Curb Radius and Injury Severity at Intersections

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February 17, 2012

Abstract: The link between curb radius and injuries at intersections is a topic of greater interest as agencies seek to provide safe facilities for pedestrians and bicyclists while also accommodating large vehicle traffic, including trucks and buses. Factors to consider include the geometry and design of right turn facilities, vehicle movements through intersections, and pedestrian safety. No prior research was found which examines the injury severity of vehicle collisions and pedestrian incidents related to different curb radii. This research gap may result from a focus on highway settings for collisions involving encroachment when information is needed about urban streets; insufficient data collection and a lack of national standards or general framework; and inconsistent terminology. There is a need for research which explores the relationship between curb design in intersections and the severity of accidents involving pedestrians and bicyclists.

Executive Summary

Background: The design vehicles used in the design of highways and streets in California determine the curb radii for intersections. The Caltrans Highway Design Manual provides conservative estimates for the turning radius of design vehicles, which ensures a wider margin of safety but also creates larger curb radii that are more dangerous for bicycles and pedestrians.[1] The guidelines included in the AASHTO guidebook *A Policy on Geometric Design of Highways and Streets* (the Green Book) proposes smaller minimum and maximum radii which allow for smaller intersections.[2]

Vehicle clearance has long been the main focus of the geometric design of streets: could vehicles of every size safely turn at intersections without encroaching into other lanes or oncoming traffic? This was the primary safety concern but recently there has been an increasing focus on the impact of the geometric design of intersections on pedestrian and bicycle safety. Due to the lack of relevant data, context sensitive design is subjective in nature.

Summary of Findings: By and large intersection geometry is dictated by the AASHTO Green Book, though some allowances may be made for context sensitive design. Examining the highway design manuals of several states, they largely conform to the AASHTO policy. Increasingly, though, there is more attention on the effects of intersection design on pedestrian and bicycle safety. This awareness, in conjunction with other efforts such as Complete Streets

[1] Caltrans *Highway Design Manual: Chapter 4, Intersections at Grade*, Section 404.4 (2009) http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0400.pdf
[2] AASHTO *A Policy on Geometric Design of Highways and Streets*, 2-10:2-32 (2011)

and Smart Growth America, has led to more discussion about design compatible for both vehicles and pedestrians, yet there has not been much research in the field at this time. In urban areas a distinction is made between streets with significant volumes of traffic from trucks and buses, versus normal automobile traffic. In more residential areas, small curb radii of 15 to 25 feet is preferable because it reduces traffic speeds. In areas with significant traffic volume from large trucks and buses, curb radii of 30 to 45 feet accommodate the turning radius of the vehicle without encroachment on other lanes or the curb. The larger radii are less safe for bicycles and pedestrians because they allow for higher vehicle speeds through the turn and result in larger crossing distances. Smaller curb radii create facilities that are more pedestrian and bicycle friendly through shorter crossing distances.

For the most part research on the safety of right turns in intersections has been grouped in these three areas: the design and the geometry of the intersection itself, the actions of vehicles turning, and pedestrian and bicycle safety.

- Right Turn Lanes: The geometry and design of right turn facilities can greatly affect the safety of an intersection. Evaluation of road features and their correlation to safety through the analysis of accident statistics and incidents reports illuminates risk factors related to vehicle accidents. Configurations with too little space between the roadside and the curb, or poor buffers with the sidewalk promote crash cluster locations. Channelization of right turn lanes decreases the propensity of vehicle encroachment into other lanes or opposing traffic, though that design creates wider intersections which leave pedestrians vulnerable. Channelization can lead to higher turning speeds, which is also an additional hazard for pedestrians.
- Vehicle Movement in Intersections: The interaction between vehicles travelling through intersections and the likelihood of resulting incidents is another research area. Some of the risks are dependent upon driver behavior, both of trucks and normal light vehicles. Data mining crash statistics have found that incidents often occur when drivers misjudge the maneuverability of large trucks and buses on urban arterials. The size of vehicles involved is another risk factor, though it is more so the width than the length of the truck or bus.
- Pedestrian safety at intersections is directly related to the vehicle speeds and the facilities available for pedestrians to occupy. For intersections with large curb radii and wider crossing sections, pedestrians are prone to vehicle collisions. The severity of injuries to these pedestrians correlates to the speed the vehicles traveling through the turn. Signalization and islands can mitigate these risks by reducing vehicle speeds, in addition to providing a haven and safe timing for pedestrians to cross.

Gaps in Findings: There has yet to be any research that examines the injury severity of vehicle collisions and pedestrian incidents related to different curb radii. One reason may be the gap in research related to specific facilities. Most of the injury research related to vehicle collisions resulting from encroachment or lane departure has been focused on highways and their interchanges, not arterials and intersections. Pedestrian safety research has focused by and large on urban environments, where there are greater volumes of pedestrian and bicycle traffic. Insufficient attention has been paid to showing any relationship between the two.

One obstacle for this type of research is insufficient data collection, particularly for bicycles and pedestrians. There is not yet a national standard or general framework for evaluating the safety of roadways and intersections. The Virginia Transportation Research Council developed a framework to evaluate their bicycle and pedestrian safety project, which is a start in the right direction. VTRC acknowledges the need for more safety studies after the implementation of treatments, as it is still very difficult to assess the impact and efficacy of these programs.[3] The Highway Safety Information System from Turner-Fairbank Highway Research Center has developed a GIS tool which can be used to determine high volume pedestrian crash zones and safe bike routes.[4] The tool may help with the analysis of the data, but that only reinforces the need for better data collection for more robust and holistic data sets.

Inconsistent terminology and non-standard vocabulary is another problem. "Encroachment" is frequently used to describe vehicles traveling beyond their lane lines, but this term often also has the connotation of departing the roadway completely. "Lane departure" is also commonly used to describe the same phenomena, but it could also cover the act of changing lanes. This ambiguity in terminology adds another obstacle when looking for research or safety guidelines.

Next Steps: The relationship between intersection design and injury severity of pedestrian, bicycle, and vehicle accidents is an area needing more extensive research. One initial step would be to compare accident statistics and incident reports for vehicles and pedestrians geospatially, perhaps with the HSIS GIS Safety Analysis Tool, to find any relationship between different intersection geometries and accident rates. This data could then be correlated to injury data to compare injury severity between the two. The development of a research needs statement could raise visibility of the issue and possibly lead to a framework or guidebook to comprehensively address the affect of curb radii for vehicles, bicycles, and pedestrians.

National Guidance

The National recommendations for the geometric design are contained in AASHTO's Green Book. Chapter 2 covers Design Controls and Criteria, focusing on design vehicles, including diagrams of the turning radius for each vehicle and the recommended curb radius. Chapter 9 deals with Intersections and all of the design elements involved with at-grade intersections. The geometry of curb radii for minimum edge-of-traveled-way designs are diagrammed for each of the design vehicles described in Chapter 2.[5]These diagrams illustrate both the design of the curb as well as the turning radius and path of the design vehicle.

AASTHO's *A Guide for Achieving Flexibility in Highway Design* suggests that context is important when selecting the design vehicle. The design vehicle used for rural roads is most likely not appropriate for urban streets. Questions about encroachment of vehicles into adjacent

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[3]Natarajan, S., Demetsky, M.J., and Lantz, K.E., *Framework for Selection and Evaluation of Bicycle and Pedestrian Safety Projects in Virginia*, Virginia Transportation Research Council, Virginia DOT, report no. FHWA/VTRC 08-R8 (2008)
http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-r8.pdf

[4] "Pedestrian and Bicycle GIS Safety Analysis Tool", HSIS, Turner-Fairbank Research Center, FHWA
http://www.hsisinfo.org/ped-bike-gis.cfm

[5] AASHTO *A Policy on Geometric Design of Highways and Streets*, 9-64:9-79 (2011)

lanes and shoulders need to be balanced with intersection size and impacts related to cost, land use, and safety. Using a single school or transit bus is often the appropriate design vehicle in urban streets given the limited space and geometry. If the street has substantial truck traffic, then a larger design vehicle, such as a multi-unit semi-trailer, may be preferable. Engineers and designers are encouraged to use their judgement when selecting the design vehicles for their situation. Once the design vehicle is selected, the AASHTO Green Book provides a number of guidelines.[6]

The AASHTO *Guide for the Planning, Design and Operation of Pedestrian Facilities* describes the conflict between larger curb radii, which allow for easier vehicle turning, and smaller curb radii, which not only reduce vehicle speeds but also decrease the size of the intersection. If the radius is too small or the curb protrudes, there is a risk of the vehicles driving over the curb which could damage the curb or injure pedestrians standing at it.[7] For situations with little turning truck traffic, a radius of 3.0 to 4.5 meters (10-15 feet) should be used. For streets with more ample truck traffic, a larger radius is recommended but then the stop bar should be set back on the receiving street to give large vehicles ample room to turn.[8] This approach is echoed by the National Complete Streets Coalition. In a recent paper, they recommend reducing traffic speed by tightening curb radii to the minimum feasible design vehicle. Possible encroachment or lane departure would not be as dangerous due to the reduced speeds.[9]

The FHWA Safety Program published a series of countermeasures for safety improvements in 2009. They recommend radii of 15 to 25 for arterial streets to accommodate buses and emergency vehicles, while still providing adequate facilities for bicycles and pedestrians. The benefits include slower right turning vehicles, reduced crossing distances, improved visibility for pedestrians and driver, and improved signal timing.[10] FHWA has also produced the PEDSAFE[11] and BIKESAFE[12] Countermeasure Selection Systems. These tools provide guidance for agencies to effectively measure the safety of their existing facilities, collect better data about bicycle and pedestrian incidents, and implement treatments to improve safety.

State Practices

Surveying highway design manuals from other states, by and large they conform to the recommendations from AASHTO's 2004 edition of the Green Book, recently superseded by the 2011 edition. Some states had more specific recommendations:

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[6] AASHTO *Guide for Achieving Flexibility in Highway Design*, 3.8.1, 3.8.2, pp 82-83 (2004)

[7] AASHTO, *Guide for the Planning, Design and Operation of Pedestrian Facilities*, 3.3.1, pp 73 (2004)

[8] *ibid*. pp 74

[9] LaPlante, J & McCann, B, "Complete Streets in the United States", 91st Annual *Transportation Research Board Annual Meeting* (2012)
http://amonline.trb.org/12jlnh/1

[10] "Road Design: 9. Curb Radius Reduction", FHWA Department of Safety (2009)
http://safety.fhwa.dot.gov/saferjourney/library/countermeasures/09.htm

[11] "PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System", FHWA (2004)
http://www.walkinginfo.org/pedsafe/

[12] "BIKESAFE: Bicycle Countermeasure Selection System", FHWA (2005)
http://www.bicyclinginfo.org/bikesafe/

- New Jersey recommends that intersection design, "should be based on the 'effective' turning radius of the design vehicle, rather than the actual corner radius." While radii of 15-25 feet are recommended for passenger vehicles, an effective radius of 30 feet allows for occasional trucks or buses without too much encroachment.[13]
- Florida also recommends radii of 30 feet when practical to prevent too much encroachment from trucks and other large vehicles. For intersections with frequent truck traffic, radii of 40 feet are recommended, but the design should be coordinated with crosswalk distances to make facilities efficient for all pedestrians which may include medians or some other form of pedestrian refuge.[14]
- Oregon's *Mainstreet Handbook for Oregon Communities* advocates for corners with greater than 40 feet radii to implement alternative design practices, such as compound corners. The handbook also reminds users, "...it is important to remember that every corner is unique and needs to be designed individually."[15]

Relevant Research

Intersection and Right Turn Lane Design

One research area related to this issue is the design of right turn facilities and how the geometry of intersections can prevent traffic accidents or reduce the severity of injuries. Factors considered include turn speed, pre-crash movement, and visibility.

"Urban Roadside Safety: Cluster Crash Evaluation"
Dixon, K., Liebler, M., and Hunter, M. *Transportation Research Record*, no. 2120, pp 74-81 (2009)
http://trb.metapress.com/content/w1214370u4755j32/

> Roadside safety in rural environments has been the focus of considerable study, but direct application of this knowledge to the constrained urban environment has posed many challenges. Restricted right-of-way with a greater demand for functional use of the space adjacent to urban roads makes the maintenance of a wide clear zone impractical. This paper summarizes a corridor roadside crash analysis used to help identify urban roadside safety issues and illuminate possible solutions for attempting to mitigate objects in the roadside that have the potential to increase injury severity if hit. The paper focuses on arterial and collector-type facilities in urban areas with speed limits between 25 and 50 mph. The authors assessed corridors of urban roadside conditions and compared 6 years of historic crash data with roadside features. The goal of this effort was to identify potential configurations that posed a greater risk by the use of cluster-crash analysis. Locations with similar features without these companion crashes provided insight into prospective alternative treatments for roadside safety in urban environments. The higher-risk roadside locations identified by these approaches were referred to as urban control

[13] New Jesery DOT "NJDOT Roadway Design Manual," Section 6.4.3 (2011) http://www.state.nj.us/transportation/eng/documents/RDM/sec6.shtm#turningraddiiunchannel
[14] Florida DOT, *Florida Intersection Design Guide*, Section 3.5 (2007) http://www.dot.state.fl.us/rddesign/FIDG-Manual/FIDG2007.pdf
[15] Oregon DOT, *Main Street... when a Highway runs through it: A Handbook for Oregon Communitites*, pp 41 (1999) http://www.oregon.gov/ODOT/HWY/BIKEPED/docs/mainstreethandbook.pdf

zones. The most commonly observed roadside crashes included locations in close lateral proximity to the curb face or lane edge, lane merge locations, select auxiliary lane treatments, sidewalk buffer configurations with rigid objects in close proximity to the travelway, driveway and intersection locations, high-cluster-crash locations, and other common roadside crash conditions.

Turn Speeds and Crashes Within Right-Turn Lanes
Fitzpatrick, K and Schneider, W.H., Texas Transportation Institute (2005)
http://tti.tamu.edu/documents/0-4365-4.pdf

Right-turn lanes are used to provide space for the deceleration and storage of turning vehicles and to separate the turning vehicles from the through movement. When larger corner radii are used at the right turn, vehicles can turn at higher speeds (thereby minimizing the speed differential between turning and through vehicles) and can more efficiently merge with the cross-street traffic. A concern with the higher operating speed is the challenge it provides pedestrians attempting to cross the street. Equations are available for predicting speeds on a horizontal curve; however, these equations should not be used for predicting speeds in a right turn. This project analyzed the impact of right-turn lane treatments on vehicle speeds and vehicle safety using nine intersections for the safety study and 18 approaches for the speed study. Each approach for the speed study had an exclusive right-turn lane that was separated from the through lane with either a lane line or with a raised corner island. The corner radii ranged between 27 and 86 ft. The speed study included only free-flow right-turning vehicles. The 85th percentile speed near the middle of the right turn ranged from 13 to 21 mph while on the approach it ranged from 17 to 29 mph. Speed prediction equations were developed. For the nine intersections included in the crash study, the monthly crash rate for a shared lane with island (0.67 right-turn crashes per approach per year) was the highest of the treatments studied. The next highest was the right-turn lane with island design with 0.21 right-turn crashes per approach per year.

"Distribution of Roadway Geometric Design Features Critical to Accommodation of Large Trucks"
Harwood, D.W., Glauz, W.D., Elefteriadou, L., Torbic, D.J., and McFadden, J. *Transportation Research Record*, no. 1685, pp 77-88, 1999
http://trb.metapress.com/content/d557513733677043/

The ability of the roadway system to accommodate large trucks is constrained by the geometric design of key features, including horizontal curves, interchange ramps, interchange ramp terminals, at-grade intersections, and steep grades. The distribution of the dimensions of roadway elements that are critical to accommodation of larger trucks on the highway is shown, including horizontal curves and grades on mainline roadways, horizontal curves on interchange ramps, and curb return radii for at-grade ramp terminals and intersections. Frequency of mainline and ramp curves with very sharp radii and of very steep mainline grades was found to be very limited. For example, only about 5 percent of interchange ramps have horizontal curves with radii of 30 m (100 ft) or less, and approximately 20 percent of rural ramps and 30 percent of urban ramps have radii of 75 m (250 ft) or less. Curb return radii less than or equal to 12 m (40 ft) on which trucks would frequently encroach are more frequent. Curb returns with sharp radii are more prevalent in urban than in rural areas and are more prevalent at intersections than at ramp terminals.

Effects and Safety of Turning Vehicles at Instersections

Another research area focuses on the characteristics and behaviours of turning trucks at intersections. How does the turning radius of large vehicles affect the safety of the intersections for vehicles? Encroachment into other lanes and off the road is the primary concern in this area of research.

"Truck Safety Factors on Urban Arterials"
Daniel, J. and Chien, S.I-J. *Journal of Transportation Engineering*, v. 130 no.6, pp 742-752 (2004)
http://link.aip.org/link/doi/10.1061/(ASCE)0733-947X(2004)130:6(742)

Despite the high percentage of large truck trips on Interstate roadways, only 24% of fatal truck crashes occurred on these roadways. About 59% of large truck fatal crashes occurred on undivided highways that do not have controlled access and have signalized intersections. These statistics suggest that truck safety research should not only be aimed at Interstate driving conditions, but should also focus on improving truck safety for secondary roadways. One approach that can be used to better understand factors that impact truck safety on arterial roadways is through the use of accident prediction models. This paper describes the use of Poisson regression and negative binomial accident prediction models for truck accidents on an urban arterial with heavy truck volumes and a large number of signalized intersections. A model combining both signal and roadway segments showed good fit and demonstrates the ability to capture the impacts of both signal and roadway segments in one model.

Severity Analysis of Driver Crash Involvement on Multilane High Speed Arterial Corridors
Nevarez-Pagan, A., Masters Thesis at the University of Central Florida (2008)
http://etd.fcla.edu/CF/CFE0002080/Nevarez-Pagan_Alexis_200805_MS.pdf

Arterial roads constitute the majority of the centerline miles of the Florida State Highway System. Severe injury involvements on these roads account for a quarter of the total severe injuries reported statewide. This research focuses on driver injury severity analysis of statewide multilane high speed arterials using crash data for the years 2002 to 2004. The first goal is to test different ways of analyzing crash data (by road entity and crash types) and find the best method of driver injury severity analysis. A second goal is to find driver, vehicle, road and environment related factors that contribute to severe involvements on multilane arterials. Exploratory analysis using one year of crash data (2004) using binary logit regression was used to measure the risk of driver severe injury given that a crash occurs. A preliminary list of significant factors was obtained.

"Effects of Turns by Larger Trucks At Urban Intersections"
Hummer, J.E., Zegeer, C.V., and Hanscom, F.R., *Transportation Research Record* no. 1195, pp 64-74 (1988)

This paper gives results and conclusions from part of a study done for the Federal Highway Administration on the safety and operational effects of large truck operations.

Computer simulation and manual observations at six intersections in California and New Jersey were used to investigate turns by large trucks at urban intersections. The encroachment of a truck into adjacent lanes during a turn was studied using the computer simulation. The field data examined on a particular truck turn included the encroachment, the time to complete the turn, and the conflicts with other vehicles in the traffic stream caused by the truck. Field observations were made of turning trucks in the traffic stream and also of a control truck of known size driven repeatedly through a study intersection by a professional driver who knew the purpose of the experiment. The results showed that small curb radii, narrow lane widths, and narrow total street widths were among the geometric features associated with increased operational problems. The results also showed that large trucks will have little impact (compared with smaller trucks) at most urban intersections of the types tested, but some adverse operational effects should be expected at some intersections. Trailer length was found to be a more critical element to smooth operations than trailer width for the trucks tested. Many site, driver, and equipment factors should be considered before the decision is made to regulate truck traffic in a certain manner.

"Examining Traffic Crash Injury Severity at Unsignalized Intersections"
Haleem, K. and Abdel-Aty, M., *Journal of Safety Research*, v. 41 no. 4, pp 347-357 (2010)
http://dx.doi.org/10.1016/j.jsr.2010.04.006

This study presents multiple approaches to the analysis of crash injury severity at three- and four-legged unsignalized intersections in the state of Florida from 2003 until 2006. An extensive data collection process was conducted for this study. The dataset used in the analysis included 2,043 unsignalized intersections in six counties in the state of Florida. For the scope of this study, there were three approaches explored. The first approach dealt with the five injury levels, and an ordered probit model was fitted. The second approach was an aggregated one, and dealt with only the severe versus non-severe crash levels, and a binary probit model was used. The third approach dealt with fitting a nested logit model. Results from the three fitted approaches were shown and discussed, and a comparison between the three approaches was shown. Several important factors affecting crash severity at unsignalized intersections were identified. These include the traffic volume on the major approach, and the number of through lanes on the minor approach (surrogate measure for traffic volume), and among the geometric factors, the upstream and downstream distance to the nearest signalized intersection, left and right shoulder width, number of left turn movements on the minor approach, and number of right and left turn lanes on the major approach. As for driver factors, young and very young at-fault drivers were associated with the least fatal probability compared to other age groups. The analysis identified some countermeasures to reduce injury severity at unsignalized intersections. The spatial covariates showed the importance of including safety awareness campaigns for speeding enforcement. Also, having a 90-degree intersection design is the most appropriate safety design for reducing severity. Moreover, the assurance of marking stop lines at unsignalized intersections is very essential.

Pedestrian and Bicycle Safety at Intersections

The relationship between intersection design and non-motorized transportation safety is a topic that attracts considerable research interest. As pedestrian and bicycle safety becomes a greater concern, the causes of accidents involving them have been looked at with greater attention. Methods and treatments to improve safety or consider the impact of geometry on pedestrians is a topic of great interest.

"Association Between Roadway Intersection Characteristics and Pedestrian Crash Risk in Alameda County, California"
Schneider, R.J, *et al*, *Transportation Research Record*, no. 2198, pp 41-51 (2010)
http://trb.metapress.com/content/v8688824w73lkp84/

> Each year from 1998 to 2007, an average of approximately 4,800 pedestrians were killed and 71,000 pedestrians were injured in traffic crashes in the United States. Because many pedestrian crashes occur at roadway intersections, it is important to understand the intersection characteristics that are associated with pedestrian crash risk. The present study uses detailed pedestrian crash data and pedestrian volume estimates to analyze the pedestrian crash risk at 81 intersections along arterial and collector roadways in Alameda County, California. The analysis compares pedestrian crash rates (the number of crashes per 10,000,000 pedestrian crossings) with intersection characteristics. In addition, more than 30 variables were considered for use in the development of a statistical model of the number of pedestrian crashes reported at each study intersection from 1998 to 2007. After the pedestrian and motor vehicle volumes at each intersection were accounted for, negative binomial regression showed that significantly more pedestrian crashes occurred at intersections with more right-turn-only lanes, more nonresidential driveways within 50 ft (15 m), more commercial properties within 0.1 mi (161 m), and a greater percentage of residents within 0.25 mi (402 m) who were younger than age 18 years. Raised medians on both intersecting streets were associated with lower numbers of pedestrian crashes. These results, viewed in combination with other research findings, can be used by practitioners to design safer intersections for pedestrians. This exploratory study also provides a methodological framework for future pedestrian safety studies.

"Pilot Model for Estimating Pedestrian Intersection Crossing Volumes"
Schneider, R.J., Arnold, L.S., and Ragland, D.R., *Transportation Research Record*, no. 2140, pp 13-26 (2009)
http://trb.metapress.com/content/c513687133247113/

> Better data on pedestrian volumes are needed to improve the safety, comfort, and convenience of pedestrian movement. This data collection requires more carefully developed methodologies for counting pedestrians as well as improved methods of modeling pedestrian volumes. The methodology used to create a simple pilot model of pedestrian intersection crossing volumes in Alameda County, California, is described. The model is based on weekly pedestrian volumes at a sample of 50 intersections with a wide variety of surrounding land uses, transportation system attributes, and neighborhood socioeconomic characteristics. Three alternative model structures were considered, and the final recommended model has a good overall fit (adjusted $R2$ =.897). Statistically significant factors in the model include the total population within a 0.5-mi radius,

number of jobs within a 0.25-mi radius, number of commercial retail properties within a 0.25-mi radius, and the presence of a regional transit station within a 0.1-mi radius of an intersection. The model has a simple structure, and it can be implemented by practitioners using geographic information systems and a basic spreadsheet program. Because the study is based on a relatively small number of intersections in one urban area, additional research is needed to refine the model and determine its applicability in other areas.

"Turning at Intersections and Pedestrian Injuries"
Roudsari, B., Kaufman, R., and Koepsell, T. *Traffic Injury Prevention*, v.7 no.3, pp 283-289 (2006)
http://dx.doi.org/10.1080/15389580600660153

Research evaluating the association of precrash vehicle movement (right-turn, left-turn, straight) with the severity of pedestrian injury is presented in this article. The authors examined comprehensive data on pedestrian, vehicle, and injury-related characteristics. The research is based on the Pedestrian Crash Data Study (PCDS) conducted by the National Highway TrafficSafety Administration between 1994 and 1998. The authors used a logistic regression model that considered the vehicle type, age of pedestrians, and the intermediate effect of impact speed. Results showed that in a total of 255 collisions studied, 48% of pedestrians were injured in straight movement accidents, 32% in right-turn accidents, and 10% in left-turn accidents. Pedestrians in 60% of the left-turn accidents and 67% of right-turn accidents were struck from their left sides. In straight movement accidents, pedestrians shared a 50% likelihood of being struck from either the left- or the right-side of the street.

Appendix

Handbooks

AASHTO, *Guide for Achieving Flexibility in Highway Design* (2004)

AASHTO, *Guide for the Planning, Design and Operation of Pedestrian Facilities* (2004)

AASHTO, *A Policy on Geometric Design of Highways and Streets* (2011)

Caltrans, *Highway Design Manual: Chapter 4, Intersections at Grade* (2009)
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Related Research

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