-ramp junctions (pcu/h), and C_m was the possible capacity of the middle lane of mainlines (pcu/h).

On the basis of Eqs. (4), (5) and (6), on-ramp junction possible capacity calculating model for Chinese urban freeways was obtained by integral evaluation. However, this integral model could not be expressed by elementary function, and it was dealt with the numerical method of integration instead.

4 Parameters calibrating

4.1 Critical headway

In the gap-acceptance theory model, there were two key parameters, namely, the critical headway and the following time. In general, the critical headway was the major parameter, and the following time parameter could be computed with the linear relation model.

From the above analysis, the critical headway was defined with the method of improved Drew[6]. In this method, the average acceleration of standard cars was expressed by the linear relation model with merging speed, which was based on the assumption of inflow vehicles entering mainlines with the speed below or equal to the mainline flow speed. The critical headway of abouchement process for ramp vehicles was described by Fig.

In Fig., T was the critical headway of inflow vehicles; T_f was the safe headway between waiting for entering vehicles and mainline forward vehicles; T_b was the safe headway between the waiting for entering vehicles and the mainline following cars; T_l was the lost time because of the acceleration action when the entering mainline for the waiting for vehicles; Tm was the correction factor. According to the theory of kinematics, the critical headway of the merging process was calculated by Eq. (7):

$$T = T_f + T_b + T_l - T_m \tag{7}$$

And also, the safe deceleration time for vehicles to stop was calculated by Eq. (8):

$$T_f + T_b = (\frac{L_f}{v} + t_a) + (\frac{L_\gamma}{v} + t_a) = \frac{L_f + L_\gamma}{v} + 2t_a \tag{8}$$

where L_f and L_r were different for average vehicles' length of