Improving Pedestrian Safety at Signalized Intersections: Impacts of Corner Radius

Article *in* Ite Journal · June 2022

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Improving Pedestrian Safety at Signalized Intersections: Impacts of Corner Radius

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Many transportation agencies are placing greater emphasis on improving pedestrian safety and reducing the risk for a fatality or serious injury to pedestrians. Both safety and design practitioners require a methodical approach to assess pedestrian safety benefits for different countermeasure options. A crash modification factor (CMF) is a measure of the safety effectiveness of a treatment or design element. By adding to the availability of reliable CMFs and gaining an understanding of how design elements affect operating speed, agencies can aid the implementation of effective countermeasures for addressing pedestrian crashes.

A recent Federal Highway Administration (FHWA) project was established to determine the safety effectiveness of low- to medium-cost engineering countermeasures in reducing pedestrian fatalities and injuries at controlled and uncontrolled intersections.[1] The project started with FHWA researchers identifying the pedestrian treatments in use along with the preference for which treatments need a CMF. By using these findings, the FHWA stakeholder engagement working group set the research direction to investigate the relationship between intersection corner radius design with crashes and intersection corner radius with turning speed.

Pedestrian or Right-Turn Crashes Associated with Corner Radius

The researchers began the statistical evaluation of the relationship between intersection corner radii and crashes at signalized intersections by identifying potential sites. The research team selected intersections with the following characteristics:

- Movement count (vehicles and pedestrians) for at least 2 hours.
- Traffic control signal is present.
- Typical geometric intersection configurations (including three- and four-leg intersections) are present. Intersections with five legs or a large skew were removed.
- Known or visible (from aerial photos) road or sidewalk construction is not present during the years matching the crash data.

The research team obtained preexisting vehicle turning movement and pedestrian counts for signalized intersections in three U.S. cities (Richmond, VA; Bellevue, WA; and Portland, OR). The research team used expansion factors to convert the available counts, which were typically only for several hours within a day, to represent a daily, and then an annual, value for both vehicles and pedestrians. Crash data were collected in Washington between 2011 and 2017 (7 years), in Virginia between 2013 and 2018 (6 years), and in Oregon between 2012 and 2017 (6 years).

Methodology

The radius of each corner of an intersection can be unique; therefore, the research team attempted to assign crashes to an intersection corner rather than to the entire intersection by using information on the latitude and longitude of the crash, along with information on the vehicles' directions and the crash type. Because these two methods did not always lead to the assignment of the crash to the same corner, the research team included a weighting scheme in the analysis to consider the level of certainty that the crash was being assigned to the correct corner—crashes with a higher certainty level would thus influence the result more than crashes with a lower certainty level.

The research team considered the vehicle volumes on the legs (both directions of traffic) adjoining the intersection corner of interest for the pedestrian crash evaluation and on the samedirection lanes nearest to the corner for the right-turn analysis. The pedestrian and bicyclist (when available) volumes included the number of pedestrians and bicyclists who were on the two legs that connected the corner of interest. The research team assembled a spreadsheet with one record for each intersection corner (i.e., a fourleg intersection would be described by four records) that included the roadway characteristics that describe the approaching and receiving legs in relation to the right-turn movement at the corner. For example, the southeast corner's record would include variables to describe the south (approach) and east (receiving) legs. The research team used aerial and street-level photography sources available online to extract roadway characteristics for each corner.

For the corner analyses, the research team used generalized linear mixed-effects models to perform the safety analyses. After the research team performed exploratory and preliminary analyses, they used the Virginia dataset (1,017 corners) because its large size produced more stable coefficients and because a greater proportion of the corner crash assignments had a high level of certainty for being assigned to the correct corner.

Results—Pedestrian Crashes

For signalized intersection corner-level pedestrian crashes, the following variables were found to be positively related (i.e., the number of pedestrian crashes increased as the value of the variable increased):

- Pedestrian/bicyclist volume on the approach leg
- Pedestrian/bicyclist volume on the receiving leg
- Vehicle volume on the approach leg
- Vehicle volume on the receiving leg
- Corner radius
- Shoulder width

The number of pedestrian crashes was higher when both legs at a corner were one-way streets, with traffic moving away from the corner, or when there was a mix of two- and one-way operations present at the intersection. Fewer pedestrian crashes occurred when on-street parking existed on the approach leg.

Results—Right-Turn Crashes

For corner-level, right-turn vehicle crashes, including pedestrian crashes when the involved vehicle was turning right or a single-vehicle or multiple-vehicle crash when one of the vehicles was turning right, the following results were found:

- Pedestrian/bicyclist and vehicle volumes on the approach and receiving legs were positively related
- Number of vehicles making a right turn at the corner was positively related to the number of right-turn crashes

- Other variables that were positively related to corner-level, right-turn crashes included the presence of a median or the shoulder width on the receiving leg
- Variables that were associated with fewer right-turn crashes included one of the legs having only one lane on the approach or the intersection having four legs rather than three legs

Results—CMF

The focus of the corner-level safety analysis was to investigate the relationship between the intersection corner radius and pedestrian crashes. For pedestrian crashes, the evaluation found a statistically significant relationship with corner radius. The statistical model estimate for corner radius can be used to generate a CMF. The pedestrian CMFs for the range of corner radii included in the evaluation, assuming a baseline condition of a 10-foot (3 meter [m]) radius, are shown in Figure 1. In general, the relationship between corner radii and pedestrian crashes is directly proportional: On average, larger corner radii at a signalized intersection are associated with more pedestrian crashes. For example, Figure 1 shows that with everything else being equal, 39 percent more pedestrian crashes are expected at a location with a corner radius of 40 ft. compared with a location with a corner radius of 10 feet (ft.) (3 m). The largest contrast seen in the figure is between 70-(21.3 m) and 10-ft. radii. The former is expected to experience about 59 percent as many pedestrian crashes as the latter (from a corresponding CMF of 1.59).

Pedestrian Crashes at Signalized Intersections

The analysis of the pedestrian crashes at signalized intersections considered data for 299 intersections in Oregon, Washington, and Virginia. Both three- and four-leg signalized intersections with streets with two-way traffic operations were represented. The best model found an increase in pedestrian crashes with increases in pedestrian and bicycle volume, major street vehicle volume, or minor street vehicle volume. These results were not surprising because it is reasonable to assume that pedestrian crash risk will grow with the increasing exposure of pedestrians to vehicles at an intersection.

Although the dataset represented several median types, only the condition of a leftturn lane without a raised median (LTLwoR) remained in the statistical model. The other groups—none, raised, and mixed median types—did not remain in the model. One hypothesis for why more pedestrian crashes are occurring is a lack of pedestrian refuge areas on major streets with an LTLwoR. Major streets with no median also lack pedestrian refuge areas, yet a similar finding of greater pedestrian crashes was not found. Therefore, additional research may be needed to fully understand this relationship. The research team found that all the sites with an LTLwoR had four or more through lanes than the other intersections in the dataset, which included intersections with only two through lanes. Although the number of through lanes was not found to be statistically significant, a larger sample size may add to the understanding of how median design is associated with pedestrian crashes. Figure 2 illustrates the findings from the prediction model for a range of major road volumes. The model is available in the research report.[1]

Right-Turn Speed

This study explored the relationship between observed right-turn vehicle speeds and roadway geometrics, especially corner radii, at signalized intersections.

Figure 1. Corner radius CMF for pedestrian crashes based on the Virginia model.[1]

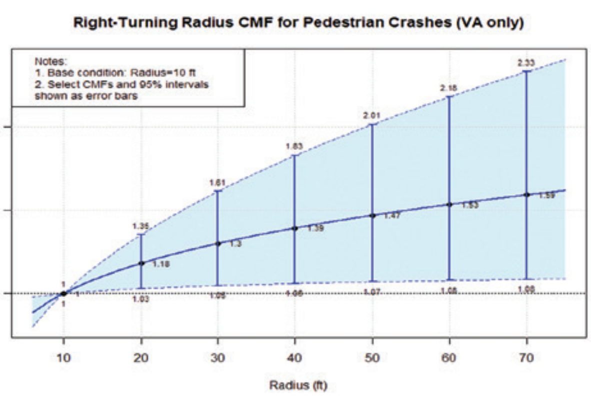
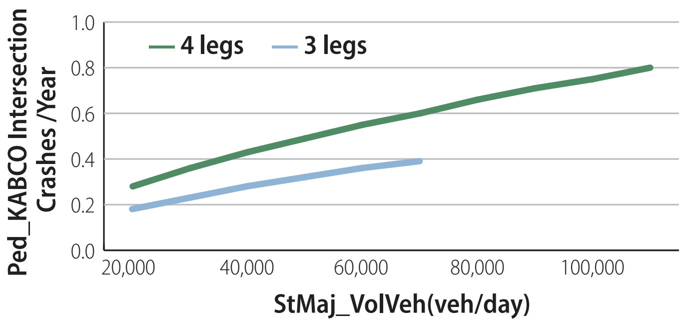


Figure 2. Pedestrian intersection crash model predictions by major vehicle volumes and number of legs.[1]



Base conditions:

State = Virginia or Oregon; Median = LTLwoR, each major volume curve plotted at mean value of StMin_VolVeh and t_ent_PedBike:

4L StMin_VolVeh = 19,214 veh/day.

3L StMin_VolVeh = 14,781 veh/day.

4L t_ent_PedBike = 767 ped or bikes/day.

3L t_ent_PedBike = 613 ped or bikes/day.

St = street; Veh = vehicle; Vol = volume.

Site Selection and Methodology

The study included 31 sites, with radii varying between 15 (4.6 m) and 70 ft. The study also considered other roadway variables, including type of right-turn lane, number of right-turn lanes, length of right-turn lane, distance to nearest upstream and downstream driveways, number of lanes on the receiving leg, and speed limit. No bike or parking lanes were present on the approach or the receiving leg for any of the sites. All sites were at a signalized intersection.

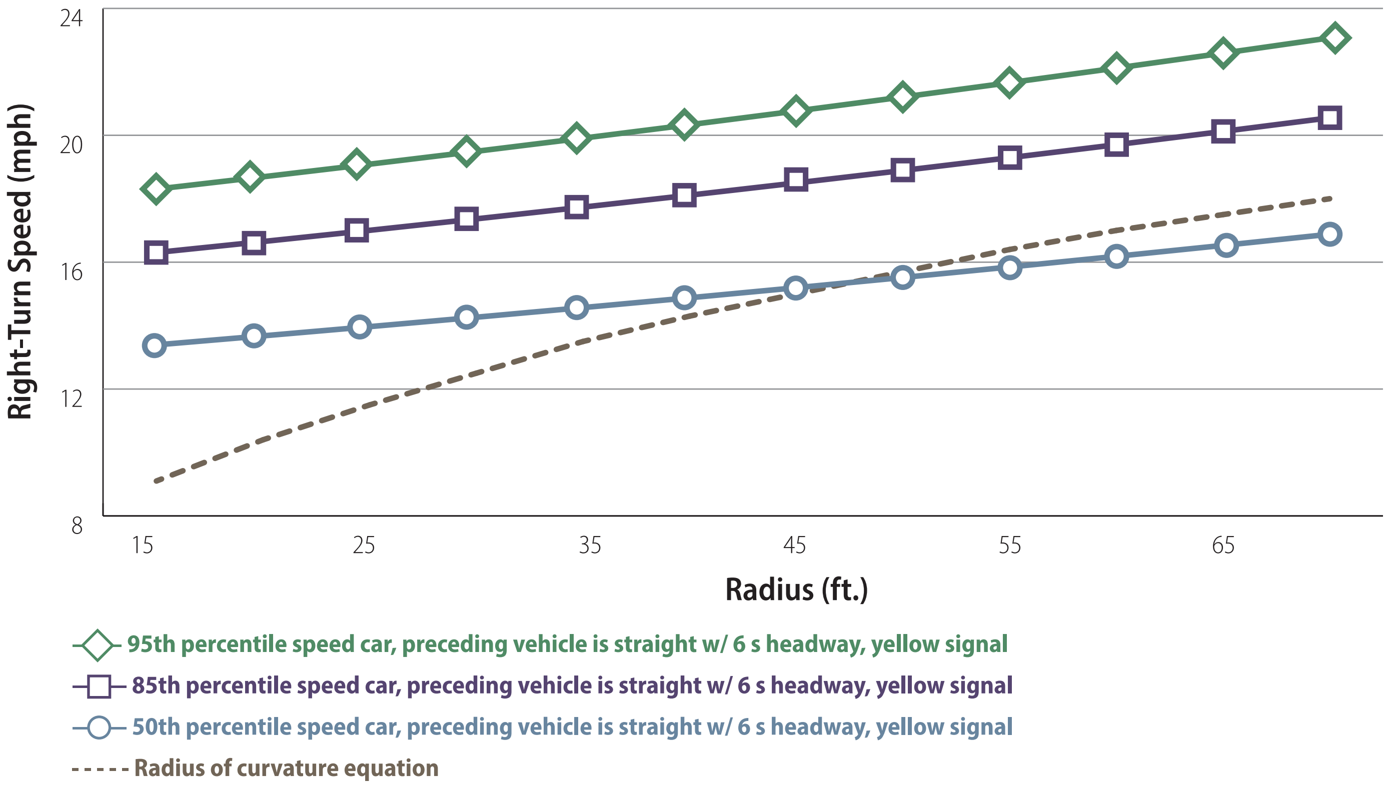
The right-turn speed measurement methodology involved collecting video footage at signalized intersection approaches and postprocessing the footage to extract speed measurements, along with headway between the turning vehicle and the preceding vehicle. This study allowed the inclusion of variables that described conditions that were present when the subject vehicle was turning right, including the signal indication (steady circular green indication or steady circular yellow indication), type of turning vehicle (car or truck), and characteristics of the vehicle immediately preceding the turning vehicle (going straight or turning right).

Results

The analysis found that conditions during the specific right turn (i.e., headway, signal indication) are more influential than the site characteristics (i.e., length of right-turn lane), except for corner radius. The analysis found convincing evidence that right-turn speeds are a function of corner radius. The increase in turning speed for corner radii between 15 and 70 ft. was about 4 miles per hour (mph) (2.5 kilometers per hour [km/hr]). The larger the corner radius, the higher the turning speed. The final selected model from this study can be used to predict turning speeds at different speed distribution values. For example, for the 85th percentile, the value of Z is 1.0364, which amounts to approximately 23 percent faster right-turn speeds than the median speed.

The range of speeds rather than just the average speed should be considered when evaluating how traffic is operating at an intersection, especially with respect to safety and to pedestrians. The equation, available in the final research report, can be used to calculate a range of expected speeds rather than just the average speed.[1] The resulting predicted right-turn speeds were compared with the speeds that were generated by using the radius of curvature equation. The radius of curvature equation is available from several sources, including the American Association of State Highway and Transportation Officials' *A Policy on Geometric Design of Highways and Streets* (commonly known as the Green Book).[2] Figure 3 shows the speeds comparison using calculated 50th, 85th, and 95th percentile right-turn speeds for a turning car (rather than a truck),

Figure 3. Comparison of predicted percentile right-turn speeds and radius of curvature equation.[1]



on a yellow (rather than green) signal, and for when the preceding vehicle is going straight with a headway of 6 seconds. The figure demonstrates that the speed prediction, when using observed rightturn vehicles, has 50th percentile (median) turning speeds higher than when the values are calculated by using the radius of curvature equation for radii up to 45 ft. (13.7 m). For radii greater than 45 ft., the 50th percentile turning speed is slightly below the radius of curvature equation. For all radii values, all the predicted 85th or 95th percentile speeds are greater than the value generated with the radius of curvature equation.

Computer simulation of vehicle operations at an intersection can consider speed distribution that may be reflective of a site or a condition. The newly developed equation can be used with the necessary assumptions to generate a distribution, or the field data can provide a general speed distribution for right-turn vehicles. Figure 4 provides the speed distribution for a sample of corner radius values by using the equation available in the research report along with the average speed observed for comparison.[1]

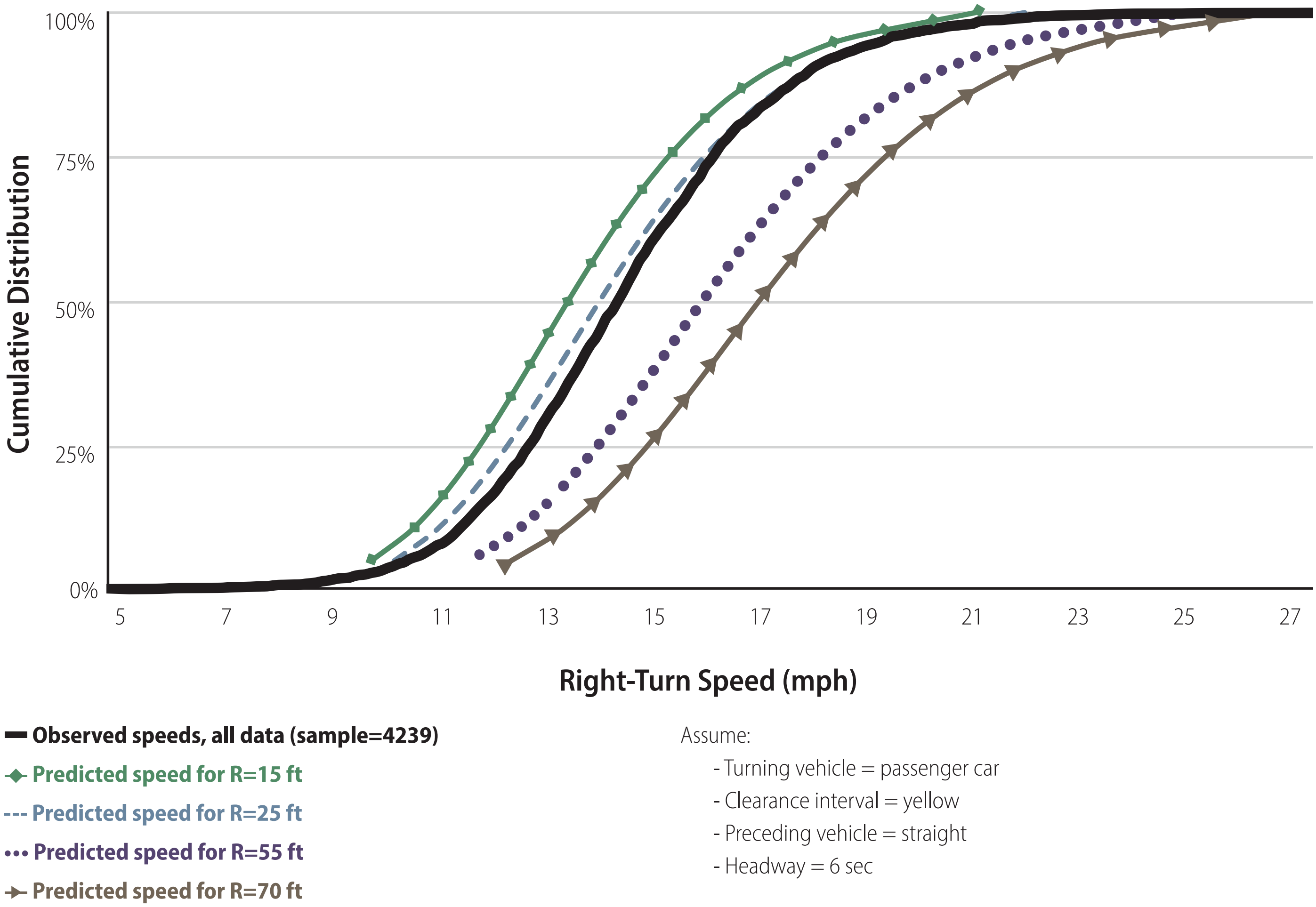
Conclusions

Findings

This project investigated the influence of intersection corner radius on pedestrian crashes, rightturn crashes, and right-turn vehicle speed. The corner radius can be unique to each corner at an intersection; therefore, this study assigned crashes to an intersection corner rather than to the entire intersection. This study's findings support the development of a CMF for corner radius. Assuming a baseline condition of 10 ft., the pedestrian CMFs for corner radius for the range of corner radii included in the evaluation went from 1.00 for a 10-ft. radius to 1.59 for a 70-ft. radius. This study also generated a crash prediction equation for pedestrian crashes at signalized intersections.

The findings from the operational study of right-turn speeds can be used to update the discussion contained in design manuals, especially with respect to designing intersections. For example, the National Association of City Transportation Officials recommends limiting right-turning speeds to 15 mph

Figure 4. Predicted passenger car right-turn speed distribution.[1]



(9.3 km/hr) or less, and the equation provided in the research report can be used to predict the geometric influence of a corner radius design on the anticipated speed of the right-turning movement to compare with the target criteria.[1,3]

Future Research Needs

This research identified areas needing additional investigations. Additional research focusing on pedestrian crashes at signalized intersections could look more closely at the difference in the number of crashes with one-way and two-way traffic patterns. The statistical analysis found moderate evidence of an increase in the odds of pedestrian crashes occurring at locations where both the approach leg and the receiving leg of the intersection are one way, with traffic moving away from the corner.

Additional research could help agencies explore other variables that would affect right-turn speed, such as the presence of parking or bike lanes. The research should consider whether vehicles are present in the parking spaces to understand how the additional space, which changes the effective radius, influences turning speeds. Future research could also explore speed differences that occur when the roadway has a shoulder versus a curb and gutter. Similarly, a truck apron can be used to accommodate large trucks at an intersection corner, and research is needed on the effects of the truck apron design components on turning speed. **itej**

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