TECHBRIEF

Crash Modification Factor for Corner Radius, Right-Turn Speed, and Prediction of Pedestrian Crashes at Signalized Intersections

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This document is a technical summary of the Federal Highway Administration report *Crash Modification Factor for Corner Radius, Right-Turn Speed, and Prediction of Pedestrian Crashes at Signalized Intersections* (FHWA-HRT-21-105).

INTRODUCTION

Many transportation agencies are placing greater emphasis on improving pedestrian safety and reducing the risk of a fatality or serious injury to pedestrians. Nonmotorized fatalities and serious injuries have also been a part of safety performance measures. Pedestrian safety practitioners need and ask for a methodical approach to assess pedestrian safety benefits for different countermeasure options. The Crash Modification Factors Clearinghouse provides several crash modification factors (CMFs). A CMF is a measure of the safety effectiveness of a treatment or design element. Most of the available CMFs related to pedestrian crashes, however, do not have a reliable star rating. Adding to or expanding the availability of reliable CMFs can aid in the implementation of effective countermeasures for addressing pedestrian crashes.

STUDY OBJECTIVE

The objective of this Federal Highway Administration (FHWA) project was to determine the safety effectiveness of low- to medium-cost engineering countermeasures in reducing nonmotorist (i.e., pedestrian) fatalities and injuries at controlled and uncontrolled intersections.[1] The project started with a survey to identify the use of pedestrian treatments and preference for which treatments need a CMF. Using the survey findings, the FHWA stakeholder engagement working group set the research direction for investigating the relationship of intersection corner radius design with crashes and turning speed.

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The following three analyses were completed and are summarized below:

- Signalized intersection corner radius CMF.
- Pedestrian crashes at signalized intersections.
- Right-turn speed.

SIGNALIZED INTERSECTION CORNER RADIUS CMF

The analysis aimed to determine the safety effectiveness of intersection corner radii in reducing nonmotorist crashes at signalized intersections.

Site Selection

For the signalized intersection corner radius CMF study and the pedestrian crashes at signalized intersections study, the research team selected intersections with the following characteristics:

- At least a 2-h turning movement count of the number of vehicles and pedestrians present.
- Traffic control signal presence.
- Typical intersection geometric configurations (including three- and four-leg intersections). Intersections with five legs or a large skew were removed.
- No visible road or sidewalk construction during the years matching the crash data.

The research team obtained data files, collected by a consultant for another project, of vehicle turning movement and pedestrian counts for signalized intersections in three cities (Richmond, VA; Bellevue, WA; and Portland, OR).[1] Since the count data were generally only collected for several hours within a day, the counts were expanded using appropriate expansion factors 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 yr), Virginia between 2013 and 2018 (6 yr), and Oregon between 2012 and 2017 (6 yr).

Methodology

The radius of each corner of an intersection can be unique; therefore, this study 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 directions in which the vehicles were moving 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 created a weighting scheme 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. For the Oregon dataset, the assignment showed that most of the crashes were assigned to the southeast corner, which was different from the distribution of vehicle or pedestrian volumes that, overall, had a similar distribution for all corners. Therefore, the data for Oregon were not included in the corner-level analysis but were included in the intersection-level analysis.

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 same direction lanes nearest to the corner for the right-turn analysis. The pedestrian volumes included the number of pedestrians 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 four-leg intersection would be described by four records) and variables to 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 the following observations to describe each corner:

- Number of lanes on each leg.
- Traffic configuration of each leg—two-way, one-way with traffic approaching intersection, or one-way with traffic departing intersection.
- Corner radius for the right-turn movement.
- Lane and shoulder widths (or presence of curb) on each leg.
- Right-turn lane presence and type on the approach leg.
- Curb extension presence.
- Right-turn channelizing island presence.

[1] Data files were obtained by the research team via personal communication from the cities.

- Bike lane presence.
- Development type—residential, commercial/retail/industry, or rural/parks.
- Distance to nearest driveways, if within 300 ft of the corner.
- Median type on each leg—none, left-turn lane without raised pedestrian refuge (LTLwoR), raised, or flush paved.
- Presence and type of on-street parking on each leg—none, parallel, angle, or perpendicular.
- Posted speed limit on the approach leg.
- Pedestrian crossing distance across each leg of the intersection.

For the corner analyses, the research team used generalized linear mixed-effects models to perform the safety analyses. After performing exploratory and preliminary analyses, the research team selected the modeling process using the Virginia dataset (1,017 corners). The combined Virginia and Washington models (1,285 corners) included a State variable indicating that there were significant differences between the two subsets of data. The Virginia dataset was selected because its larger 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 (for example, with the weighting scale, 69 percent of the Virginia corners had a high level of certainty, whereas only 61 percent of the Washington corners had a high level of certainty).

Results

For 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 volume on the approach leg.
- Pedestrian 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.

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 and vehicle volumes on the approach and receiving legs were found to be positively related.
- The number of vehicles making a right turn at the corner was also positively related to the number of right-turn crashes between a turning vehicle and pedestrians.
- Other variables positively related to corner-level, right-turn crashes included the presence of a median or the shoulder width on the receiving leg.
- Variables 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.

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 considered. The best model found convincing evidence of an increase in pedestrian crashes with increases in pedestrian and bicycle volume, major street vehicle volume, or minor street vehicle volume for Oregon and Virginia. Overall, and using a general rule-of-thumb summary, a 10 percent increase in any of these volumes corresponded to about a 5 percent increase in pedestrian crashes. This result is not surprising, since it is reasonable to assume that pedestrian crash risk will increase with increasing exposure of pedestrians to vehicles at an intersection.

While several median types were represented in the dataset, only the LTLwoR remained in the statistical model, whereas 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 this lack of a pedestrian refuge on major streets with an LTLwoR. Major streets with no median also lack pedestrian refuge, yet a similar finding of greater pedestrian crashes was not present. Therefore, additional research may be needed to fully understand this relationship. The research team notes that all the sites with an LTLwoR had four or more through lanes compared with the other intersections in the dataset that included intersections with only two through lanes. While the number of through lanes was not significant, a larger sample size may add to the understanding of how median design is associated with pedestrian crashes. Everything else being equal, pedestrian crash frequency increased by a factor of 1.5636 when an LTLwoR was present on the major street compared with the presence of all other median types (none, raised, or a mix of median types for the major street approaches).

RIGHT-TURN SPEED

This study explored the relationship between observed right-turn vehicle speeds and roadway geometrics, especially corner radii, at signalized intersections. Right-turning-vehicle volume affects intersection capacity and delay. The interactions between pedestrians and right-turning vehicles also contribute to pedestrian delay and exposure. The selection of a large radius for a corner permits higher turning-vehicle speeds in free-flow situations. The higher turning-vehicle speeds may result in smaller speed differentials with vehicles that are following, leading to less severe rear-end conflicts in the through lanes. While the potentially increased vehicle speed through the right-turn lane is more efficient for the driver, trade-offs exist for this design. Increased vehicle speeds create more challenges for pedestrians attempting to cross the roadway. Some of these challenges include the evaluation of vehicle gaps, the drivers' expectation that they do not have to stop since a free-flow right-turn lane is present, and the potentially increased severity of vehicle-pedestrian crashes. While it is commonly accepted that a larger corner radius is associated with higher turning speed, few studies have attempted to quantify that relationship.

Site Selection

Because the goal was to identify the relationship between the corner radius and right-turn speed, the research team selected sites with a range of corner radii so a relationship could be derived. The analysis included a total of 31 sites with a range of radii varying between 15 and 70 ft. Other geometric variables considered included 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.

Methodology

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 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). The conditions during the specific right turn (e.g., headway, signal indication) are more influential than the site characteristics, except for corner radius.

Results

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 mph. The larger the corner radius, the higher the turning speed.

The final selected model from this study can be used to predict turning speeds. The model includes the following variables: corner radius (range of 15 to 70 ft), headway to preceding vehicle, signal indication (yellow or green), vehicle type (truck or car), and preceding vehicle movement (going straight or turning). For example, assuming the preceding vehicle goes straight through the intersection with a 6-s headway to a car that is turning right on a yellow indication, the range of the median turning speed is 13.1 mph for a 15-ft corner radius to 16.8 mph for a 70-ft corner radius. The range of the 85th percentile speed with these assumptions is 16.0 to 20.4 mph for corner radii of 15 to 70 ft.

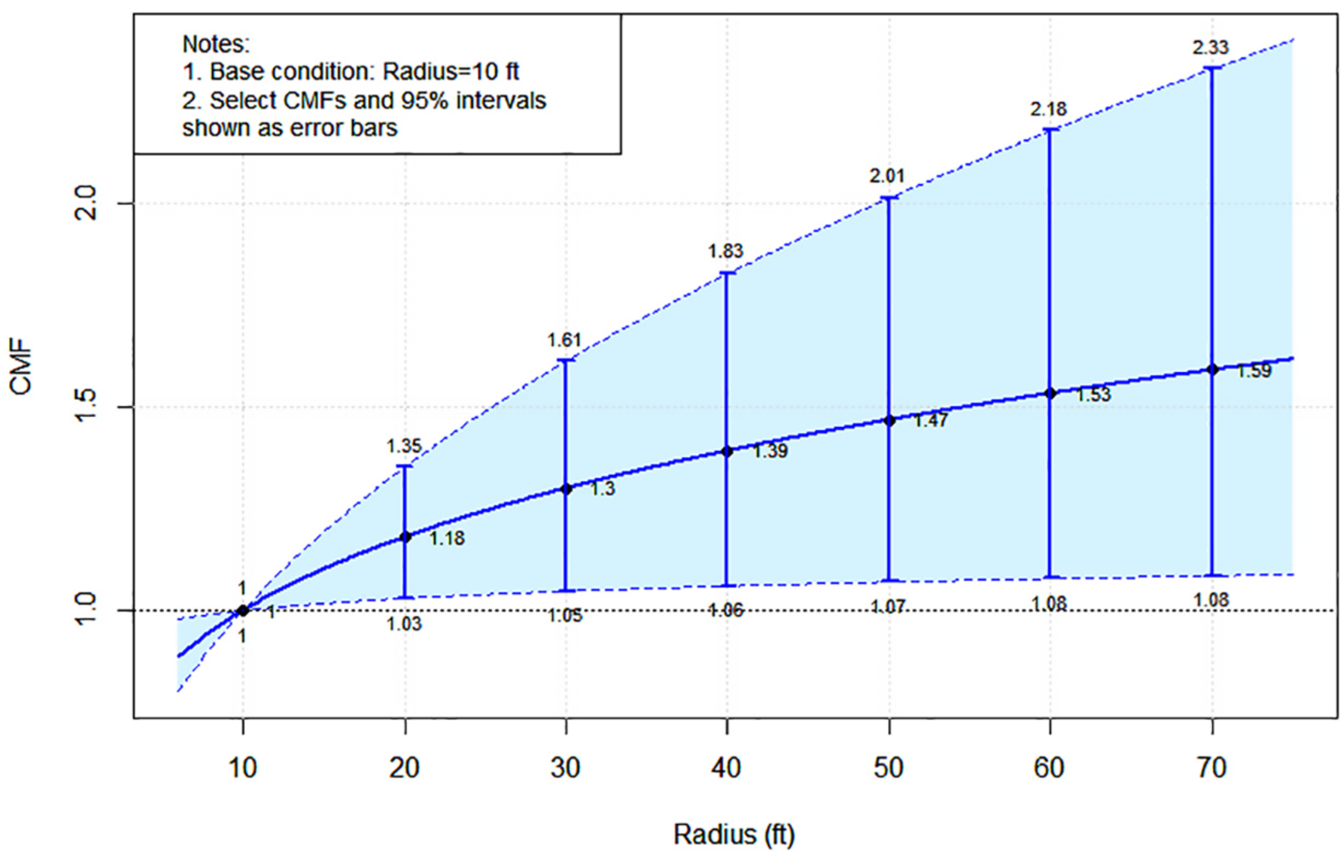
CONCLUSIONS

Findings

The focus of the corner-level safety analysis was to investigate the relationship of the intersection corner radius to pedestrian crashes. For pedestrian crashes, the evaluation did find a statistical relationship with corner radius. The statistical model estimate for corner radius can be used to generate a CMF. Assuming a baseline condition of 10 ft, the pedestrian CMFs for the range of corner radii included in the evaluation are shown in figure 1. In addition to the 95 percent confidence envelope of the curve, specific CMF values and their corresponding 95 percent confidence intervals are shown at select points of the function domain. In general, the relationship between corner radii and pedestrian crashes is directly proportional: on average, larger corner radii are linked to more pedestrian crashes. For example, figure 1 shows that, 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 ft. The largest contrast seen in the figure is between 70- and 10-ft radii; the former is expected to experience about 59 percent as many crashes as the latter (from a corresponding CMF of 1.59).

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 that turning speeds be limited to 15 mph or less, and the equation provided in the full report can be used to check a corner radius design to determine whether (or how often) the anticipated speed for the design would exceed the set criteria.[2]

Figure 1. Graph. Corner radius CMF for pedestrian crashes based on Virginia model.



Future Research Needs

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. The research team developed a hypothesis of why one-way streets moving away from the intersection were associated with more pedestrian crashes. In this scenario, drivers may be more focused on the crosswalk they first encounter going through the intersection than the second crosswalk they encounter on the receiving leg. Vehicles may also be moving faster when passing over the second crosswalk for the intersection. In-field observations are needed to gain a better appreciation for the relationship between one-way streets and pedestrian crashes.

Additional research could help 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 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.

REFERENCES

1. Fitzpatrick, K., R. Avelar, M. P. Pratt, S. Das, and D. Lord. 2021. *Crash Modification Factor for Corner Radius, Right-Turn Speed, and Prediction of Pedestrian Crashes at Signalized Intersections.* Report No. FHWA-HRT-21-105. Washington, DC: Federal Highway Administration.

2. National Association of City Transportation Officials. 2013. "Urban Street Design Guide—Corner Radii" (webpage). https://nacto.org/publication/urban-street-design-guide/intersection-design-elements/corner-radii/, last accessed September 29, 2021.

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