Analysis of Pedestrian Clearance Time at Signalized Crosswalks in Japan

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Abstract

At signalized crosswalks, pedestrian clearance time is a key design parameter for ensuring safe pedestrian crossing. It is generally defined as the time required by pedestrians who enter crosswalks at the end of the green indication to complete crossing before conflicting vehicular traffic movements are released. In Japan, pedestrian green indications are followed by pedestrian flashing green (PFG) indications during which time pedestrians are not allowed to start crossing and those in the crosswalk have to finish crossing to either side of the crosswalk; as such, some pedestrians are expected to return to the side they came from. Therefore, PFG intervals are designed to be shorter than the necessary clearance time. Instead, relatively longer red buffer intervals (BI) are provided between the end of the PFG and the succeeding vehicle green indication. This study clarifies the differences between signal setting concepts in various countries and analyses pedestrian clearing behaviors under the Japanese signal control system. Empirical analyses show that the current PFG and BI settings in Japan are shorter than the necessary clearance time and the settings in the US and Germany. As a result, most observed pedestrians who started crossing after the onset of PFG cannot finish crossing before its end and cannot even finish before the succeeding vehicle green indication.

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1. Introduction

Pedestrian safety at intersections with signalized crosswalks is an important issue. In Japan, more than one-third of fatalities in traffic accidents were pedestrians\textsuperscript{1}. Although signalized crosswalks are operated such that pedestrians’
right of way is prioritized, 29% of pedestrian fatalities (42% of elderly fatalities) can be attributed to illegal crossing behavior. This is evident from the staggeringly high number of injuries and fatalities resulting from pedestrian-vehicle crashes worldwide.

Pedestrian clearance time is a key design parameter for ensuring safe pedestrian crossing at signalized crosswalks. Although different countries follow different patterns of signal indications for clearance time, such as “DON’T WALK” in the US and a red indication in Germany, clearance time is generally defined as the time required by pedestrians who enter the crosswalk at the end of the green indication to complete crossing before conflicting vehicular traffic movements are released. In Japan, the pedestrian green indication is followed by the pedestrian flashing green (PFG) indication; therefore, one may consider PFG corresponds to the above definition of clearance time. However, according to the definition, pedestrians on crosswalks during PFG have to immediately finish crossing to either side of the crosswalk; this means that pedestrians who have not finished crossing the first half of the crosswalk at the onset of PFG are expected to return to the side where they come from. Therefore, a much shorter PFG is applied in Japan than in other countries. However, most pedestrians do not follow this rule and try to complete crossing the crosswalk. This mismatch between the definition and the pedestrian behavior leads to many pedestrians remaining on crosswalks at the end of the pedestrian phase.

Zegeer et al. showed that pedestrian signal violations show no significant differences between flashing and steady “DON’T WALK” indications. However, studies have not yet discussed pedestrian behavior under different lengths of indications. Although several studies have discussed Japanese signal indications, they mainly focused on the number of pedestrians remaining at the end of the PFG without analyzing the required clearance time.

This study aims to analyze the pedestrian clearing behavior under the Japanese signal indication system and the necessary clearance time through empirical data. Section 2 summarizes design concepts of pedestrian signal settings in Japan and other countries. Section 3 introduces the study sites and survey settings. Section 4 presents the results of empirical analyses. Section 5 presents the discussions and conclusions.

2. Design concepts of pedestrian signal settings

This section overviews theoretical and practical design concepts of pedestrian signal settings. Theoretically, the pedestrian phase consists of a discharge time and a clearance time, as explained in Subsection 2.1. Subsection 2.2 summarizes differences among the definitions of signal indications in the US, Germany, and Japan. Subsection 2.3 shows how these indications correspond to the discharge and clearance times and how they are designed.

2.1. Required time for pedestrian phase

2.1.1. Discharge time

The discharge time is the time required for pedestrians to leave the curb or shoulder. If there is a queue owing to high pedestrian demand, sufficient discharge times need to be provided so that all pedestrians waiting at the curb or the shoulder will have adequate opportunity to start crossing. Accordingly, the necessary discharge time can be the sum of a certain constant response time for the first pedestrian to start crossing and the queue discharging time, which would be a function of pedestrian demand and crosswalk width.

2.1.2. Clearance time

The clearance time is ideally designed so as to avoid collisions between pedestrians and vehicles entering in the subsequent phase. Therefore, the conflict area where the paths of pedestrians and vehicles overlap is focused upon. In ordinary four-phase intersections, the pedestrian phase is followed by a protected right-turning vehicle phase (note: subsequent discussions are based on left-hand traffic as applied in Japan). Then, the area highlighted in Fig. 1 is considered the conflict area.

For further discussion, the terms “near-side” and “far-side” are defined based on the conflict area. Near-side means the side where pedestrians and exiting right-turning vehicles can conflict, and far-side is the other side. In addition, pedestrians whose origin is the near-side and far-side are called near-side and far-side pedestrians, respectively (corresponding to Pedestrians A and B in Fig. 1). Near-side pedestrians can pass through the conflict area in the first half of crossing. Therefore, the necessary clearance time for them is the time required to go through
half of the crosswalk in this case. Meanwhile, far-side pedestrians need to complete crossing to pass the conflict area. Therefore, they need sufficient clearance time to cross the entire crosswalk length.

2.2. Definitions of pedestrian signal indications

The US system has three types of pedestrian signal indications: “WALK,” flashing “DON’T WALK,” and “DON’T WALK.” According to MUTCD, the “WALK” indication means that “a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning vehicles.” A flashing “DON’T WALK” means that “a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a WALK signal indication shall proceed to the far side of the traveled way of the street or highway.” “DON’T WALK” means that “a pedestrian shall not enter the roadway in the direction of the signal indication.” The flashing “DON’T WALK” signal starts immediately after the end of the “WALK” signal.

The German system does not have dedicated indications for clearance time; it uses green and red indications. At green indications, pedestrians can start crossing, and they should not enter the crosswalk at red indications. In Japan, pedestrian signal indications consist of green, flashing green, and red indications. Green indications mean that pedestrians can start crossing. Flashing green indications mean that pedestrians should not start to cross; those who are on crosswalks should complete crossing immediately or give up crossing and return to the origin curb. Red indications mean that pedestrians should not start crossing.

2.3. Designed time intervals for signal indications

In the US, the “WALK” interval is typically >7 s (MUTCD) so that pedestrians can leave the curb or shoulder before the pedestrian clearance time begins. An at least 3-s long buffer interval (BI), which is a part of the steady “DON’T WALK” indication, is provided immediately after the end of the flashing “DON’T WALK” indication. The BI is provided before releasing any conflicting vehicular movement. The pedestrian clearance time is given by the sum of the flashing “DON’T WALK” and BI. Clearance time $t_u$ is the time required to finish crossing at a walking speed of 3.5 feet/s (=1.07 m/s). Given crosswalk length $L$ and walking speed $V$, it is written as

$$t_u = \frac{L}{V} \quad (1)$$

In Germany, the minimum pedestrian green interval is set so that pedestrians can cross at least half the crosswalk length. Pedestrian clearance time, which is covered by the beginning of the pedestrian red interval, is designed as
\[ t_y = \frac{L_{cp}}{V} \]  

where \( L_{cp} \) is the clearing distance, i.e., the distance between the entering curb and the conflict area. In ordinary intersections such as that shown in Fig. 1, \( L_{cp} \) is equivalent to \( L \). \( V \) is usually set as 1.2 m/s (1.0 m/s for handicapped or elderly people) and as 1.5 m/s at most.

In Japan\(^6\), the minimum pedestrian phase interval \( t_j \) is determined by

\[ t_j = \frac{L}{V} + \frac{p}{sW} \]  

where \( p \) is the number of queuing pedestrians at the onset of pedestrian green indication; \( s \), the saturation flow of pedestrians per unit width; and \( W \), the crosswalk width. The first and second terms of this equation correspond to the clearance time and discharging time, respectively. The sum of the pedestrian green and PFG should be greater than \( t_j \).

The PFG length is calculated by \( L/2V \), which guarantees that pedestrians on a crosswalk can go out either edge of the crosswalk. \( V \) is set as 1.0 m/s if many elderly pedestrians are present; however, 1.5 m/s is practically applied. At Japanese signalized intersections, there is an interval between the end of PFG and the end of the associated vehicle green to provide turning vehicles with right-of-way without conflicting with pedestrians. Usually, it is 1–5 s long, although it can be greater under high traffic of turning vehicles. This is followed by vehicle amber and clearance times before the onset of the successive vehicle green phase. Thus, the BI length is their sum, as shown in Fig. 2.

2.4. Discussions on clearance time settings

Fig. 2 shows the designated pedestrian indication. For simplicity, pedestrian demand is neglected and the same walking speed \( V \) is assumed in the comparison. In the US, time \( L/V \) is provided for pedestrians who start crossing at the end of green before the start of the successive vehicle phase. In Germany, time \( L/V \) minus the vehicle entering time is provided, which is the time for the first entering vehicle in the successive phase to arrive at the conflict area.

![Diagram](image-url)

Fig. 2. Illustration of signal indications and their intervals in US, Germany and Japan
In both cases, necessary clearance time is provided to pedestrians. In Japan, the time interval between the end of pedestrian green and the onset of the successive vehicle green phase is $L/2V + BI$. However, $L/2V + BI$ is often lower than $L/V$, the necessary clearance time for pedestrians who enter at the end of pedestrian green to finish crossing. $BI$ is determined by the amber and the clearance time of the associated vehicle phase as well as the demand of left-turning vehicles without any consideration of pedestrian-related variables.

3. Study sites and survey settings

Seven crosswalks at three signalized intersections located in Nagoya City, Japan, were selected as study sites. Table 1 lists the geometric characteristics and signal settings of each site. The Imaike and Yagoto-Nisseki intersections are operated under ordinary four-phase signal control, and the Sasashima intersection is operated using fully protected phases, thus providing separate green phases for vehicles and pedestrians to avoid vehicle–pedestrian conflicts, as shown in Fig. 3. There are red signal intervals for pedestrians between the PFG and the subsequent vehicle green phases, as explained in the last section. These durations are considered as $BI$.

These intersections are located in urban areas where most users are adults. The elderly and young students are rarely observed. The pedestrian volumes listed in Table 1 are average hourly volumes during the survey period. The study sites are large intersections with crosswalk lengths of ~20–30 m or more, and cycle lengths are greater than 130 s. Such an intersection geometry is common in Japan’s urban areas, where two-stage crossing is rarely applied.

The pedestrians’ maneuvers were videotaped at each study site using video cameras located atop nearby high-rises that provided a clear view without obstacles. Among observed pedestrians, only those upstream of the concerned crosswalks at the onset of PFG and approaching were considered as subjects. Table 2 shows the total number of observed subjects. Some subjects gave up crossing after arriving at the crosswalk; therefore, the number of subjects who actually started crossing after the onset of PFG are listed in Table 2 (numbers in parentheses). The observation periods include both off-peak and peak hours. As shown in Table 2, significant numbers of pedestrians enter crosswalks even after the onset of PFG. The extracted data from the video tapes are pedestrian positions at the onset of PFG as well as the times when pedestrians enter crosswalks, pass medians, and finish crossing.

Table 1. Information of study sites

<table>
<thead>
<tr>
<th>Intersection name</th>
<th>Approach</th>
<th>Crosswalk length (m)</th>
<th>Pedestrian volume (ped/h)</th>
<th>Pedestrian green length (s)</th>
<th>PFG length (s)</th>
<th>BI length (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Near-side</td>
<td>Far-side</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sasashima</td>
<td>West</td>
<td>31</td>
<td>394</td>
<td>1631</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>20.6</td>
<td>1058</td>
<td>180</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>37</td>
<td>900</td>
<td>203</td>
<td>40</td>
<td>7</td>
</tr>
<tr>
<td>Imaike</td>
<td>West</td>
<td>22</td>
<td>158</td>
<td>202</td>
<td>44</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>21</td>
<td>158</td>
<td>169</td>
<td>44</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>22</td>
<td>68</td>
<td>79</td>
<td>42</td>
<td>8</td>
</tr>
<tr>
<td>Yagoto-Nisseki</td>
<td>North</td>
<td>18</td>
<td>28</td>
<td>222</td>
<td>44</td>
<td>4</td>
</tr>
</tbody>
</table>

Fig. 3. Signal phase sequence at study sites
4. Empirical data analysis

4.1. Remaining pedestrians after the end of PFG and BI

The right-hand side of Table 3 lists the number of pedestrians remaining at crosswalks at the onset and the end of BI. Almost all pedestrians who started to cross after the onset of PFG cannot finish crossing during the PFG period. Even at the end of BI, which is the onset of the subsequent conflicting exclusive right-turn phase, many pedestrians remain on the crosswalks. This problem is contributed to by the insufficient clearance time.

Ideally, clearance time is provided to avoid conflicts between pedestrians and entering vehicles in the subsequent phase, as shown in Fig. 1. Safe crossing is guaranteed if pedestrians finish crossing and clear the conflict area before the conflicting traffic stream is released in the subsequent phase at the end of the BI. To pass through the conflict area, near-side pedestrians need to cross only half of the crosswalk whereas far-side pedestrians have to finish crossing the entire crosswalk.

The left-hand side of Table 3 lists the number of pedestrians who could not finish crossing the conflict area at the onset and at the end of BI. Clearly, many pedestrians remain at the onset and at the end of BI. Some pedestrians at the crosswalk at the end of BI already finished crossing the conflict area, especially those whose origin was at the near side. This explains why the number of pedestrians remaining at the crosswalks at the end of BI is significantly higher than that of pedestrians remaining who did not finish crossing the conflict area.

4.2. Clearance time of the last pedestrian in each cycle

To analyze the necessary clearance time, the last pedestrian who finished crossing is extracted for each cycle. Fig. 4(a) shows the cumulative distributions of the time when the last pedestrians finished crossing. The sample size of each distribution is equal to the number of observed signal cycles that have at least one pedestrian crossing after the onset of PFG. It is clear that pedestrians finish crossing extremely late at long crosswalks such as Sasashima West and South and Yagoto-Nisseki, which in some cases goes beyond 10 s after the end of BI and the start of the subsequent vehicle phase. This creates severe safety problems for pedestrians.

To examine the conflicts between pedestrians and turning traffic more closely, the last pedestrian clearing the conflict area in each cycle is extracted. Fig. 4(b) shows the distribution of the time from the end of BI for the last pedestrian to finish crossing the conflict area. Clearly, at long crosswalks (Sasashima and Yagoto-Nisseki), a significant portion of pedestrians cross the conflict area late; some of them finish crossing up to 10 s after the end of BI and the onset of the following vehicle phase. Furthermore, a comparison of Fig. 4(a) and 4(b) shows that the distributions of the Yagoto-Nisseki intersection are significantly different. This is because most of the remaining
pedestrians at the Yagoto-Nisseki crosswalk come from the near-side; therefore, at the end of BI, they have already finished crossing the conflict area that is located for near-side pedestrians in the first half of the crosswalk.

The clearance time of the last far-side pedestrians is important to determine the necessary clearance time to be provided. In this study, 85 percentile of the clearance times of the far-side pedestrians is chosen as the reference for the necessary clearance time setting, which is illustrated in Fig. 5. For comparison, the clearance times calculated by Equation (1) assuming $V$ equal to 1.5 m/s and 1.0 m/s are also shown in Fig. 5. Clearly, the observed 85 percentile clearance times at all crosswalks are less than the calculated clearance time with $V$ equal to 1.0 m/s. The observed time at Sasashima West and South crosswalks is relatively large owing to the longer crosswalks.

Compared to the signal indication, the observed clearance times are significantly larger than PFG + BI. There is no correlation between the current PFG/BI settings and the observed clearance time. This means that regardless of the signal indication, the pedestrians spend necessary clearance times after the onset of PFG. Therefore, when the PFG and BI length are insufficient as in the West and South approaches of the Sasashima intersection, there is a risk that pedestrians cannot finish crossing the conflict area before the arrival of the conflicting vehicular traffic of the subsequent phase.

It is important to note that by providing sufficient clearance time where PFG + BI is at least equal to $L/V$, it is not guaranteed that there will be no remaining pedestrians on the crosswalk at the end of BI when the conflicting vehicular traffic of the subsequent phase is released. Some pedestrians start crossing at the end of the PFG and even after. These pedestrians will not be able to finish crossing before the end of BI. Therefore, it is important to select a proper signal indication for clearance time that minimizes the possibility of start crossing.

### Table 3. Number of pedestrians remaining at crosswalks/conflict areas at the onset and the end of BI

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Approach</th>
<th>Number of pedestrians remaining at crosswalks</th>
<th>Number of pedestrians remaining at conflict area</th>
<th>Total number of pedestrians crossed after PFG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>At BI onset</td>
<td>At the end of BI</td>
<td>At BI onset</td>
</tr>
<tr>
<td>Sasashima</td>
<td>West</td>
<td>534 (100%)</td>
<td>449 (84.1%)</td>
<td>532 (99.6%)</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>555 (99.5%)</td>
<td>210 (37.6%)</td>
<td>510 (91.4%)</td>
</tr>
<tr>
<td></td>
<td>South</td>
<td>219 (98.6%)</td>
<td>174 (78.4%)</td>
<td>217 (97.7%)</td>
</tr>
<tr>
<td>Imaike</td>
<td>West</td>
<td>186 (97.9%)</td>
<td>77 (40.5%)</td>
<td>159 (83.7%)</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>143 (97.3%)</td>
<td>45 (30.6%)</td>
<td>107 (72.8%)</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>85 (98.8%)</td>
<td>33 (38.4%)</td>
<td>74 (86.0%)</td>
</tr>
<tr>
<td>Yagoto-Nisseki</td>
<td>North</td>
<td>67 (100%)</td>
<td>66 (98.5%)</td>
<td>67 (100%)</td>
</tr>
</tbody>
</table>

Fig. 4. Distributions of clearance time of the last pedestrian in each cycle

(a) clearance time to finish crossing overall crosswalk; (b) clearance time to finish crossing the conflict area
5. Discussions and concluding remarks

This study overviewed pedestrian signal indications and how their durations are determined in different countries. It was shown that the signal settings in Japan may not provide sufficient pedestrian clearance time between the end of the pedestrian green indication and the onset of the subsequent vehicle green indication.

The empirical analysis clarified that a significant number of pedestrians enter crosswalks during PFG, although pedestrians are not allowed to enter crosswalks during PFG, and sufficient clearance time is not guaranteed for them. The BI duration, which in Japan is ideally provided to increase the capacity of left-turn movement by avoiding conflicts with pedestrians, is also implicitly used by pedestrians as a part of the clearance time. Furthermore, even considering BI, the current setting of PFG + BI is shorter than the necessary clearance time. It is concluded that the clearance time setting in the US is sufficient for the observed crosswalks in that most of the pedestrians who start crossing at the onset of PFG can finish crossing.

This analysis is based on the current Japanese signal indication system. As pedestrians make decisions by observing signal indications, their behavior, i.e., stop-cross decision after the end of the green indication and walking speed adjustment, may change with the different indications and settings of their durations. Therefore, an international comparison study is advantageous to understand how pedestrians behave under different systems. The subject pedestrians in this study are ordinary adults who can walk fast and who may ignore the signal indication. Meanwhile, the behavior of children, disabled, or elderly people who are not able to walk fast is also important for determining reasonable signal time settings, which has already been highlighted.

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References