EXPLORATION OF PEDESTRIAN GAP ACCEPTANCE BEHAVIOR AT SELECTED LOCATIONS

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ABSTRACT
This paper describes the efforts to evaluate pedestrian gap acceptance as part of a recent TCRP/NCHRP project. Pedestrian crossing data were collected at 42 study sites in seven states. From those sites, 45 pedestrian approaches had at least one crossing event with a vehicle that passed through the approach during that event (i.e., at least one gap was rejected by the pedestrian), 11 of which had at least 20 such crossing events. Focusing on the 11 approaches, researchers evaluated the gap acceptance behavior of crossing pedestrians based on a two-part analysis: behavioral analysis and statistical analysis. Behavioral analysis revealed that pedestrians did not always wait to cross the street when all lanes were completely clear; rather, they anticipated that the lanes would clear as they crossed and used a “rolling gap” to cross the street. Statistical analysis revealed that the 11 approaches had 85th percentile accepted gaps between 5.3 and 9.4 seconds, with a trend of increasing gap length as crossing distance increased. All of the observed 85th percentile accepted gaps were less than the critical gap as defined in the MUTCD for a walking speed of 3.5 ft/s (1.1 m/s) at their respective sites, indicating that if 3.5 ft/s (1.1 m/s) were used as the design criterion, it would be sufficient to serve at least 85 percent of the observed pedestrians at the study sites.

INTRODUCTION
A recent research project titled “Improving Pedestrian Safety at Unsignalized Roadway Crossings,” (1), jointly funded by the Transit Cooperative Research Program (TCRP) and the National Cooperative Highway Research Program (NCHRP), was conducted by the Texas Transportation Institute to study selected pedestrian treatments at unsignalized locations to determine their effectiveness. A field study approach was developed in that project to provide insight into the actual behavior of motorists and pedestrians at locations with existing pedestrian crossing treatments. Researchers evaluated the effectiveness of the crossing treatments using seven measures of effectiveness (MOE): pedestrian visual search, pedestrian crosswalk compliance, pedestrian activation, pedestrian-vehicle conflicts, pedestrian delay, pedestrian walking speed, and motorist compliance. Additionally, the research team collected data on “causal factors” at existing crossing treatment locations, which were used to help explain the variation in MOE results for similar treatments at different locations.

The locations chosen as field study sites in that project were selected to represent a variety of treatment types, site conditions, and geographical positions. Specific site selection was based on several factors so that the research team could obtain data across a representative range of treatment types, street environments, and traffic conditions. The factors included the following:
- proximity to transit stop – sample of sites near or at a transit stop
- roadway type – moderate to high traffic volumes
- proximity to driveways – locations where turning traffic conflicts from nearby driveways are nominal
- area type – suburban and urban
- pedestrian age and ability – sample of sites with a range of pedestrian ages represented including the elderly and pedestrians with disabilities

In total, 42 study sites were selected in seven different states. Pedestrian crossing data were collected for approximately four hours at each site, and the data were analyzed on the basis of the MOE. In addition to the MOE and causal factors analyses, researchers looked for opportunities to use the data to explore and investigate the characteristics of other pedestrian and
motorist behaviors. One such behavior is that of pedestrian gap acceptance. Researchers questioned whether they could gain an appreciation of the reasonableness of results from the critical gap acceptance equation in relation to observed pedestrian behavior.

This paper describes the efforts to evaluate pedestrian gap acceptance as a part of the TCRP/NCHRP project. The objectives of this portion of the project were:

• To determine the characteristics of available and accepted gaps.
• To identify behavioral patterns and statistical trends associated with the gap acceptance data.
• To compare the accepted gaps with the corresponding critical gap.

A crossing maneuver involves the pedestrian making a decision to accept a particular gap in the traffic stream. The pedestrian must make a “yes/no” decision for each gap in traffic that occurs; either the pedestrian accepts the gap or rejects it. The “yes/no” nature of the decision gives gap acceptance a unique set of conditions that can be utilized in analysis. Evaluation of actual accepted and rejected gaps can be assessed via logistic regression (or logit transformation). The evaluation provides the probability of accepting a gap of a certain length. In this way, the accepted gap for selected percentiles of the pedestrian population can be determined for each site or group of sites. The logit model was used to determine accepted gaps at several sites within this research project.

BACKGROUND

A thorough review of pedestrian gap acceptance requires a familiarity with the various kinds of gaps that are encountered. There are gaps defined by the characteristics of the site (referred to as adequate gaps and critical gaps) and gaps dependent on the conditions present at the time a pedestrian attempts to cross (referred to as available, accepted, and rejected gaps). The available gap is the gap present for a pedestrian. If the pedestrian accepts the available gap (i.e., crosses the street within that gap), then it is an accepted gap, otherwise it is a rejected gap. The adequate gap for a site is determined by dividing the crossing distance by the walking speed and adding an appropriate start-up time. However, while an approximate walking speed is used for such a calculation, the actual walking speed for each pedestrian will vary, largely depending on age and physical ability, along with the conditions present at the site. The Highway Capacity Manual (HCM) defines the critical gap as “the time in seconds below which a pedestrian will not attempt to begin crossing the street. If the available gap is greater than the critical gap, it is assumed that the pedestrian will cross, but if the available gap is less than the critical gap, it is assumed that the pedestrian will not cross.” (2) The term adequate gap is used in the Manual on Uniform Traffic Control Devices (MUTCD) and is assumed to be the same as the critical gap in the HCM. A question is whether the gaps being accepted at sites are, in fact, less than the calculated critical (adequate) gap. An analysis of the actual accepted and rejected gaps can reveal whether the critical gap is reasonable.

That the determination of the critical gap for a crossing maneuver requires a value for walking speed indicates the strong relationships between walking speed and gap acceptance. The value chosen for an approximate walking speed at a given site determines the length of a critical gap. If the assumed walking speed is unrealistic, so is the critical gap. Conversely, if observed behavior shows that accepted gaps are equal to or less than the calculated critical gaps, the chosen value of walking speed is validated for that site. The following analysis of observed gap acceptance behavior utilized results from the portion of the TCRP/NCHRP project that investigated appropriate walking speeds (1).
The ability of various groups of pedestrians to select appropriate gaps depends on their ability to determine the speed of approaching vehicles and the time necessary to cross the street. This ability varies primarily with age and physical limitations. Oxley et al. (3) conducted a study with two experiments to investigate age differences in the ability to choose safe time gaps in traffic in a simulated road-crossing task as well as some of the factors involved in such judgments. Participants were divided into three age groups: “younger” (between 30 and 45 years old), “young-old” (between 60 and 69 years old), and “old-old” (75 years and over). The first experiment investigated age differences in gap selection during road-crossing tasks in a simulated traffic environment in which time gap and vehicle speed were systematically varied, with five levels of time gap and three levels of vehicle speed. Participants were asked to make decisions under time pressure, and the resulting mean decision times were much lower than in on-road observational studies. The authors considered that perhaps, under time constraints, decisions are made primarily on the most immediately available and most easily accessible information, which was distance to the approaching vehicle. Judgments about speed require information about vehicles over time and this may require longer time to process with advancing age. It is, therefore, possible that, if given more time to inspect the stimulus display and to make a crossing decision, participants are more likely to base their decisions on the time gap (integrating distance and speed) rather than the distance alone. This may be especially important for the oldest participants, leading to less risky crossing decisions. These possibilities were explored in the second experiment by examining the effect of different presentation times of virtual traffic scenes on the ability to judge safe gaps in traffic.

The results (3) showed that, for all age groups, gap selection was primarily based on vehicle distance rather than time of arrival. As it turned out, presentation time made little difference to the proportion of acceptance responses of the younger group. Rather, distance, and to a lesser extent, time gap seemed to influence their decision to cross. That is, even at short presentation times, young participants were more likely to cross when distances were longer even though time gaps did not vary, but they also accepted gaps more often when the reverse was true. Thus, younger adults were able to process both distance and speed of vehicles in very short periods of time, even though they primarily based their crossing decisions on vehicle distance. For the middle and oldest age categories, these observations were somewhat similar, but depended more on longer observation times. Thus, older pedestrians are more likely to make incorrect decisions about the length of a critical gap if compelled to make a quick decision, which can lead to higher rates of crashes, injuries and fatalities in older pedestrians. Therefore, the ability to correctly estimate the length of a critical gap at a particular site can improve pedestrian safety at that site.

DATA COLLECTION
For the TCRP/NCHRP project, a field study was conducted that observed pedestrian crossing behavior at 42 sites in seven states. During the field study, researchers made a video recording of the pedestrian activity for approximately four hours at each site. After the in-field work was completed, technicians reviewed the video to observe pedestrian crossings and record characteristics of each crossing maneuver. For gap acceptance analysis, the time each pedestrian arrived at the crossing and the time each vehicle entered the crosswalk was recorded. For vehicles that entered the crosswalk, their travel lane and stopping behavior were recorded. The stopping behavior of each vehicle was categorized by whether that vehicle stopped, slowed down, or should have stopped but continued through the crosswalk. All of the observed
characteristics were recorded on data sheets and used to create an electronic master database for storage and reduction of the data. The length of each gap was then calculated from the differences between the arrival times of two consecutive vehicles, as shown in Figure 1.

![Figure 1 Definition of gap length.](image)

**DATA REDUCTION**

A review of the master database revealed that there were 45 approaches that had at least one crossing event with a vehicle that passed through the approach during that event (i.e., at least one gap was rejected by the pedestrian). The pedestrian and vehicle arrival data collected from the video for the crossing events on each approach were used to compile a gap acceptance database in the format shown in Table 1.

Table 1 provides data for one half of a crossing on a divided roadway. The gap acceptance data were organized so that each direction of vehicular traffic and each direction of pedestrian traffic were in separate categories; thus, a study site could have as many as four sets of data in the database (two directions of vehicular traffic for each of two directions of pedestrian traffic). In the sample shown in Table 1, the pedestrian arrival time would be equivalent to the time a westbound pedestrian walks to the edge of the median to cross the second (southbound) portion of the roadway. After the pedestrian approaches the edge of the median, nine vehicles pass through the crosswalk at intervals ranging from one to three seconds; the waiting pedestrian rejects those gaps as too short. The pedestrian then determines that the available gap between the ninth and tenth vehicles is sufficient to complete the crossing, accepts the gap, and crosses the street. The tenth vehicle slows down upstream of the crosswalk to allow the pedestrian to cross, then passes through the crosswalk six seconds after the ninth vehicle. Thus, the accepted gap for the pedestrian in Table 1 was six seconds.
TABLE 1 Sample of Gap Acceptance Data

The resulting database contained 3632 gaps observed by 605 individual pedestrians or groups of pedestrians, of which 3027 gaps were rejected and 605 were accepted. Within the 3027 rejected gaps, there were 572 gaps of zero duration. These were caused by a vehicle arriving at the crosswalk at the same time as a pedestrian, or by two vehicles arriving at the crosswalk traveling side-by-side. These zero-duration gaps were removed from the database prior to analysis, leaving 2455 rejected gaps, or 3060 total gaps. An additional review of the dataset revealed that 11 approaches had more than 20 pedestrians crossing. The evaluations focused on those 11 approaches. Table 2 lists the characteristics for the 11 approaches included in the evaluation.

### ANALYSIS

The analysis was comprised of two components: behavioral analysis and statistical analysis. The former was concerned with identifying actions and patterns that pedestrians commonly use in crossing events. The latter was intended to provide a mathematical model to determine gaps size for a proportion of the crossing population.

### Behavioral Analysis

There are some specific behavioral patterns that have an effect on the way the data are presented. One particular pattern is the concept of the “rolling gap.” During data reduction, gap lengths were measured based on the times when vehicles entered the crosswalk. At certain sites, particularly sites with high volumes of traffic, pedestrians did not wait to cross the street when all lanes were completely clear. Rather, they anticipated that the lanes would clear as they crossed and used a “rolling gap” to cross the street; essentially, there was a separate gap for each lane of traffic that occurred to coincide with the pedestrian’s path across the street.

For example, consider the conditions presented in Figure 2. There is not a sufficient gap for the pedestrian to cross the entire two-lane segment from the curb to the median between approaching vehicles, because the traffic volumes are too high and are distributed between both lanes. In the “rolling gap” scenario, the pedestrian would begin the crossing maneuver when the
acceptable gap between vehicles A and C occurred in the near (curb) lane, even though a second vehicle (vehicle B) might be approaching in the adjacent lane, as in Figure 3. However, by the time the pedestrian reaches the adjacent lane, vehicle B has already passed through the crosswalk, leaving an open lane to complete the crossing, as shown in Figure 4. After this, another approaching vehicle in the curb lane (vehicle C) might enter the crosswalk, giving the appearance that the actual gap was very small; but if the pedestrian properly timed the crossing, the gap is acceptable to the pedestrian at a comfortable walking speed.

TABLE 2 Characteristics for Each Approach

<table>
<thead>
<tr>
<th>Approach</th>
<th>Pedestrian Crossing Treatment*</th>
<th>Number of Pedestrians</th>
<th>Number of Gaps</th>
<th>Crossing Distance (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OfPa</td>
<td>34</td>
<td>150</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>OfPa</td>
<td>32</td>
<td>241</td>
<td>38</td>
</tr>
<tr>
<td>3</td>
<td>Refuge</td>
<td>40</td>
<td>137</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>Refuge</td>
<td>30</td>
<td>125</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Refuge</td>
<td>31</td>
<td>132</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Refuge</td>
<td>29</td>
<td>170</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>Refuge</td>
<td>21</td>
<td>521</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>OfPb</td>
<td>22</td>
<td>124</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>OfPb</td>
<td>34</td>
<td>232</td>
<td>46</td>
</tr>
<tr>
<td>10</td>
<td>OfPb</td>
<td>22</td>
<td>105</td>
<td>54</td>
</tr>
<tr>
<td>11</td>
<td>Flag</td>
<td>22</td>
<td>61</td>
<td>45</td>
</tr>
<tr>
<td>ALL Approaches where a Pedestrian made a Gap Decision</td>
<td>N/A</td>
<td>605</td>
<td>3060</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*OfPa = overhead flashing beacon with passive detection
OfPb = overhead flashing beacon with push button detection and flags
Refuge = refuge island is primary treatment at site
Flag = flags

NOTE: 1 ft = 0.305 m

Approaches 1 and 2 are opposing approaches on a four-lane divided roadway with a configuration similar to that shown in Figure 2. Under these conditions, there is essentially a separate available gap for each lane that the pedestrian decides to accept or reject. Those gaps may or may not begin or end at the same time, but they occur in such a way that, when taken together, they create a combined gap sufficient for the pedestrian to cross the entire segment. Of the combined 66 accepted gaps at Approaches 1 and 2, 60 percent (39 accepted gaps) were “rolling gaps.”

One conclusion that can be drawn from this analysis is that pedestrians are often creative and adaptable to conditions. A pedestrian who feels he or she has waited an inordinate amount of time for all lanes to clear, particularly one who is familiar with the crossing, will adjust his or her perception of what is an acceptable gap. In this study, that revised perception often is focused on only one lane at a time.

This behavior is not captured in most designs; the usual assumption is that the pedestrian waits for all lanes to clear before crossing. While this assumption is not always realistic, it provides a more conservative design. Pedestrians who are comfortable with “rolling gaps” may
voluntarily accept them. However, to minimize the potential for crashes and injuries, designs should not encourage the acceptance of “rolling gaps” by pedestrians who are not comfortable with them and would otherwise reject them.

FIGURE 2 Pedestrian waiting to cross at crosswalk with high traffic volumes.
FIGURE 3 Pedestrian crossing first lane of approach using a “rolling gap.”

FIGURE 4 Pedestrian crossing second lane of approach using a “rolling gap.”
Statistical Analysis
The Statistical Analysis Software (SAS) computer program was used for the logistic regression analysis. Each approach of roadway was considered individually in the analysis; that is, each site was analyzed separately, and if the roadway was divided at that site, each side of the roadway had a unique analysis. As a result, 47 distinct analyses were performed, in addition to an overall analysis of all gaps for reference.

Using the gap acceptance database for each site, the gap length and pedestrian action were considered for each crossing. If the pedestrian rejected the gap the action was assigned a value of zero, while if the pedestrian accepted the gap it was assigned a value of one.

By default, SAS proc logistic models the probability of y=0; that is, the program returns the percentage of pedestrians rejecting a gap. Subtracting this value from 1.0 produced the percentage of pedestrians accepting a gap. The predicted values (p) for the percentage of pedestrians rejecting a gap at a given location are computed by Formula 1:

\[ p = \frac{e^{\beta x}}{1 + e^{\beta x}} \times 100 \]  

where \( e \) is the natural log, \( x \) is the value of the gap in seconds, and \( \beta \) represents the coefficient to be estimated for that location. Similarly, the predicted percentage of pedestrians accepting a gap is computed by Formula 2:

\[ q = 1 - p = \left(1 - \frac{e^{\beta x}}{1 + e^{\beta x}}\right) \times 100 \]  

For example, the equation for the WB2/EB1 approach of CA-SM-3 is \( \beta x = 6.9634 - 1.1879 \times \text{gap} \). Using Formula 2, the percentage of pedestrians accepting a seven-second gap would be:

\[ q = \left(1 - \frac{e^{6.9634 - 1.1879 \times 7}}{1 + e^{6.9634 - 1.1879 \times 7}}\right) \times 100 = 79.44\% \]

From this equation a graph can be generated showing the cumulative distribution of pedestrians accepting gaps of various lengths. Figure 5 shows an example of this type of graph.
FIGURE 5 Sample cumulative distribution of gap acceptance.

The data from some sites did not meet the convergence criterion. In order for the logistic model to run successfully, the values of accepted and rejected gaps must overlap and not be completely or almost completely separated. That is, there should be a gap length (or small range of gap lengths) that was both accepted and rejected by a considerable number of pedestrians. At sites with no overlap in values, the maximum likelihood estimate did not converge, but SAS continued with the analysis and matched a function. Under these conditions, the function does not have the smooth s-curve as shown in Figure 5, but rather resembles a step function, with a straight (and very steep) line between the values of the longest gap rejected and the shortest gap accepted (see Figure 6 in the Findings section). The results obtained from these functions have a lower level of confidence than the functions where the maximum likelihood estimate existed. This condition is explained in further detail in the Findings section. The complete set of results from the SAS logistic analysis is shown in Table 3.
TABLE 3 Results of SAS Logistic Analysis for Approaches with More Than 20 Pedestrians

<table>
<thead>
<tr>
<th>Approach</th>
<th>$\beta'(x)$</th>
<th>50th Percentile Gap (sec)</th>
<th>85th Percentile Gap (sec)</th>
<th>Number of Pedestrians</th>
<th>Maximum Likelihood Estimate Converges?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.0462-0.8193x</td>
<td>6.2</td>
<td>8.3</td>
<td>34</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>7.9928-1.5001x</td>
<td>5.3</td>
<td>6.5</td>
<td>32</td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>12.6355-2.4996x</td>
<td>5.1</td>
<td>5.8</td>
<td>40</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>37.0931-7.2800x</td>
<td>5.1</td>
<td>5.3</td>
<td>30</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>6.9634-1.1879x</td>
<td>5.9</td>
<td>7.3</td>
<td>31</td>
<td>Y</td>
</tr>
<tr>
<td>6</td>
<td>11.8970-2.0942x</td>
<td>5.7</td>
<td>6.5</td>
<td>29</td>
<td>Y</td>
</tr>
<tr>
<td>7</td>
<td>65.1435-10.6485x</td>
<td>6.2</td>
<td>6.3</td>
<td>21</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>6.7212-0.9039x</td>
<td>7.4</td>
<td>9.4</td>
<td>22</td>
<td>Y</td>
</tr>
<tr>
<td>9</td>
<td>14.4907-1.7604x</td>
<td>8.2</td>
<td>9.2</td>
<td>34</td>
<td>Y</td>
</tr>
<tr>
<td>10</td>
<td>6.2673-1.2341x</td>
<td>5.1</td>
<td>6.5</td>
<td>22</td>
<td>Y</td>
</tr>
<tr>
<td>11</td>
<td>42.176-8.7008x</td>
<td>4.8</td>
<td>5.0</td>
<td>22</td>
<td>N</td>
</tr>
<tr>
<td><strong>ALL Sites and Approaches</strong></td>
<td><strong>6.2064-0.9420x</strong></td>
<td><strong>6.6</strong></td>
<td><strong>8.4</strong></td>
<td><strong>512</strong></td>
<td><strong>Y</strong></td>
</tr>
</tbody>
</table>

FINDINGS

Using the probability equations obtained from SAS, the accepted gap for each site can be determined. According to Table 3, the approaches had an 85th percentile accepted gap between 5.3 and 9.4 seconds.

Several elements can affect the size of the 85th percentile accepted gap. First, the amount of data can have a significant effect, especially when only a few pedestrians were faced with making a gap acceptance decision. To minimize the potential effect that only a few pedestrians could have on the results, only those approaches with more than 20 pedestrians on the approach were considered in this evaluation.

Second, the distribution of the data can affect the analysis of a large number of data points. At Approach 2 there were 241 observed gaps but only 32 pedestrians. Out of these 241 gaps, 196 required the pedestrian to make a gap acceptance decision on a gap of three seconds or less while only 10 were gaps of longer than 10 seconds. With such dense traffic the gap acceptance was skewed lower. The gap acceptance results would be stronger if based only on free-flow vehicles; however, using only free-flow vehicles does not capture the true nature of the conditions faced by the pedestrian. When the location is within a coordinated corridor the pedestrian may ignore the gaps within the platoons of vehicles and wait for the larger gap present between the platoons.

Third, the lack of some overlap in the accepted and rejected gaps is an important factor, as mentioned in the Analysis section above. If there is separation of data, the maximum likelihood estimate does not converge; however, SAS will still provide an output, which will often have a very large standard error. An example is Approach 4, which had 125 observed gaps. An examination of the data reveals that all but one gap between one and five seconds were rejected (one five-second gap was accepted), and all the gaps above five seconds were accepted. The logit model tries to match this data with an equation, but because of the complete separation for the accepted and rejected gaps, the equation almost forms a straight vertical line between five
and six seconds where no data exists. An example of a cumulative distribution with extreme values, based on Approach 4, is shown in Figure 6.

![Cumulative distribution of gap acceptance with separation of data.](image)

**FIGURE 6** Cumulative distribution of gap acceptance with separation of data.

Table 4 lists those approaches whose distribution is similar to Figure 6. This table shows the values of the longest gaps rejected by at least 85 percent of pedestrians and of the shortest gaps accepted by at least 85 percent of pedestrians.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Value of Longest Rejected Gap (sec)</th>
<th>Value of Shortest Accepted Gap (sec)</th>
<th>Number of Pedestrians</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4.0</td>
<td>6.0</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>5.0</td>
<td>6.0</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
<td>7.0</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>6.0</td>
<td>7.0</td>
<td>21</td>
</tr>
<tr>
<td>9</td>
<td>7.0</td>
<td>10.0</td>
<td>34</td>
</tr>
<tr>
<td>11</td>
<td>4.0</td>
<td>6.0</td>
<td>22</td>
</tr>
</tbody>
</table>

**TABLE 4 Summary of Gap Distribution for Approaches with Separation of Data**

**COMPARISON OF OBSERVED AND CRITICAL GAPS**

The findings show that the accepted gap increases as crossing distance increases (see Figure 7). Also shown in Figure 7 is the plot of the critical gap for a walking speed of 3.5 ft/s (1.1 m/s). Inspection of Figure 7 reveals that all of the observed 85th percentile accepted gaps were less than the calculated critical gap for a walking speed of 3.5 ft/s (1.1 m/s). Thus, the pedestrians in this study were not consistently accepting gaps exceeding the calculated critical gap, and the 3.5 ft/s (1.1 m/s) design criterion appears sufficient for the pedestrians observed.
Recommendations from the TCRP/NCHRP project \( (I) \) included the adoption of 3.5 ft/s (1.1 m/s) as the design walking speed. Gap acceptance findings as shown in Figure 7 indicate that this would be a conservative value to use for crossing distances of at least 30 ft (9.1 m).

Figure 7 also shows the plots of the critical gap for walking speeds of 3.0 ft/s (0.9 m/s) and 4.0 ft/s (1.2 m/s). The TCRP/NCHRP project recommended 3.0 ft/s (0.9 m/s) for use at intersections with a high number of older pedestrians, and it provides an even more conservative estimate than 3.5 ft/s (1.1 m/s) in comparison to the observed accepted gaps. The plot for a 4.0 ft/s (1.2 m/s) walking speed represents the value that is currently in widespread use; it is just sufficient to serve 85 percent of the observed pedestrians, being approximately equal to the highest observed gap at a crossing distance of 30 ft (9.1 m).

**FIGURE 7** Comparison of trends for observed 85\textsuperscript{th} percentile gaps and calculated critical gaps for walking speeds of 3.0, 3.5, and 4.0 ft/s (0.9, 1.1, and 1.2 m/s).

**CONCLUSIONS**

Taking the above findings into account, the following conclusions can be made from the data:

- A behavioral pattern in response to high volumes of traffic on a multi-lane approach is the use of a “rolling gap.” Pedestrians often timed their crossing maneuvers to take advantage of an adequate gap in each individual lane, and thus complete their crossings even though the approach as a whole did not have a critical gap during their crossings.
- While “rolling gaps” are a behavioral adaptation made by many pedestrians, the design
assumption that pedestrians will wait for all lanes to clear produces a more conservative design that minimizes the potential for crashes and injuries for pedestrians who do not accept “rolling gaps.”

- For approaches with more than 20 observed pedestrians, the trend of the 85th percentile accepted gap increases with crossing distance. The critical gap calculations also result in larger gaps for longer crossing distances.
- The observed 85th percentile accepted gaps were less than the calculated critical gaps recommended for design when using a walking speed of either 3.0 ft/s (0.9 m/s) or 3.5 ft/s (1.1 m/s). The latter is recommended for adoption as the design walking speed for general conditions, while the former is recommended for locations with high numbers of older pedestrians.
- The observed 85th percentile accepted gaps were also less than or equal to the calculated critical gaps when using a walking speed of 4.0 ft/s (1.2 m/s), which is commonly used as the current design walking speed.

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