Driver Approach Speed and its Impact on Driver Yielding to Pedestrian Behavior at Unsignalized Crosswalks

Tom Bertulis
Northeastern University
360 Huntington Avenue
400 Snell Engineering Center
Boston, MA 02115
tombertuliswalc@gmail.com
(617) 510 6310

Daniel M. Dulaski
Northeastern University
360 Huntington Avenue
400 Snell Engineering Center
Boston, MA 02115

Submitted to the Transportation Research Board for presentation at the 2014 Annual Meeting and subsequent publication

November 15, 2013

Number of Words: 4,230
Number of Tables: 3 (250 Equivalent words) = 750 Equivalent Words
Number of Figures: 5 (250 Equivalent words) = 1,250 Equivalent Words
Total: 6,230
Abstract

This report is an evaluation of the effect of motor vehicle speed on yielding rates to pedestrians in marked crosswalks. The experimental design was to measure the 85th percentile speed at nine locations and then run 100 tests at each of the nine locations to check for motorist yielding for different speeds. After calculating the 85th percentile speed and using AASHTO guidelines to calculate Stopping Sight Distance (SSD), a cone was placed that distance away from the marked crosswalk and a pedestrian was asked to step out in the street to test yielding behavior used a staged experiment. Data were collected on site and recorded for analysis. Overall, there was an inverse correlation: the higher the motor vehicle speed, the lower the yield rate. Out of the eight two-lane roadways, the range started at a 75% yield rate for the 20 mph street and went to a 17% yield rate for the 37 mph street, a significantly lower yield rate. The one street that was four-lanes wide had only a 9% yield rate. The results are unequivocal in that speed was the major factor in the changing yield rates. The strong correlation pointed to a likelihood of low yield rates regionally on high-speed roadways, information that may prove useful for agencies looking to develop a pedestrian-friendly environment.
Introduction

Isaac Newton famously proclaimed that an object will stay in motion unless acted on by an external force. A common question asked by researchers is: *how does the presence of a pedestrian influence the actions of a driver in motion?* Moreover, a pressing issue is determining which factors affect whether that driver will yield or not. The safety of pedestrians on American roadways is a national public health issue. The total number of roadway fatalities and pedestrian fatalities has decreased over the last decade from 42,196 fatalities in 2001 to 32,885 fatalities in 2010 (table 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Fatalities</th>
<th>Pedestrian Fatalities</th>
<th>Pedestrian Percent of Total Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>42,196</td>
<td>4,901</td>
<td>12</td>
</tr>
<tr>
<td>2002</td>
<td>43,005</td>
<td>4,851</td>
<td>11</td>
</tr>
<tr>
<td>2003</td>
<td>42,884</td>
<td>4,774</td>
<td>11</td>
</tr>
<tr>
<td>2004</td>
<td>42,836</td>
<td>4,675</td>
<td>11</td>
</tr>
<tr>
<td>2005</td>
<td>43,510</td>
<td>4,892</td>
<td>11</td>
</tr>
<tr>
<td>2006</td>
<td>42,708</td>
<td>4,795</td>
<td>11</td>
</tr>
<tr>
<td>2007</td>
<td>41,259</td>
<td>4,699</td>
<td>11</td>
</tr>
<tr>
<td>2008</td>
<td>37,423</td>
<td>4,414</td>
<td>12</td>
</tr>
<tr>
<td>2009</td>
<td>33,883</td>
<td>4,109</td>
<td>12</td>
</tr>
<tr>
<td>2010</td>
<td>32,885</td>
<td>4,280</td>
<td>13</td>
</tr>
</tbody>
</table>

Based on the data, although the frequency of pedestrian crashes has decreased, the percentage of fatalities that are pedestrian related has plateaued (table 1). The percentage of pedestrian fatalities had been holding steady at 11% of total fatalities from 2002 to 2007. However, the percentage of pedestrian fatalities increased during the subsequent three years. The National Highway Traffic Safety Administration NHSTA lists a total of 4,280 pedestrian fatalities in 2010 and out of a total of 32,885 traffic fatalities, which is 13% (1). This, in the context of walking trips, comprises 10.9% of the 388 billion trips that Americans make every year (2).

Just for children ages 14 and younger, the total cost of pedestrian death and injury is $5.2 billion per year (3). Senior citizens above the age of 55 are at an especially high risk. Their rate of pedestrian deaths per 100,000 people is 66% higher for seniors compared to the under 55 age group (1). In terms of contributing factors, 29% of pedestrian fatalities were related to improper crossings and 15% due to failure to yield right of way at crossings. The low compliance rates of driver in terms of yielding to pedestrians at unsignalized locations is a serious issue (Figure 1).
All transportation users are pedestrians at some point in their trip. The fact that walking trips are environmentally friendly, and generally cost less to taxpayers and the user, is further motivation to make our streets pedestrian friendly. One of the places on the network where a pedestrian is vulnerable is in a crosswalk.

Researchers have identified myriad factors potentially involved in yielding rates, from street trees and traffic calming features to land use and cultural factors. The 85th percentile speed of drivers is but one variable yet it is one of the most critical factors. The research question for this paper is: How does a change in the 85th percentile speed of a driver change the yielding behavior to pedestrians of the approaching driver? The paper will analyze the yielding behavior of drivers to pedestrians at unsignalized crossings based on 85th percentile speeds (as opposed to posted speed limits.) The hypothesis of this research is that drivers have a tendency to stop with greater frequency for pedestrians in a crosswalk on low-speed streets (such as along 20 mph zones) as compared to high-speed streets.

Literature Review

Although there have been some investigations into driver yielding behavior, research studies have more commonly focused on pedestrian behavior while crossing. However, any research on yielding behavior to date has been based on posted speed limits rather than 85th percentile speeds, due to the ease of obtaining posted speed limits for large studies as compared to 85th percentile speeds. Nonetheless, past research is certainly relevant to set the stage for this paper.
Past research includes the Serpico (5) study, which looked at driver yielding rates on four-lane facilities with a speed limit of 45 miles per hour (mph). It focused on Rectangular Rapid Flash Beacons (RRFBs) and their impact on yielding rates.

The Serpico study specifically looked at before and after data at RRFBs. The average yielding rate prior to installation was 18%; following installation the average yielding rate more than tripled to 80%. The conclusion of the study was that RRFBs should be considered for installation on high-speed facilities where there are posted speeds greater than 35 miles per hour if there are non-motorized users using the facility and a history of crashes.

Another study, performed by Huybers, et al, (6) did not consider a variation in motor vehicle speed, but it considers the effect of signs and markings on yielding behavior. The study found that using road markings alone was more effective than using signs alone. Surprisingly, the study also found that using road markings alone was as effective as using signs and road markings together, meaning the markings were the critical aspect in increased yielding behavior. In particular, yield line marking consisting of a series of white triangles were the type that were used in the study. Motorist yielding rates for the latter situation varied from 72% to 81%, depending on the location of the site. In summary, markings are a key part of any mitigation measure. Fisher (7) had similar findings in his simulator-based study of advanced yield markings of mid-block crossings on multi-lane roads. The study found that advanced yield markings and prompt signs encouraged drivers to yield sooner and more often as compared to when the markings and signs were not placed on the roadway.

Finally, Turner (8) investigated motorist yielding rates to pedestrians in high-visibility crosswalks based on speeds. The study found that at 35 mph posted speeds, yielding rates averaged only 20%. That figure jumped to 91% yielding for 25 mph posted speeds. It also found that in-street crossing signs placed in streets in the 25-30 mph range led to 90% yield rates. The study did follow-up research on staged pedestrian crossings and a comparison of previous studies. He also reported that pedestrians using orange colored “pedestrian crossing flags” led to motorist yielding levels of 46-79%, with an average of 65%. Posted speeds were 30 to 35 mph and the study included two-lane roadways as well as four-lane roadways, although the report didn’t specify what the difference in yielding rates were for the different-sized roadways. Many of the aforementioned studies also measure driver yield rates although they correlate their results with posted speed limits. This study proposes to measure the 85th percentile speed and analyze trends with that data.

**Study Methodology**

The objective of this effort was to build upon findings of earlier research and develop a model for Boston area streets, the hypothesis being that speed is one of the main determinants that
relates to yielding – an inverse relationship – as the speed increases, the driver yielding rate decreases. Therefore, a methodology was designed to measure how driver speed affects yielding rates. This experiment was designed to be “staged” in order for each driver to be faced with the exact same pedestrian and have the exact same amount of time to react and decide whether they would yield or not yield. In theory, there would be a pattern in the results that would explain yielding behavior. An analysis of those results could help drive policy and practice with regards to design of urban roadways.

The two participants in the experiment were the pedestrian and the observer at each of the nine uncontrolled crossing locations. Eight of the locations were in Boston and one was in nearby Brookline, Massachusetts. The observer had a hand-held speed radar gun and a notebook to record the number of yields during attempted crossing events by the subject.

Two possible methodologies exist for an experiment such as this. One is to be “selective”, as the police would perform a “sting” operation. In that method, the pedestrian steps into the street as a driver is approaching, but with enough lead time for the driver to notice and brake. The other method is “random”. In this method, the pedestrian crosses, walks away for 10 to 20 seconds, then walks back and attempts to cross the street again. The challenge with the random version is that for some crossings there might be no conflicting vehicle, or the pedestrian might arrive in the middle of a platoon, making it difficult for the observer to decide which vehicle is supposed to be the one that yields. This research study employs the selective method.

The observer first used the radar gun to measure the speed of at least a dozen vehicles and obtain the 85th percentile speed. Then, only the free flowing vehicles going within two mph of the 85th percentile speed were recorded. If the 85th percentile speed was 30 mph, then the observer would only include the vehicles in the study going between 28 mph and 32 mph. Vehicles traveling at other speeds were disregarded. For every site, the pedestrian took one to two steps into the crosswalk when each vehicle was a distance of SSD away. Per the AASHTO guidelines the SSD formula is given as follows:

$$d = 1.47vt + \frac{v^2}{30((\frac{a}{32.2})\pm G)}$$

where $d$ is SSD in feet (ft); $t$ is brake-reaction time in seconds (s), where the typically value of 2.5 s was used; $v$ is design speed (mph); $a$ is deceleration rate (11.2 ft/s); and $G$ is grade (decimal) ($I$).

Consequently, for the 20 mph roadways, a 115-foot SSD was used, for the 30 mph roadways, a 200-foot SSD was used, and for the 40 mph roadways, a 305-foot SSD was used. A bright
orange cone was placed a distance of SSD one direction from the crosswalk, and then another cone was placed a distance of SSD in the other direction from the crosswalk. That way, the pedestrian could choose to have a vehicle yield from either side. Taking one to two steps into the street is considered a relatively assertive maneuver for a pedestrian attempting to cross the street. The assertive pedestrian maneuver was consistent throughout the data collection. Locations were chosen so there were not sight-distance issues with lack of visibility of the pedestrian. If there was on-street parking on a particular street, a site was chosen where there were no vehicles within 30 feet of the crosswalk, there were no sight distance issues, and the pedestrian would stand in a place close to the traveled way where the effective crossing width was two lanes, as can be seen in figure 2 below.

![Figure 2: Site Location Showing Effective Pedestrian Crossing Width is Two Lanes](image)

The observer stayed out of sight with the radar gun (by staying in a parked car strategically placed) so as to not influence the speed of the drivers. The observer would note each yielding event as the pedestrian stepped off the street. A total of 100 observations were recorded per location for a grand total of 900 yielding or no-yielding events. The radar gun was pointed at an acute angle as possible to the traffic to minimize errors in the speed readings. To account for any errors, the speed readings were corrected by multiplying the individual observations by the cosine of the angle, per manufacture’s recommendations.
Study locations

The study area is located in eight marked crosswalk locations at intersections in Boston and one intersection in Brookline, Massachusetts. All sites were “uncontrolled” locations. During site identification, a preliminary assessment was conducted prior to a site visit to identify locations that had similar geometry, lane configuration, parking, and surrounding land use (Table 2).

Every attempt was made to keep consistency across all locations in terms of lane width, lane use, parking type and other roadway characteristics. All are two lane facilities, with the exception of Hyde Park Avenue at Eldridge Road, which is a four-lane divided roadway. All of the locations had marked crosswalks. None of the locations have traffic calming features such as raised intersections, raised crossings, or humps, any of which would likely affect the results. For example, Gibson Street at Dorchester Avenue has on-street parking and is in a mixed-use location while King Street at Adam Street has no on-street parking and is in a residential location. Centre Street has on-street parking and dense residential land use with a higher demand for pedestrian use, compared to West Roxbury Parkway, which has no on-street parking and a “park-like” feel due to the tree-lined roadway with houses that have large front yards. None of the locations have advanced yield markings.

Once onsite, the author used a radar instrument to attempt to find locations that generally fit one of three 85th percentile speeds: 20 mph, 30 mph, or 40 mph. It was difficult to find marked crosswalks without signals on 40 mph roadways, but several came close to fitting the criteria, which includes being uncontrolled with a similar number of lanes.
Table 2: Study Locations by Speed, Lane Configuration, On-Street Parking, and land Use

<table>
<thead>
<tr>
<th>Location</th>
<th>85th%ile Speed Group (mph)</th>
<th>Number of Lanes</th>
<th>On-Street Parking</th>
<th>Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibson Street at Dorchester Avenue</td>
<td>20</td>
<td>2</td>
<td>Yes</td>
<td>Mixed</td>
</tr>
<tr>
<td>Auckland Street at Savin Hill Avenue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St Paul Street at Sewall Avenue</td>
<td></td>
<td></td>
<td></td>
<td>Residential</td>
</tr>
<tr>
<td>King Street at Adam Street</td>
<td></td>
<td></td>
<td></td>
<td>Residential</td>
</tr>
<tr>
<td>Mayfield Street at Pleasant Street</td>
<td>30</td>
<td>2</td>
<td>No</td>
<td>Residential</td>
</tr>
<tr>
<td>Dorchester Avenue at Van Winkle St</td>
<td></td>
<td></td>
<td>Yes</td>
<td>Mixed use</td>
</tr>
<tr>
<td>Hyde Park Avenue at Eldridge Road</td>
<td></td>
<td>2</td>
<td>Yes</td>
<td>Residential</td>
</tr>
<tr>
<td>Fletcher Street at Centre Street</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Hill Rd at W Roxbury Parkway</td>
<td></td>
<td>4</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

In the study there are two 20 mph streets in Brookline and one in Boston, both are located in Dorchester (Figure 3). Their locations are as follows:

- Gibson Street at Dorchester Avenue
- Auckland Street at Savin Hill Avenue
- St Paul Street at Sewall Avenue in Brookline

Unsignalized pedestrian crossings are less common at 30 mph as compared to 20 mph streets, but nonetheless there are several of them in Boston, enough that a sufficient number of yield-or-no-yield events were collected to generalize some results. All three of the 30 mph sites chosen for this study are in Dorchester. Their locations are as follows:

- King Street at Adam Street
- Mayfield Street at Pleasant Street
- Dorchester Avenue at Van Winkle Street
Unsignalized pedestrian crossings at with 85th percentile speeds at 40 mph proved difficult to find, but the most appropriate locations found are all in Boston and they are as follows:

- Hyde Park Avenue at Eldridge Road
- Fletcher Street at Centre Street
- Peak Hill Road at West Roxbury Parkway

**Figure 3: Locations for Pedestrian Yield Study in Boston and Brookline, MA**

In order to ensure that the sample size was sufficient, an analysis of the required sample size given a certain probability of success was performed on the data. For the eight chosen locations, the following equation was used:

\[ n = \left[ p(1-p) \right] \times (Z/E)^2 \]

where

- \( n \) = the required sample size
- \( p \) = the probability of success (of yielding, in this case)
- \( Z \) = the value that corresponds to a certain percentile
- \( E \) = the margin of error

For \( Z \), the value chosen was the 95 percentile so the figure that corresponds to that percentile is 1.96. The \( E \), (margin of error) chosen was 0.10 while a \( p \) of 0.5 was used. The analysis showed
that the required sample size \( (n) \) equals 96.04, equating to at least 97 yield-or-no-yield observations per location to ensure that there is a 95 percent chance that the average of the observations will be within 0.10 of the actual value. Therefore, 100 observations were performed at each location.

**Results and Discussion**

The results of this research centered on the driver speed and yielding rates to pedestrians in uncontrolled, marked crosswalks. The 85th percentile speed was recorded on-site with a radar instrument and was used as the 85\(^{th}\) percentile speed. The driver did not have to come to a complete stop for an event to be considered a yield event. A driver was considered to be yielding if he or she slowed enough to let the pedestrian cross. The yielding rates, and the maximum and minimum speeds recorded varied by site. Figure 4 below shows the raw data and whether statistical significance was reached.

**Table 3: Raw Data and Statistical Significance for Yielding Events**

<table>
<thead>
<tr>
<th>Location</th>
<th>Speed Group (mph)</th>
<th>Maximum speed (mph)</th>
<th>Minimum speed (mph)</th>
<th>85th%ile speed (mph)</th>
<th>Number of yield events</th>
<th>Number of observations</th>
<th>Percentage yielding</th>
<th>Statistically significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auckland Street at Savin Hill Avenue</td>
<td>x</td>
<td>22</td>
<td>18</td>
<td>20</td>
<td>75</td>
<td>100</td>
<td>75%</td>
<td>Yes</td>
</tr>
<tr>
<td>Gibson Street at Dorchester Avenue</td>
<td>x</td>
<td>24</td>
<td>20</td>
<td>22</td>
<td>73</td>
<td>100</td>
<td>73%</td>
<td>Yes</td>
</tr>
<tr>
<td>St Paul St at Sewall Ave (in Brookline)</td>
<td>x</td>
<td>25</td>
<td>21</td>
<td>23</td>
<td>63</td>
<td>100</td>
<td>63%</td>
<td>Yes</td>
</tr>
<tr>
<td>King Street at Adam Street</td>
<td>x</td>
<td>32</td>
<td>28</td>
<td>30</td>
<td>40</td>
<td>100</td>
<td>40%</td>
<td>Yes</td>
</tr>
<tr>
<td>Dorchester Avenue at Van Winkle St</td>
<td>x</td>
<td>29</td>
<td>25</td>
<td>27</td>
<td>52</td>
<td>100</td>
<td>52%</td>
<td>Yes</td>
</tr>
<tr>
<td>Mayfield Street at Pleasant Street</td>
<td>x</td>
<td>31</td>
<td>27</td>
<td>29</td>
<td>42</td>
<td>100</td>
<td>42%</td>
<td>Yes</td>
</tr>
<tr>
<td>Fletcher Street at Centre Street</td>
<td>x</td>
<td>39</td>
<td>35</td>
<td>37</td>
<td>17</td>
<td>100</td>
<td>17%</td>
<td>Yes</td>
</tr>
<tr>
<td>Peak Hill Rd at West Roxbury Parkway</td>
<td>x</td>
<td>39</td>
<td>35</td>
<td>37</td>
<td>19</td>
<td>100</td>
<td>19%</td>
<td>Yes</td>
</tr>
<tr>
<td>Hyde Park Avenue at Eldridge Road</td>
<td>x</td>
<td>40</td>
<td>36</td>
<td>38</td>
<td>9</td>
<td>100</td>
<td>9%</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The general driver yielding trend, as expected, is inverse to speed. As speeds increase, yielding rates decrease, from 75% yield rates at 20 mph speeds to 9% yield rates at 38 mph speeds. Interestingly, Hyde Park Avenue at Eldridge Road was the only four-lane roadway in the study area and the increased crossing distance resulted in a reduction in yield rate.

The data were relatively consistent in that the sites in the 40 mph speed group that were two-lane streets showed relatively similar yield rates, at 17%, and 19% when compared with the lower speed approaches. In the other two speed groups, the yield rates ranged up to 12%. The three sites in the 30 mph speed group had yield rates at 40%, 42%, and 52%. For the 20 mph speed group, the three sites had yield rates of 63%, 73%, and 75%. It should be noted that at St. Paul Street at Sewall Avenue, the results were recorded as the sun was beginning to set and with the drivers having the sun in their eyes they might be less likely to yield if they can’t see the pedestrian. Consequently that location had only a 63% yield rate, compared to 73% and 75% for two other sites with similar 85th percentile speeds. All the data were collected during daylight hours in order to stay consistent. Two of the locations have the exact same 85th percentile speed of 37 mph, namely Fletcher Street at Centre Street and Peak Hill Rd at West Roxbury Parkway.

Figure 4: Driver Speed and Yielding Compliance at the Nine Study Locations in the Boston and Brookline Area
Ideally, the yield rates would be the same for both. However, the latter had a higher yielding rate (19% compared to 17%) possibly due to the increased sight distance along West Roxbury Parkway. Nonetheless, it is somewhat counterintuitive that Centre Street would have a lower yielding rate given that it has on-street parking, dense residential land use and relatively few trees, compared to West Roxbury Parkway, which has no on-street parking and large leafy trees. Further study is recommended to account for these variables.

**Consistent Trends**

In order to determine whether or not there is a relationship between the data, the data were plotted and observations were made (Figure 4). The eight, two-lane roadway locations were analyzed for observable and transferrable trends, while the ninth location, Hyde Park Avenue at Eldridge Road, the only four-lane road, was removed from the sample set due to its uniqueness to the data set. Based on the scatter plot and the observable trend, a regression analysis (linear) of the two-lane roads was performed to identify how strong the relationship is between the 85th percentile approach speeds and yield rates. The best-fit line had an $R^2$ of 0.99, indicting an almost perfect linear relationship for the observed data.

![Figure 5: Relationship Between Yielding Rate and Approach Speed for the eight two-lane road locations](image_url)
Conclusions and Recommendations

This paper builds upon previous research to study the effect of motor vehicle speeds on yielding to pedestrians. The hypothesis stated earlier proved correct, that pedestrian yielding will decrease as driver speed increases. The data show that increasing speeds are inversely correlated with decreasing yield rates – as driver speed increases, the yielding rate decreases. Based on the observed data, there is a linear relationship – with an $R^2$ of 0.99.

This report certainly complements past research. For one, it is geographically specific so it may be especially useful for any projects implemented in the New England area. More importantly, the study was completed with 85th percentile speeds instead of posted speed limits, which give a more accurate representation of the actual situation in the field. It is well known from research by Eric Dumbaugh (10) that it is not the posted speed limit that sets the 85th percentile speed but rather characteristics of the built environment that set that speed.

This formalized study provides data that can potentially be used to mitigate the lack of a safe crossing. This research could provide a springboard for a potentially much larger, multi-year, study to further analyze the impacts of speed on yielding. An option for future research is to find several four-lane roads with the same characteristics, collect data on pedestrian yielding, and then analyze that data collectively. One added characteristic to measure in future research is gap size and how it affects yielding rates. This research has demonstrated that the data collection approach of using a hand-held radar gun to gauge speed while recording yield or no-yield events of motorist compliance is simple, feasible and recommended for future research studies.

Engineers may want to consider implementing a speed reducing measure near marked crosswalks on high-speed (e.g., greater than 30 mph) to promote driver yielding.
REFERENCES


(7) Fisher, Donald and Lisandra Garay-Vega, University of Massachusetts, Amherst, Advanced Yield Markings and Drivers’ Performance in response to Multiple-threat Scenarios at Mid-block Crosswalk, Accident Analysis & Prevention, Volume 44, Issue 1, January 2012.

