Pedestrian Crossing-Time Requirements at Intersections

MARK R. VIRKLER and DAVID L. GUELL

ABSTRACT

Existing procedures for determining pedestrian crosswalk-time requirements are inadequate because they ignore the number of people crossing. A study of six crossing locations showed that those in large crossing groups walk at fairly uniform headways and uniform speeds. Pedestrian headways are close to 6.7 sec per pedestrian per foot width of walkway and speeds are close to 4.5 ft/sec. A model of crossing time is developed. The inputs are the number crossing, crosswalk length, and crosswalk width.

The time required by pedestrians to cross streets at signalized intersections must be determined to ensure safe and efficient operation of the intersection. Most procedures used today (1-3) treat crossing time as a function of crosswalk length divided by a walking speed. However, crossing time is also a function of the number crossing (4).

Figure 1 shows the times required by groups (herds) of four or more to cross a street in downtown Richmond, Virginia. The ordinate is the time between when the first person in the herd leaves the curb and when the last person reaches the opposite curb. The horizontal lines are the crossing times predicted by dividing the crosswalk length (32 ft) by walking speeds of 3.5 and 4.0 ft/sec (the values usually recommended). The diagonal line is the regression line of best fit. The slope of this line was significantly different from zero at the 1 percent level.

The purpose of this study was to develop an improved design procedure for considering pedestrians in traffic signal timing. Data on crossing times are examined in the next section. A basis for modeling pedestrian crossing times is then developed. This is followed by a recommended design procedure.

METHODOLOGY AND DATA ANALYSIS

Data were collected for 85 herd crossings at 6 crossing locations. Four crossings were in downtown Richmond, Virginia. These crossings were controlled by pedestrian signals, and crosswalk lines were marked on the pavement. A majority of pedestrians were shoppers. The other crossings were near the University of Missouri-Columbia football stadium. These had no crosswalk lines and traffic was controlled by a police officer. The pedestrians were football patrons going to the stadium.

Data Collected

For all the crossings, curb-to-curb distance (L) was measured. For the downtown shoppers, crosswalk width
(W) was measured and used in the calculation of pedestrians per foot width of walkway. For the football patrons, the width selected by each herd was used for the crosswalk width.

Two time measurements were made for each observation. The first \( t_1 \) was the time between when the first person stepped off the curb and when the first person stepped on the opposite curb (not necessarily the same person). The second \( t_n \) was the time between when the first person stepped off the curb and when the last person stepped on the opposite curb. In all cases the number (N) in each herd was limited by the requirement that a person be a part of the herd before it left the curb.

With the downtown shoppers, herd sizes ranged from 4 to 24 persons. Although many violated the signal indication, data were taken only from herds abiding by the signal indications. In general, these pedestrians stayed within the crosswalk lines and experienced little interference from turning vehicles.

The herd sizes of football patrons ranged from 9 to 125, and widths selected ranged from 6 to 30 ft. These pedestrians were highly obedient to the police officer's indications and received almost no interference from vehicles.

The ranges and means of the data are shown in Table 1. In most cases time measurements were taken at the site with a stopwatch. In one case (f) measurements were taken from a videotape.

### Data Analysis

The flow rate \( q \) for each herd when it reached the opposite curb was determined by using the following equation:

\[
q = \frac{[N-1]/W}{(t_n - t_1)}
\]

No significant relationship between flow rate and size of herd \( N/W \) was found. The flow rate for herds with large numbers of people was almost always within Fruin's level of service B \([6 \text{ to } 10 \text{ pedestrians/(ft} \cdot \text{min)}] \). For instance, crossing \( f \) had a mean flow rate of 8.10 pedestrians/(ft\cdot min) with a standard deviation of 1.65. The 95 percent confidence interval for mean flow rate was from 7.4 to 8.8 pedestrians/(ft\cdot min).

Flow rates fluctuated widely \([3.9 \text{ to } 34.5 \text{ pedestrians/(ft} \cdot \text{min)}] \) for the data from downtown shoppers. The large flow rates were attributed to fairly small groups walking nearly abreast. When these herds were effectively combined (front to back) by using the following equation, the overall flow rate was 8.16 pedestrians/(ft\cdot min):

\[
q = \frac{\Sigma(N-1)/W}{\Sigma(t_n - t_1)}
\]

It was also observed that pedestrians seldom passed each other and tended to maintain fairly uniform spacings. These characteristic led to the possibil-

<table>
<thead>
<tr>
<th>TABLE 1 Data Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossing ( \text{Downtown Shoppers} )</td>
</tr>
<tr>
<td>( \text{a} )</td>
</tr>
<tr>
<td>No. of observations</td>
</tr>
<tr>
<td>Crosswalk length (ft)</td>
</tr>
<tr>
<td>Crosswalk width (ft)</td>
</tr>
<tr>
<td>Pedestrians per foot width of walkway</td>
</tr>
<tr>
<td>Avg pedestrians per foot</td>
</tr>
<tr>
<td>Avg ( t_1 ) (sec)</td>
</tr>
<tr>
<td>Avg ( t_n ) (sec)</td>
</tr>
<tr>
<td>Maximum ( t_n ) (sec)</td>
</tr>
</tbody>
</table>
ity that a linear relationship between crossing time \(t_N\) and pedestrians per foot of crosswalk width \((N/W)\) could provide an appropriate model. The linear regression equations found for the crossings are given in Table 2. All of the slopes were found to be different from zero at a 1 percent significance level.

**TABLE 2 Regression: Crossing Time Versus Pedestrians per Foot of Crosswalk Width**

<table>
<thead>
<tr>
<th>Crossing</th>
<th>Downtown Shoppers</th>
<th>Football Patrons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) and (b)</td>
<td>(c)</td>
</tr>
<tr>
<td>Crosswalk length (ft)</td>
<td>40</td>
<td>22</td>
</tr>
<tr>
<td>Avg (N/W) (pedestrians/ft)</td>
<td>0.73</td>
<td>0.66</td>
</tr>
<tr>
<td>No. of observations</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>(A_0) (sec)</td>
<td>5.05</td>
<td>5.97</td>
</tr>
<tr>
<td>(A_1) ([sec/(pedestrian \cdot ft))]</td>
<td>4.08</td>
<td>6.83</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.66</td>
<td>0.90</td>
</tr>
<tr>
<td>Sample standard deviation from regression</td>
<td>1.64</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Note: \(t_N = A_0 + A_1 \cdot N/W\); \(t_N\) is in seconds.

Crossings \(a\) and \(b\) were combined because of their identical lengths and widths.

Two shortcomings of these particular models were apparent. First, a given equation would apply only for a particular crosswalk length. Second, the variance of the data from the fitted lines did not appear to be constant. Rather, the variance increased with \(N/W\). To deal with these problems a more general model was developed:

\[
t_N = \left(\frac{L}{V}\right) + H \cdot (N/W)
\]

(3)

where

\[L = \text{crosswalk length (ft)},\]

\[V = \text{speed of front of herd (ft/sec)},\]

\[H = \text{time headway (reciprocal of flow rate)} \quad [\text{sec/(pedestrian} \cdot \text{ft)}].\]

To find \(H\), \(t_{tq} = t_N - t_{t1}\) was calculated for each observation and plotted as a function of \(N/W\) \((t_{t1}\) was the average \(t_{t1}\) for the given crossing). \(H\) was then calculated as the slope of the line of best fit. In determining the slopes it was assumed that the variance of the error from the fitted line was proportional to \(N/W\) and that all lines would pass through the origin.

The slopes and implied flow rates for each crossing are given in Table 3. The data and line of best fit are shown in Figure 2. Combining all of the data

**TABLE 3 Best Fit: Flow Time Versus Pedestrians per Foot of Crosswalk Width**

<table>
<thead>
<tr>
<th>Crossing</th>
<th>No. of Observations</th>
<th>Avg Speed of Front of Herd ((V)) ([ft/sec])</th>
<th>Slope ((H)) ([sec/(pedestrian} \cdot \text{ft}))</th>
<th>Weighted Standard Error from Fitted Line</th>
<th>Standard Error of Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a,b)</td>
<td>18</td>
<td>4.33</td>
<td>5.80</td>
<td>1.87</td>
<td>0.52</td>
</tr>
<tr>
<td>(c)</td>
<td>8</td>
<td>4.42</td>
<td>6.94</td>
<td>1.40</td>
<td>0.61</td>
</tr>
<tr>
<td>(d)</td>
<td>28</td>
<td>4.61</td>
<td>6.76</td>
<td>2.24</td>
<td>0.50</td>
</tr>
<tr>
<td>(e)</td>
<td>9</td>
<td>4.10</td>
<td>3.59</td>
<td>1.98</td>
<td>0.53</td>
</tr>
<tr>
<td>(f)</td>
<td>22</td>
<td>4.74</td>
<td>7.47</td>
<td>3.09</td>
<td>0.37</td>
</tr>
<tr>
<td>(a,b,c,d)</td>
<td>54</td>
<td>4.42</td>
<td>6.46</td>
<td>2.04</td>
<td>0.33</td>
</tr>
<tr>
<td>(e,f)</td>
<td>31</td>
<td>4.54</td>
<td>6.82</td>
<td>3.69</td>
<td>0.40</td>
</tr>
<tr>
<td>All</td>
<td>85</td>
<td>4.47</td>
<td>6.71</td>
<td>2.74</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Note: \(t_{tq} = H \cdot (N/W)\). It is assumed that lines pass through origin and that the variance of residuals is proportional to \(N/W\).

*The square root of the weighted mean square of the residuals from the fitted line.

![FIGURE 2 Flow time versus pedestrians per foot of crosswalk width.](Image)
led to a slope (H) of 6.7 sec/(pedestrian•ft) [a flow rate of 8.94 pedestrians/(ft•min)]. The weighted mean square of the residuals was 7.53, implying a standard error of the estimate of (7.53 x (N/W))^(1/2). The 95 percent confidence interval for the slope was from 6.23 to 7.19 sec/(pedestrian•ft) [flow rates from 9.6 to 8.3 pedestrians/(ft•min), well within the limits for level of service B]. Except for crossing e, the slopes for each crossing fell within a relatively narrow range.

**DESIGN PROCEDURE**

The following equation is recommended for determining crossing time for a herd (this time is a reasonable lower limit for green plus amber time):

\[ T = t + \frac{L}{V} + H \cdot \frac{N}{W} \]  \hspace{1cm} (4)

where

- \( T \) = crossing time (sec),
- \( t \) = pedestrian starting time = 3 sec,
- \( L \) = length of crosswalk (ft),
- \( V \) = walking speed = 4.5 ft/sec, and
- \( H \) = time headway between persons = 6.7 sec/(pedestrian•ft).

The pedestrian starting time is the value recommended in the TRB Interim Materials on Highway Capacity (5). The walking speed was the average (for the front of the herd) found in this study. The value of \( H \) was the slope of best fit for all of the data collected.

If the number crossing was small and \( W \) and \( L \) were large, the crossing time given by this equation would be less than that given by most earlier techniques and therefore inadequate for slower pedestrians. However, a herd of modest size (e.g., four to eight people) would yield higher crossing times through this technique than through the earlier techniques.

**Using the Equation**

Some judgement is required in determining an appropriate \( N/W \). For \( W \) the largest herd expected during the pedestrian peak hour appears reasonable. At times this number would be exceeded or a herd of a slightly smaller size could have a higher crossing time than expected. However, the crossing time allowed would be exceeded only during a small percentage of the signal phases within the peak hour. When the time expired, the end of the herd would be close to the opposite curb.

In this study, the crosswalk width was either that selected by the herd or that painted on the pavement. In both cases this width was almost always available to the herd. At many locations the behavior of motorists could constrain the available width. Similarly, large herds might select a width greater than that provided by pavement markings.

The largest \( N/W \) value in the data was 6.4 pedestrians/ft. For values larger than this (e.g., 80 people using a width of 10 ft) the model of crossing time may not be reliable.

**Additional Considerations**

The pedestrian space for level of service B ranges from 24 to 40 ft²/pedestrian. Fruin (7) described this as being in the upper range of "tolerable." Pushkarev and Supan (8) described this range as "constrained" (between "crowded" and "impeded"). Fruin stated that in this range pedestrians can select a normal speed and when in primarily one-directional flows can pass other pedestrians. Minor conflicts would occur if reverse-direction or crossing flows existed, thereby lowering average speeds [5]. These considerations would imply that if two large herds of roughly equal size met while traveling in opposite directions, the equation for crossing time would underestimate the time needed for crossing.

Crossing time could also be affected by constraints before or after the crossing. For instance, sidewalk furniture, parked vehicles, or the presence of other pedestrians might reduce the rate at which people could leave the curb. The same factors could cause a bottleneck when the herd reaches the opposite curb. In the interest of consistency, one might seek to ensure that a pedestrian level of service near B was provided at those two locations. A minimum requirement might be that the available walkway capacity would not be exceeded by the herd plus any other pedestrians near the crosswalk.

Finally, it should be recognized that turning vehicles could have a large effect on the time required for crossing. Equation 5 is based on little interference with pedestrians by vehicles.

**SUMMARY**

Earlier techniques for determining pedestrian crossing-time requirements are adequate for small numbers of pedestrians but do not provide enough time for larger numbers. Those who are first to cross in large herds travel at about 4.5 ft/sec. Those behind the first ones maintain fairly constant spacings and require about 6.7 sec/(pedestrian•ft) to reach the opposite curb.

If an appropriate starting time (to perceive and react to a signal indication) is included, adequate time can be provided for the herd to cross. Particular care is needed for determining the effective crosswalk width and to ensure that flows will not be limited by conditions at the curb that the pedestrians leave or the curb that they reach.

**REFERENCES**

6. Interim Materials on Highway Capacity, Transportation Research Circular 212. TRB, National
Walking Straight Home from School: Pedestrian Route Choice by Young Children

MICHAEL R. HILL

Abstract

Unobtrusive observations of 50 randomly selected pedestrian youngsters were made after the children had been dismissed from elementary schools in Lincoln, Nebraska. The results demonstrate that (a) 88 percent of the students walked directly to a residential dwelling; (b) 98 percent chose a least-distance path from their school to their residence or other destination; (c) the majority of students (62 percent), by choosing to minimize distance, found their route choices reduced to a single route option; and (d) when faced with the choice between two or more distance-minimizing routes, the children in this study selected structurally more complex routes than did adults. All the children in this study were among the first students to leave school after class and walked home unaccompanied. The children appear to follow the admonition to come straight home from school, but in so doing they are generally limited to a single shortest-distance option. Such children thus have a much constrained opportunity for environmental exploration.

Pedestrian Skills in Children

Selecting a route that leads from school to home represents a high degree of pedestrian skill. This skill builds on the ability to walk per se as well as on development of sufficient risk-assessment capability to cross streets without being struck by motor vehicles. In addition, each youngster learns a subtle set of social norms (for example, which side to step to in order to avoid collision with another pedestrian, how to look at other pedestrians without appearing to stare at them, what minimum distance to maintain when following another pedestrian, and so on) that facilitate walking in its social context. Finally, the pedestrian navigator also requires knowledge of his or her spatial environment and the ability to utilize this information to choose and follow a route (1).

The age at which these interrelated skills are adequately developed and integrated is not known at this time with certainty. It is likely that development is influenced by culture, social class, and the texture of the physical environment. Routledge et al. (2) found that school children can provide reliable estimates of their exposure to risk during the journey to and from school. Reiss (3) suggests that school children can be quite verbal about their reasons for following a particular route, for example, that it is the shortest or safest way. He concludes his paper with the following observation (3, p.43): "The pattern of responses shows a progression of pedestrian capability from kindergarteners to the eighth graders."

Young children in the United States are frequently directed by their parents to come straight home from school. Whether this admonition is generally heeded as well as questions about trip length, walking velocity, and route complexity form the central focus of this study. An empirical investigation of the pedestrian routes selected by youngsters after they are dismissed from elementary school is reported here. A random sample of grade-school students from public schools was unobtrusively tracked and their routes were mapped in order to gather the data required for this study. The sections below provide a description of the methodology employed and a discussion of the results obtained. First, however, it is noted that choosing a route involves somewhat more than just the ability to place one foot in front of the other.