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Study on the model of pedestrian cross-time in signalized intersection

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Abstract: For studying the law of pedestrian cross-time in the signalized intersection, based on gap theory, a probability chorological discipline model of crossing pedestrians is built based on the observed data. Moreover, the number of pedestrians passing through in a critical gap is estimated under different conditions by three models. Then the models of pedestrian crosswalk average time, the 85th percentile pedestrian cross-time and the 90th percentile pedestrian cross-time are deduced. By quantitative analyses and the exemplification of the models, the main correlative factors acting on pedestrian cross-time are found, including the length of the crosswalk, the probability of the time-headway being less than the critical gap and the number of the turned motor vehicles in the intersection. The results indicate that the estimated errors of the models are less than 5%.

Key words: signalized intersection; conflict; critical gap; pedestrian cross-time

At present, because conflicting technology is applied to deal with different problems, there are great differences in the explanations to the conflicts[1-4] of different countries and organizations. By studying the conflicts in the four-cross signalized intersection, the conflicts can be divided into seven types. And three kinds of conflicts among them are the most serious. They are the weaving between the left-turn motor vehicle and straight motor vehicle, the weaving between the left-turn non-motor vehicle and straight motor vehicle, and the weaving among pedestrians and the turned vehicles. The conflict action between the turned motor vehicles and pedestrians is analyzed in this paper, and models of the pedestrian cross-time are set up.

1 Distribution of Motor Vehicle's Time-Headway

The distribution characteristic of time-headway is an important component in traffic flow theory. Most of the distributed models are based on statistical distributions[5-7]. Liu et al.[8] summarized headway distribution models as shown in Tab. 1.

Tab. 1 Saturation degree, arriving time and distribution of time-headway

Saturation degree C_s	Arriving time	Distribution of time-headway $f(t_{hd})$
0. 5 to 0. 6	Random arrival of poisson distribution	Negative exponential distribution
0. 6 to 0. 7	Free traffic stream in condition without congestion	Lognormal distribution, Pearson Ⅲ distribution, and Erlang distribution
0. 7 to 0. 8	Free traffic stream and no-free traffic stream	Shift negative exponential distribution and lognormal distribution
0. 8 to 0. 9	No-free traffic stream in condition of congestion	Shift negative exponential distribution and lognormal distribution

2 Theory of the Gap for Passing Through

2.1 Critical gap t_c^p

The critical gap t_c^p refers to the minimal gap that permits waiting pedestrians to pass through in an uninterrupted flow at an intersection. According to the observed data of the gap abandoned or accepted by pedestrians in Tab. 2, if the percentage of the gap accepted by pedestrians portrays out from the middle point in every set of the gap, the depicted curve will approximate the cumulative normal curve. The distribution function is

$$F_p(t) = \frac{100}{\sigma_p\sqrt{2\pi}}\int_{-\infty}^{t}\exp\left[-\frac{(t-\bar{t}_p)^2}{2\sigma_p^2}\right]dt \qquad (1)$$

where $F_p(t)$ is the distributed function of percentage for t seconds' gap accepted by pedestrians; $\bar{t}_p$ is the average value of the accepted gap; σ_p is the deviation for the value of the accepted gap.

Tab. 2 Survey data of the gap which is abandoned or accepted by pedestrians

Time sets of the gap for passing through/s	Observed data of the gap abandoned	Observed data of the gap accepted	Percentage of the gap accepted/%
0. 25 to 1. 25	46	0	0
1. 25 to 2. 25	153	11	7
2. 25 to 3. 25	122	29	19
3. 25 to 4. 25	94	44	32
4. 25 to 5. 25	58	71	55
5. 25 to 6. 25	35	78	69
6. 25 to 7. 25	11	86	89
7. 25 to 8. 25	3	93	97
8. 25 to 9. 25	0	66	100

By χ^2 check, the results indicate that there are no obvious differences between the distributions of the observed values and the theoretical values. So it is proved that the accepted gap accords with the normal distribution. The mean value of the acceptable gap $\bar{t}_p$ is 4. 75 s, and normal deviation of the accepted gap σ_p is 1. 8 s.

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2.2 Concluding the numbers of passed and waiting pedestrians

In a signal cycle, the probability of time-headway in one motor lane which is less than critical gap t_c^p is given by

$$p_{tc}^p = \int_0^{t_c^p} f(t_{hd})\,dt \tag{2}$$

where p_{tc}^p is the probability of motor vehicle time-headway being less than t_c^p at a crosswalk of intersections; t_c^p is the time of the critical gap of a vehicle stream passed through by pedestrians; $f(t_{hd})$ is the function of the density distribution of motor vehicle time-headway.

Under normal conditions, n_{lag}^p pedestrians can pass through in t_c^p, which is estimated by

$$n_{lag}^p = S_{ahp} d = \frac{1}{2} B_{ha} b_a d = \frac{1}{2}(t_c^p - (t_{smp} + t_{spm}))\frac{1\,000 v_a}{3\,600} b_a d \tag{3}$$

where n_{lag}^p is the number of pedestrians passing through in t_c^p; S_{ahp} is the area supplied to the pedestrians in t_c^p, referring to Fig. 1, and is given by $S_{ahp} = \frac{1}{2} B_{ha} b_a$; d is the density when pedestrians pass through at traffic peaks, which is set as 0.45 person/m^2; B_{ha} is the distance between two motor vehicles, which is computed by

$$B_{ha} = (t_c^p - (t_{smp} + t_{spm}))\frac{1\,000 v_a}{3\,600} \tag{4}$$

where b_a is the lane width of a left-turn or a right-turn motor vehicle, which is chosen to be 3.5 m; t_{smp} is the safe time between pedestrians and passed motor vehicles, which is chosen to be 1.4 s; t_{spm} is the safe time between pedestrians and passing motor vehicles, which is set as 1.0 s; v_a is the average speed of vehicle flow uninterrupted in the intersection, which is set as 15 km/h.

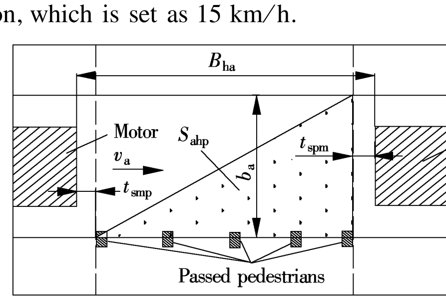

Fig. 1 The estimated value of the pedestrians crossing the road in the midst of turning vehicles

Substituting parameters into Eq. (3), the number of pedestrians passing through is equal to 4.7 in t_c^p. The value of n_{lr}^p should be a little more than that of n_{lag}, and here we take $n_{lr}^p = 5$.

For different numbers of lanes, the times of pedestrians passing through motor vehicles are different. The number of pedestrians passing through in a signal cycle will be respectively discussed for two and four lanes in the following.

In two-lane intersection, the number of the pedestrians passing through the merging flow of left turn and right turn vehicles is computed by

$$n^p = \left[(q_C^{lr} - 1)(1 - p_{tc}^p) + \frac{\Delta t}{t_c^p} \right] k^p \tag{5}$$

where n^p is the number of the pedestrians passing through in a signal cycle of a two-lane intersection; q_C^{lr} is the number of merging vehicles in a signal cycle at the intersection, which is computed by $q_C^{lr} = (q^l + q^r)C$; q_l is the motor vehicle flow of left turn vehicles at crosswalk (pcu/s); q_r is the motor vehicle flow of right turn vehicles at crosswalk (pcu/s); p_{tc}^p is the probability of motor vehicle time-headway being less than t_c^p at the crosswalk; Δt is the time that pedestrians pass through the conflict point before the motor vehicle comes up; k^p is the average number of pedestrians passing through in a gap longer than t_c^p, which can be set as 5.

In a four-lane intersection, the number of the pedestrians only passing through a left-turn and right-turn vehicle flow are, respectively, computed by the following Eqs. (6) and (7):

$$n_1^p = \left[(q^l C - 1) \times (1 - p_{tc1}^p) + \frac{\Delta t}{t_c^p} \right] k^p \tag{6}$$

where n_1^p is the number of pedestrians only passing through a left-turn vehicle flow in a signal cycle of a four-lane intersection; p_{tc1}^p is the probability of time-headway of left-turn motor vehicles being less than t_c^p at the crosswalk.

$$n_2^p = \left[(q^r C - 1)(1 - p_{tc2}^p) + \frac{\Delta t}{t_c^p} \right] k^p \tag{7}$$

where n_2^p is the number of pedestrians only passing through a right-turn vehicle flow in a signal cycle of a four-lane intersection; p_{tc2}^p is the probability of time-headway of right-turn motor vehicles being less than t_c^p at the crosswalk.

In a signal cycle of a four-lane intersection, the number of pedestrians who can pass through a left-turn vehicle flow and a right-turn vehicle flow at one time should be a minimal one between n_1^p and n_2^p, namely,

$$n^p = \min(n_1^p, n_2^p) \tag{8}$$

3 Model of Pedestrian cross-time at Intersection

3.1 Theoretical model

3.1.1 Model of pedestrian crosswalk average time

According to the distributed function of right-turn time-headway at the intersection and the probability of time-headway of right-turn motor vehicles being less than t_c^p, the model of a pedestrian's crosswalk average time can be given by

$$\bar{t}^p = \frac{b}{\bar{v}_p} + p_{tca}^p \frac{\left[\frac{B}{v_a} q_C^a + \bar{t}_{ha}(q_C^a - 1) \right] \eta_{qp}}{q_C^a} \tag{9}$$

where $\bar{t}^p$ is the pedestrian's crosswalk average time (s); b is the length of the crosswalk at intersection (m); $\bar{v}_p$ is the average speed of pedestrians at a crosswalk at intersection (m/s), chosen to be 1.4 m/s here; p_{tca}^p is the probability of time-headway of motor vehicles at intersection being less than t_c^p; B is the width of the crosswalk at intersection(m); v_a is the average speed of motor vehicles at intersection (m/s), which is set as 15 km/h; q_C^a is the number of motor vehicles passing through the crosswalk in a signal cycle. For a two-lane intersection, $q_C^a = q_C^{lr} = (q^l + q^r)C$; for a four-lane intersection, $q_C^a = qC^l$ or $q_C^a = q^rC$. $\bar{t}_{ha}$ is the average time-headway of motor vehicles at intersection(s). For a two-lane intersection, it is equal to the average time-headway of the merging flow at the crosswalk; and for a four-lane intersection, it is equal to the minimal one between the average time-headway of turn-left and turn-right motor vehicles at the crosswalk; η_{qp} is the coefficient of correction of the pedestrian flow.

3.1.2 Model of the 85th percentile pedestrian cross-time

In a similar way, if the distributed function of a right turn vehicle's time-headway is known, the model of the 85th percentile pedestrian cross-time can be given in the following form according to the pedestrian flow at the crosswalk (the number of pedestrians passing through in every cycle, person/c):

$$t_{0.85}^p = \frac{b}{\bar{v}_p 85\%} + p_{tca}^p \frac{\left[\frac{B}{v_a} q_C^a + \bar{t}_{ha}(q_C^a - 1)\right]\eta_{qp}\left(\frac{85\% q_C^p}{k_p \eta_d^p} - \frac{\Delta t}{t_c^p}\right)}{q_C^a} \tag{10}$$

where $t_{0.85}^p$ is the 85th percentile pedestrian cross-time at intersection(s); q_C^p is the number of pedestrians passing through in every cycle (person/c); η_d^p is the interrupted coefficient for pedestrian flow in different directions at the intersection, and its value can be set as 0.5 or so during the peak time of pedestrians passing through.

3.1.3 Model of the 90th percentile pedestrian cross-time

In a similar way, if the distributed function of right turn vehicle's time-headway is known, the model of the 90th percentile pedestrian cross-time can be deduced by

$$t_{0.90}^p = \frac{b}{\bar{v}_p 90\%} + p_{tca}^p \frac{\left[\frac{B}{v_a} q_C^a + \bar{t}_{ha}(q_C^a - 1)\right]\eta_{qp}\left(\frac{q_C^p 90\%}{k_p \eta_d^p} - \frac{\Delta t}{t_c^p}\right)}{q_C^a} \tag{11}$$

where $t_{0.9}^p$ is the 90th percentile pedestrian cross-time at intersection(s).

3.2 Exemplification

According to the survey data of pedestrian cross-time in thirty-four crosswalk lanes of nine intersections in Harbin city[9], the forenamed model of pedestrian cross-time is checked. Fig. 2 and Fig. 3 show the analysis results of the time errors.

In general, as the number of lanes at an exit increases, the time of pedestrians passing through increases and the delay also increases accordingly. Through comparing and analyzing the parameters of various models, it can be concluded that the cross-times of the 85th and 90th percentiles both increase more obviously than the pedestrian crosswalk average time with the increase in lanes.

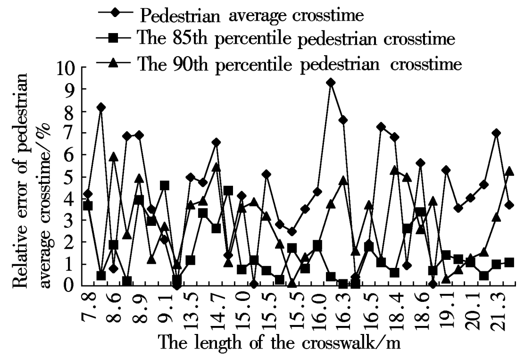

Fig. 2 The effect of the crossing width on the errors of the cross-time

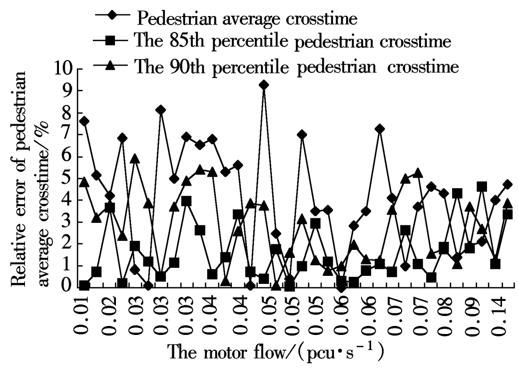

Fig. 3 The effect of the traffic flow on the errors of the cross-time

The errors of the models have an evident relationship with the length of the crosswalk and the probability of time-headway being less than t_c^p. The errors of the models of the 85th and 90th percentile pedestrian cross-times are both related to the number of turned motor vehicles. Other factors have little effect on the errors of the models. In addition, the absolute error and relative error of pedestrian average cross-time are 0.452 7 s and 4.15%, respectively; absolute error and relative error of the model of the 85th percentile pedestrian cross-time are 0.206 5 s and 1.57%, respectively; absolute error and relative error of the model of the 90th percentile pedestrian cross-time are 0.401 2 s and 2.84%, respectively. From the above, the estimate of the models is comparatively accurate. If it is necessary to enhance the model precision, it would be reasonable to substitute the adjustment parameters of the lengths of the crosswalks and the time-headways into the models, especially when crosswalk is too long or too short and the probability of time-headway being less than t_c^p does not reach 41%.

4 Conclusion

Based on the theory of the gap for passing through and the chorological discipline of pedestrians passing through by the observed data, the model of pedestrian crosswalk average time, the model of the 85th percentile pedestrian cross-time and the model of the 90th percentile pedestrian cross-time are built up. By quantitative analyses and the exemplification of the models, the main correlative factors and their measurable relations are found according to survey data of pedestrian cross-times in thirty-four crosswalk lanes of nine intersections in Harbin city. The results indicate that the model precision can meet the requirements. However, it is discounted that the relationships between the pedestrian cross-time and pedestrian attributes are not accounted for in the models. And it will be solved in future work.

References

[1] Yang Xiaoguang, Pu Wenjing, Long Liang. Traffic signal warrant study based on traffic conflict analysis for uncontrolled intersections[J]. *Journal of Tongji University*: *Natural Science*, 2005, **33**(12): 1596 − 1599. (in Chinese)

[2] Xu Liangjie. Research on the optimization control technology for single signalized-intersection[D]. Nanjing: School of Transportation of Southeast University, 2005. (in Chinese)

[3] Jardin Matt R. Grid-based strategic air traffic conflict detection[C]//*Collection of Technical Papers*: *v*1, *AIAA Guidance*, *Navigation*, *and Control Conference* 2005. Reston: American Institute of Aeronautics and Astronautics Inc., 2005: 60 − 70.

[4] Li Suyan, Yang Dongyuan, Xiong Qian. The relationship model between traffic volume and traffic conflict at the merging points of urban tunnel entrance [C]//*International Conference on Transportation Engineering* 2007. Reston: American Society of Civil Engineers, 2007: 980 − 985.

[5] Rui Neves-Silva, Maria Marques. Traffic flow-density models based on systems theory[C]//*Proceedings of the* 2007 *American Control Conference*. Piscataway: Institute of Electrical and Electronics Engineers Inc., 2007: 3139 − 3143.

[6] Cowan R J. Useful headway models[J]. *Transportation Research*, 1975, **9**(6): 371 − 375.

[7] Daamen Winnie, Hoogendoorn Serge P, Bovy Piet H L. First-order pedestrian traffic flow theory[J]. *Transportation Research Record*, 2005, **1934**: 43 − 52.

[8] Liu Jiang, Lü Jinyan, Rong Jian, et al. Headway distribution models and their application on two-lane highway in mountainous areas [J]. *Journal of Transportation Engineering and Information*, 2004, **2**(4): 16 − 22. (in Chinese)

[9] Huang Wenzhong, Yang Peikun. Delays of pedestrians and vehicles at the non-signalized zebra crossing [J]. *Journal of Tongji University*: *Natural Science*, 1995, **23**(1): 31 − 36. (in Chinese)

信号交叉口行人穿越时间模型研究

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摘要:为了研究信号交叉口行人穿越时间的特性规律,应用间隙理论和实际观测数据,建立了行人穿越的概率统计模型.进而建立了3种不同穿越条件下行人穿越数的估算模型.在此基础上,构建了行人平均过街时间模型、第85分位行人过街时间模型和第90分位行人过街时间模型.采用定量分析和模型实证分析方法,发现行人穿越的主要影响因素有:人行过街横道长度、车头时距小于临界间隙的概率以及交叉口内的转弯车辆数.结果表明模型估计误差均小于5%.

关键词:信号交叉口;冲突;临界间隙;行人穿越时间

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