Journal of Southeast University (English Edition) Vol. 22, No. 4, pp. 564 – 569 Dec. 2006 ISSN 1003—7985

Method for pedestrian signal timing at signalized intersections

Wang Jingyuan[1,2] Wang Wei[1]

([1]School of Transportation, Southeast University, Nanjing 210096, China)

([2]College of Civil Engineering, Shenzhen University, Shenzhen 518060, China)

Abstract: The pedestrian timing at signalized intersections is studied aiming at the problems of the inconsistency of the vehicular and pedestrian timing requirements and the insufficiency of pedestrian clearance. Based on the formulae of WALK and flashing DON'T WALK (FDW) in the highway capacity manual (HCM), the relationship between pedestrian signal indications and vehicular signal indications is discussed using the theory of traffic flow. Then, methods of pedestrian timing for different cases are established, particularly the methods of the pedestrian green adjustment. Ways of pedestrian crossing are analyzed for roadways with different forms and widths of the median island. The sampling values of calculation parameters are studied, and the recommended formulae of pedestrian timing for different conditions are presented.

Key words: signalized intersection; pedestrian signal timing; WALK indication; flashing DON'T WALK indication

Conventional practice generally allows pedestrians to cross a street during the vehicular indications at a signalized intersection. This requires that pedestrians must also be considered by the signal timing and that pedestrians should be assured of sufficient time to accommodate safe crossings. Vehicular and pedestrian timing requirements are often quite inconsistent. Consider the intersection of a wide major arterial and a small minor collector is illustrated in Fig. 1. Vehicle demand on the major arterial is more intense than on the minor collector, and the green split for vehicles generally results in the arterial receiving a long green and the collector a relatively short green. Unfortunately, this is exactly the opposite of what pedestrians require. Pedestrians, however, cross the wider major arterial during the short minor collector vehicular phase, and the narrower collector during the long major arterial vehicular phase[1-2]. In summary, pedestrians require a longer green during the shorter vehicular green, and a shorter green during the longer vehicular green. Otherwise, the unreasonable time distribution ratio is a ubiquitous problem of pedestrian timing in Chinese cities. The pedestrian phase is mostly a green indication; however, the pedestrian clearance interval is only about 3 s. The law on road traffic safety of China presents the pedestrian right of way as follows: Pedestrians are permitted to cross the crosswalk during the green indication; a pedestrian shall not start to cross the roadway, but any pedestrian who has entered the crosswalk shall continue to complete their crossing, or stop at the median line and wait[3]. Pedestrians entering the crosswalk at the end of the green cannot cross the roadway safely and are locked in vehicular lanes due to insufficient clearance time. This causes serious safety problems and blocks vehicular operation.

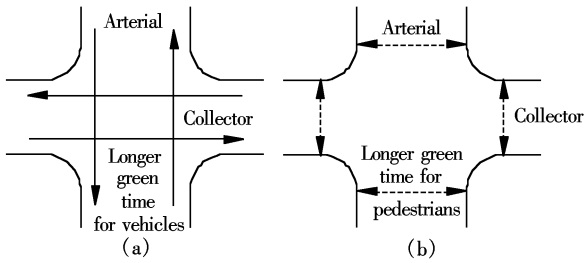

Fig. 1 Vehicle and pedestrian signal requirements. (a) Vehicular requirements; (b) Pedestrian requirements

In practice, the objective is to base signal timing on vehicular requirements, and less attention is paid to pedestrian requirements. Aiming at the existing problems and insufficient pedestrian clearance, pedestrian signal timing at signalized intersections is studied using the traffic flow theory. Then, the adaptive method and suggestions for pedestrian timing in China are presented.

1 Pedestrian Timing

1.1 Pedestrian phase components

The rounded pedestrian phase is composed of

Received 2006-03-16.

Foundation item: The National Natural Science Foundation of China (No. 50378016).

Biographies: Wang Jingyuan (1977—), male, doctor; Wang Wei (corresponding author), male, professor, wangwei@seu.edu.cn.

WALK indication, flashing DON'T WALK (FDW) indication and DON'T WALK (DW) indications. WALK indication means that pedestrians may begin to cross the roadway in the direction of the indication. Flashing DON'T WALK indication means that a pedestrian shall not start to cross the roadway in the direction of the indication, but that any pedestrian who has partly completed their crossing shall continue to a sidewalk, or to a safety island, so FDW is also named as pedestrian clearance. Steady DON'T WALK indication means that any pedestrian shall not cross. Some jurisdictions use a flashing WALK instead of a constant WALK indication where right-turning vehicles will conflict with crossing pedestrians[1]. Pedestrians are permitted to cross the crosswalk during the WALK and FDW indication. That is to say pedestrian phase crossing time is composed of WALK and FDW, for short pedestrian phase time. The pedestrian phase time must be sufficient to accommodate safe crossings for pedestrians with an assumed speed. So, parameters including WALK and FDW must be determined properly, and this is the main task of this paper.

1.2 WALK

WALK should be sufficient for all pedestrians waiting in one cycle to leave the curb and enter an intersection. According to pedestrian traveling characteristics, WALK is determined as the sum of two components, including the reaction time and the time for people to enter the crosswalk:

$$\mathrm{WALK} = t_r^p + \frac{N_p}{S_p W_E} \tag{1}$$

where WALK is the pedestrian green time (s); t_r^p is the pedestrian reaction time (s); N_p is the number of pedestrians crossing a single crosswalk during an interval (p); S_p is the pedestrian flow rate, namely the number of pedestrians crossing per second in unit width (p/(m·s)); W_E is the effective crosswalk width (m).

In Eq. (1), t_r^p and S_p are two key parameters. The value of S_p is uncertain in China at present, and there are only some theoretical studies[4]. Surveys indicate that S_p varies with trip intention and intersection properties etc[5]. It is recommended that $t_r^p = 3.2$ s and $S_p = 1.23$ p/(m·s) in the highway capacity manual[6], and the following minimum green-time requirements for pedestrian are suggested:

$$\mathrm{WALK} = \begin{cases} 3.2 + 0.81\dfrac{N_p}{W_E} & W_E > 3.0\ \mathrm{m} \\ 3.2 + 0.81\dfrac{N_p}{3.0} = 3.2 + 0.27N_p & W_E \leqslant 3.0\ \mathrm{m} \end{cases} \tag{2}$$

It is the minimum WALK provided by this equation. However, N_p is unknown before the cycle length is determined. Foreign practices[1,7-8] indicate that under normal conditions, the WALK interval should be at least 4 to 7 s in length so that pedestrians will have adequate opportunity to leave the curb before the clearance interval is shown, and that pedestrian queues requiring more than 7 s to discharge occur very rarely and will usually be found only in certain sections such as around a school. When the minimum WALK interval calculated is short under low volume conditions, the adopted value under 5 s is inadvisable and cannot be shorter than 4 s, however, the importance of the inattentiveness factor should also be weighted in this decision. It is common that pedestrian volume is large in China, and the WALK needed is longer.

1.3 Flashing DON'T WALK

The FDW is to clear pedestrians and accommodate safety crossings for pedestrians just starting to cross the street at the end of the WALK indication. The FDW can be determined by

$$\mathrm{FDW} = \frac{L_c}{S_{15}^p} \tag{3}$$

where FDW is the flashing DON'T WALK interval (s); L_c is crossing distance (m); S_{15}^p is the 15th-percentile walking speed of pedestrians (m/s).

Generally speaking, L_c takes the length of the crosswalk as the default, and it is the distance from the near curb or shoulder to the farthest conflict point, strictly speaking. When determining the distance, consideration should be given to the pedestrian's normal walking path. Research indicates[9] that far-side right turn lanes and parking lanes should be included in the crossing distance.

In selecting a walking speed, consideration must be given to the type of pedestrians, volume of pedestrians, intersection location and geometrics, and overall signal operation. The 15th-percentile pedestrian speed is generally used as the walking speed in this computation. The commonly accepted value of S_{15}^p is 1.2 m/s recommended by the Institute of Transportation Engineers (ITE)[9]. This value should be used

unless site-specific conditions suggest otherwise. In some specific conditions such as a large proportion of school-age children, handicapped and elderly pedestrians (65 years of age and older) in the walking population, a lower value is accepted. For example, if a significant number of elderly pedestrians routinely cross at an intersection, a walking speed of 1.0 m/s is recommended.

2 Relationship between Pedestrian Signal Indications and Vehicular Signal Indications

The pedestrian phase time g_p is the sum of WALK and FDW:

$$g_p = \text{WALK} + \text{FDW} \tag{4}$$

If WALK and FDW are calculated by Eqs. (2) and (3), respectively, then the sum is the minimum pedestrian phase time needed $g_p^{\min}$:

$$g_p^{\min} = \begin{cases} 3.2 + 0.81\dfrac{N_p}{W_E} + \dfrac{L_c}{S_{15}^p} & W_E > 3.0 \text{ m} \\ 3.2 + 0.27N_p + \dfrac{L_c}{S_{15}^p} & W_E \leqslant 3.0 \ m \end{cases} \tag{5}$$

The vehicular phase time T is the sum of green time displayed and the intergreen interval I[10]. The I has two components of yellow interval Y and all-red interval AR, sometimes, only AR:

$$T = g + I = g + Y + \text{AR} \tag{6}$$

For a signal timing to be viable for pedestrians, the vehicular phase time cannot be shorter than the pedestrian phase time in each phase:

$$g_p^{\min} \leqslant T = g + I = g + Y + \text{AR} \tag{7}$$

According to the pedestrian clearance interval and the vehicular intergreen interval, the relationship between pedestrian signal indications and vehicular signal indications has two basic modes (see Fig. 2 and Eq. (8)): ① Any pedestrian is forbidden to cross during the vehicular intergreen interval, and the clearance of pedestrians is only in progress during the vehicular green interval, that is to say, the flashing DON'T WALK and vehicular green end at the same time, and the DON'T WALK is displayed onset yellow; ② The vehicular intergreen interval may be included in the pedestrian clearance time, that is to say, the flashing DON'T WALK and all-red/yellow end at the same time, and the DON'T WALK is displayed onset red.

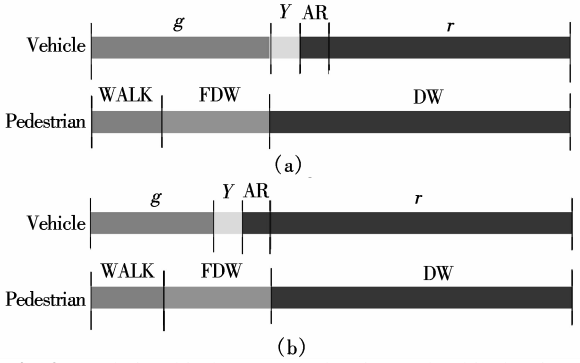

Fig. 2 Relationship between pedestrian and vehicular timing. (a) FDW and vehicular green end at the same time; (b) FDW and all-red end at the same time

$$g_p = \begin{cases} g & \text{vehicular intergreen interval included in pedestrian clearance} \\ g + I = g + Y + \text{AR} & \text{vehicular intergreen interval not included in pedestrian clearance} \end{cases} \tag{8}$$

Through Fig. 2 and Eq. (8), it is known that two modes are applicable for different cases: ① If the length of the vehicular phase is sufficient and the green displayed is not less than minimum pedestrian phase time needed, the pedestrian phase can be concluded with either the vehicular green or the all-red; that is to say, if $g \geqslant g_p^{\min}$ is met, anyone of (a) and (b) can be chosen; ② Otherwise, if the length of the vehicular phase is insufficient and the green displayed is shorter than the minimum pedestrian phase time needed, the pedestrian phase can be only concluded with the vehicular all-red, that is to say, if $g < g_p^{\min} \leqslant g + Y + \text{AR}$, only (b) can be used.

As a general practice, the length of vehicular green displayed is not less than the minimum pedestrian phase time needed, and the vehicular intergreen interval cannot be included in the pedestrian clearance time unless the phase length is restricted, but the length of the vehicular phase cannot be less than the minimum pedestrian phase time needed (see Eq. (7)). It is obvious that the length of the vehicular phase is a key parameter determining the relationship between pedestrian and vehicular timing. The value calculated by Eqs. (2), (3) and (5) is the minimum pedestrian phase time needed. From Eq. (8), it is known that parameters of the minimum pedestrian phase can be adjusted using Eqs. (4) and (8) according to the selected mode if the length of the vehicular phase is longer than the minimum pedestrian phase time needed. The commonly accepted method is to maintain FDW calculated by Eq. (3) unchanged and recalculate WALK calculated by Eq. (2). The following is a detailed discussion.

1) If $g \geqslant g_p^{\min}$

① Mode (a) is used

The WALK and FDW calculated respectively by Eqs. (2) and (3) need not to be adjusted if $g = g_p^{min}$, and if $g > g_p^{min}$, the WALK is adjusted according to $g_p = g$ maintaining FDW unchanged:

$$\text{WALK} = g - \text{FDW} = g - \frac{L_c}{S_{15}^p} \tag{9}$$

② Mode (b) is used

The WALK is adjusted according to $g_p = g + Y + \text{AR}$:

$$\text{WALK} = g + Y + \text{AR} - \text{FDW} = g + Y + \text{AR} - \frac{L_c}{S_{15}^p} \tag{10}$$

2) If $g < g_p^{min} \leqslant g + Y + \text{AR}$

The WALK and FDW calculated respectively by Eqs. (2) and (3) need not to be adjusted if $g_p^{min} = g + Y + \text{AR}$, and if $g < g_p^{min} < g + Y + \text{AR}$, the WALK is adjusted using Eq. (10).

3) If $g_p^{min} > g + Y + \text{AR}$

If Eq. (7) is not met, the vehicular phase interval cannot accommodate safety pedestrian crossings, and then the traffic engineer may retime the signal resulting in a longer cycle and phase length to satisfy the requirement. Another approach of installing pedestrian buttons may be feasible where actuated signal controllers are used[1-2].

3 Pedestrian Timing Practice

3.1 Single roadway and divided roadway with a median island less than 2 m wide

A median island less than 2 m wide is not considered a safe refuge island, so a single roadway without a median or a street with a median less than 2 m wide should be the same in pedestrian timing. For this case, pedestrians should be provided sufficient time to cross the street completely in one cycle and pedestrian indications should be installed on each side. The WALK and FDW are calculated by Eqs. (2) and (3), respectively. When parameters used for calculation are unknown, pedestrians may be provided time for crossing a roadway: ① WALK = 7 s, and this may be reduced to 4 s if it is necessary to minimize pedestrian timing considering the other factors; ② Generally, FDW should not be less than WALK time and the vehicular intergreen interval can be included in the pedestrian clearance time if the phase length is restricted.

3.2 Divided roadway with a median island over 2 m wide

A median over 2 m wide can accommodate pedestrians with a safety refuge. For this condition, two ways may be used for pedestrian timing: crossing in two cycles and crossing in one cycle.

1) Crossing in two cycles

If it is difficult for pedestrians to cross the crosswalk in one cycle due to the width of the road or the length restriction of the vehicular phase, timing can accommodate a safe crossing in two cycles, where medians or other channelizing islands are sufficient to provide pedestrian refuge. The pedestrian will cross to the median in one cycle and stop to wait at the median island, and then cross to the other side in the next cycle. The pedestrian phase time must be sufficient for two-way crossing, so, the pedestrian timing is determined according to the roadway need for longer time. The WALK and FDW will be calculated as above. The crossing distance L_c should be determined by using the longest distance from one side to the median. The distance may be from the roadside to the far side of the median or to the near side viewing the practical situation. Generally, the latter will meet the requirements of crossing in two cycles (see Fig. 3 and Eq. (11)).

$$L_c = \begin{cases} \max(D_1, D_2) \\ \max(d_1, d_2) \end{cases} \tag{11}$$

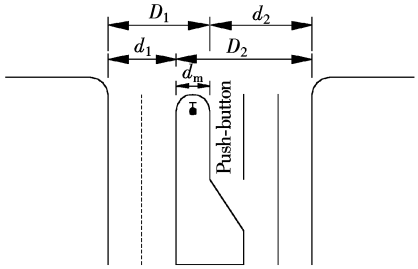

Fig. 3 The crossing distance for pedestrian timing

2) Crossing in one cycle

The common median island cannot accommodate sufficient space for waiting under high pedestrian volume conditions. Therefore, the pedestrian should be provided sufficient time to cross the total roadway in one cycle under possible conditions. It is important to maintenance an appropriate ratio of WALK to FDW for preventing pedestrians to cross against traffic regulations owing to the excessive length of FDW. In order to cross the total roadway, the pedestrian must pass or reach the median island before the Flashing DON'T WALK is displayed. If pedestrians reach the roadside during the WALK indication or begin to startup at the end of the pedestrian green time, thus

not being able to reach the median island when the Flashing DON'T WALK is displayed, the pedestrians should stop at the median island and wait till the next WALK indication appears. That is to say, the WALK indication should take all the pedestrians waiting in the DON'T WALK indication past or reach the median island before the Flashing DON'T WALK is displayed, and the Flashing DON'T WALK indication should take the pedestrians to pass the median island in the WALK indication, cross the crosswalk and begin to startup at the end of the pedestrian green time and reach the median island before the DON'T WALK is displayed. The following special timing should allow the pedestrian to cross both roadways:

$$\text{WALK} = \begin{cases} 3.2 + 0.81\dfrac{N_p}{W_E} + \dfrac{\max(d_1, d_2)}{S_{15}^p} & W_E > 3.0 \text{ m} \\ 3.2 + 0.27N_p + \dfrac{\max(d_1, d_2)}{S_{15}^p} & W_E \leqslant 3.0 \text{ m} \end{cases} \tag{12}$$

$$\text{FDW} = \frac{\max(D_1, D_2)}{S_{15}^p} \tag{13}$$

The pedestrian phase time can make all the pedestrians waiting at the roadside cross the total roadway in one cycle. If it is difficult for the length restriction of the vehicular phase, part of the pedestrians can be provided sufficient time to cross the total roadway in one cycle and the other timing can accommodate a safe crossing in two cycles. The WALK and FDW are calculated by Eqs. (14) and 15, respectively:

$$\text{WALK} = \begin{cases} \max\left[\left(3.2 + 0.81\dfrac{N_p}{W_E}\right), \dfrac{\max(d_1, d_2)}{S_{15}^p}\right] \\ \qquad W_E > 3.0 \text{ m} \\ \max\left[(3.2 + 0.27N_p), \dfrac{\max(d_1, d_2)}{S_{15}^p}\right] \\ \qquad W_E \leqslant 3.0 \text{ m} \end{cases} \tag{14}$$

$$\text{FDW} = \frac{\max(D_1, D_2)}{S_{15}^p} \tag{15}$$

All the discussions in the section are focused on the requirements of the minimum pedestrian phase time. If the vehicular phase time is longer than the minimum pedestrian phase time, then the parameters of pedestrian timing can be adjusted according to the methods introduced in section 2.

4 Conclusion

As the subject of this paper, the pedestrian timing at signalized intersections is studied aiming at the problems of the inconsistency of the vehicular and pedestrian timing requirements and the insufficiency of pedestrian clearance. Based on the formulae of the WALK and FDW in HCM, the relationship between pedestrian signal indications and vehicular signal indications is discussed in detail using the traffic flow theory. The vehicular phase time cannot be shorter than the pedestrian phase time in each phase; the pedestrian phase time equals the vehicular green or the vehicular phase time. Then, methods of pedestrian timing for different cases are established, particularly the methods of the pedestrian green adjustment. Pedestrian crossing ways are analyzed for roadways with different forms and widths of the median island. It is suggested that the pedestrian should be provided sufficient time to cross the street completely in one cycle for single roadways without a median or a street with a median less than 2 m wide, and the pedestrian may be provided sufficient time to cross the street in one cycle or in two cycles in the case of a median over 2 m wide. The sampling value of calculation parameters such as the crossing distance is studied, and the recommended formulae of pedestrian timing for different conditions are presented. In application, the appropriate option is selected according to the realities. The research outcome has important practical value. This presents a systematic approach of pedestrian signal timing at signalized intersections for the technical personnel engaged in traffic management. This makes the vehicular and pedestrian timing consistent and provides a traffic environment for pedestrian safety and vehicle smooth running.

References

[1] Mcshane William R, Roess Roger P, Prassas Elena S. *Traffic engineering* [M]. 2nd ed. New Jersey: Prentice-Hall, 1998.

[2] Roess Roger P, Prassas Elena S, Mcshane William R. *Traffic engineering* [M]. 3rd ed. New Jersey: Prentice-Hall, 2004.

[3] PRC National People's Congress Council. *Implication regulations of the law on road traffic safety of the PRC* [M]. Beijing: China Communications Press, 2004. (in Chinese)

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

[5] Lu Huapu. *Modernization management of urban traffic* [M]. Beijing: China Communications Press, 1999. (in Chinese)
[6] Transportation Research Board. Highway capacity manual (HCM) 2000 [R]. Washington, DC: National Research Council, 2000.
[7] Research Management Center. Florida intersection design guide for new construction and major reconstruction of at-grade intersections on the state highway system[R]. Florida: Florida Department of Transportation (FDOT), 2002.
[8] Federal Highway Administration. Manual on uniform traffic control devices for street and highways (MUTCD) 2003[R]. Washington, DC: Department of Transportation, 2003.
[9] Minnesota Department of Transportation (MnDOT). MnDOT traffic signal timing and coordination manual[R]. Minnesota, 2004.
[10] Quan Yongshen. *Urban traffic control* [M]. Beijing: China Communications Press, 1989. (in Chinese)

信号交叉口行人相位配时方法

王京元[1,2] 王 炜[1]

([1] 东南大学交通学院,南京 210096)
([2] 深圳大学土木工程学院,深圳 518060)

摘要:以信号交叉口行人相位配时为研究对象,针对信号交叉口行人和机动车对配时要求不一致以及我国行人相位清空时间不足的问题,借鉴 HCM 中行人绿灯最小时间和行人闪时间的计算公式,利用交通流理论,分析了行人相位和机动车相位关系,并建立了不同情况下行人信号配时方法,尤其是行人绿灯时间的调整方法. 讨论了不同中央分隔带形式和宽度的行人过街方式,对计算参数的取值进行了研究,在此基础上,给出了不同情况下建议的行人配时计算模型.

关键词:信号交叉口;行人信号配时;行人绿灯;行人闪
中图分类号:U491.5^{+}4