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Managing Pedestrian Safety

MANAGING PEDESTRIAN SAFETY I: INJURY SEVERITY

A multivariate analysis of the severity of injury sustained by pedestrians involved in collisions on state routes in King County, Washington, and a discussion of effective safety intervention and injury prevention policies

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16. ABSTRACT

This study focused on the severity of injuries and fatalities incurred by pedestrians colliding with motor vehicles. The report includes a thorough review of the literature and a description of new research carried out on correlates of injury severity and measures of their relative effects on fatal or high injury collisions. The correlates consisted of both individual-level factors and attributes of environments at or near pedestrian collision sites.

The study focused on state routes in King County, Washington. Data came from police records processed by the Washington State Department of Transportation (WSDOT) from 1999 to 2004. They included objective and modeled data in GIS on road characteristics, traffic conditions, and land uses at or near collision sites.

The results of binary and ordinal logistic models showed that fatal and high injury collisions were strongly and significantly associated with (1) a pedestrian crossing at an unsignalized intersection (versus crossing at all other locations or walking along the roadway); (2) the vehicle moving straight ahead on the roadway (versus all other types of vehicle actions). There was a lack of association between injury severity and collision frequency, suggesting that safety programs intended to reduce the number of collisions and those intended to reduce the risk of severe injury and death should use different approaches. The latter should focus on individual factors such as driver or pedestrian actions and behaviors, as well as on road environment factors such as speed limits and intersection signalization. Finally, better reports and data on vehicular speed at the time of collision, and on the type of vehicles involved in pedestrian collisions, would help to inform effective future safety programs, policies, and standards.

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CONTENTS

FIGURES

Figure		*Page*

TABLES

Table *Page*

SUMMARY

Sound transportation safety policies depend on appropriate knowledge to assess the potential effectiveness of safety programs. Safety programs for pedestrians and drivers, as well as law enforcement, have been tailored to focus on the characteristics of individuals and to affect their behaviors. Other safety programs such as road design or re-design programs have aimed to change the physical environment in order to reduce the risk of collision or to manage conflicts between different road users.

This study concentrated on the severity of injuries and fatalities incurred by pedestrians colliding with motor vehicles. Collision events and the resulting severity of injury were conceptualized as being affected by factors at both the individual and environmental levels. At the individual level, pedestrian and driver socio-demographic characteristics were considered, as well as people's behaviors or actions. At the environmental level, both the road and the neighborhood environments were taken into account to help explain the severity of injury resulting from a collision.

The study focus was to identify correlates of injury severity and to measure their relative effect by considering either individual-level factors or attributes of environments at or near pedestrian collision sites in order to support future transportation safety policies and standards.

A thorough review of the literature on pedestrian safety and injury severity preceded the analytical work.

The study relied on a uniquely rich set of multiple databases. Police records processed by the Washington State Department of Transportation (WSDOT) provided data on all pedestrians involved in collisions over a period of six years (1999 to 2004). Objective and modeled data served to capture road characteristics and traffic conditions at and near collision sites, as well as attributes of the land uses surrounding collision sites. All data were in geographic information systems (GIS).

The study focused on state routes in King County, Washington. The use of state routes, particularly within King County, offered unique opportunities to analyze pedestrian injury severity. First, more than 26.5 percent of all pedestrian collisions in the State of Washington occur on state routes. Of the collisions on these routes, 7.8 percent end in a fatality, in comparison to 2.0 percent fatalities on city streets and 3.9 percent on all roads and streets in the state. Second, King County hosts just slightly more than 28 percent of Washington State's population, yet it has 44.0 percent of the state's pedestrian collisions, 34.4 percent of its pedestrian fatalities, and 41.7 percent of its

disabling injuries. Between 1999 and 2004, state routes in King County had an average of 1.5 collisions per mile, whereas the state as a whole had 0.04. In addition, in King County, 0.4 pedestrian collisions per mile of state route resulted in a fatality or disabling injury , in comparison to 0.07 per mile of state route in all of Washington State.

Binary and ordinal logistic models were estimated to assess the relative influence of individual and environmental factors on fatality and injury severity resulting from collisions. Three models were developed using five, three, and two categories of injury severity as the dependent variables. The five-class model was based on the KABCO categories of fatality and injury. A three-step modeling process was developed to examine and identify objective built-environmental variables that affect pedestrian injury severity while controlling for other variables that have been found to be associated with pedestrian crashes and are commonly used in transportation planning. First, a base model used individual level data from the police record. Second, objective environmental variables captured within 0.5 km of the collision were tested one by one in the base model. Third, final models combined the variables from the police records and the environmental variables that had been found to be significant in the one-by-one testing.

The following variables were found to be significant in the final models ($p < 0.05$; direction of association indicated by + or -; very strong associations noted with ▲):

Direction of association	Variable	Strength of association
(+)	Age of the pedestrian	
(+)	Pedestrians being inebriated	
(+)	More than one pedestrian involved in the collision	
(-)	Pedestrian crossing at a non-intersection vs all other locations walking along roadway	
(+)	Pedestrian crossing at an unsignalized intersection vs crossing at all other locations or walking along roadway	▲
(+)	Vehicle moving straight ahead on the roadway vs all other types of movements or vehicle actions	▲
(-)	Vehicle making right turn vs all other vehicle actions	
(-)	Afternoon off-peak vs evening off-peak	
(-)	Average daily traffic (ADT) volume within 0.5 km of the collision	
(+)	Average home values within 0.5 km of the collision.	

Higher injury severity was strongly associated with vehicles moving straight along the roadway as opposed to making turns. This finding, combined with the significance of low ADT in the area proximate to a collision, suggests that vehicular speed is an important determinant of injury or fatality.

Unsignalized intersections emerged as locations where pedestrians involved in a collision were at high-risk of sustaining severe injury or dying. This finding corroborates the results of studies focusing on collision frequency rather than injury severity, which have shown strong correlations between unsignalized intersections and the risk of collision. These results suggest that pedestrian safety programs should target all intersections expected to be used by pedestrians and signalize them. However, further research is needed to improve the understanding of the type of signalization that effectively reduces both collision frequency and severity of injury.

The analysis results showed a lack of association between injury severity and collision frequency, indicating that the locations of collisions with high severity injury are not necessarily the same locations as those with high collision frequency. This finding suggests that safety programs addressing locations with high collision frequency will not necessarily help reduce the severity of injury when collisions do occur.

The majority of variables significantly associated with injury severity were at the individual and the road environment levels, but not at the neighborhood environment level. While most of the neighborhood environment variables that were considered had a significant relationship with the dependent variable in the bivariate analyses, they lost their significance when controlled for by individual- and road environment-level variables. The interesting exception was the presence of schools and educational facilities near collision locations, which was not associated with injury severity, even without controlling for individual level variables. One likely explanation is that speed limits in schools zones are effective means for preventing severe injury or death when collisions do occur near these land uses.

Overall, the findings indicated that safety programs aiming to reduce the risk of severe injury and death on state routes should focus on individual factors such as driver or pedestrian actions and behaviors, as well as road environment factors such as speed limits and intersection signalization.

The study identified two areas in which expanded data would greatly improve the understanding of correlates of injury severity. One is the need to have accurate and precise data on vehicular speed because vehicular speed is well known as a leading predictor of injury whenever collisions occur between pedestrians and motor vehicles. At the very least, police records should include speed limit and estimates of speed at the time of collision. Second is the need to systematically record the type of vehicle involved in the collision. Research has long shown evidence of the effect of vehicle weight, size, and design on fatalities and disabling injuries. Data on the type and make of vehicles involved in pedestrian collisions with a range of injury severity outcomes would support future efforts to create vehicle designs that enhance driver's awareness of pedestrians and that minimize injury to pedestrians when collisions occur.

Managing Pedestrian Safety I: Injury Severity

BACKGROUND

In 2004, the National Highway Traffic Safety Administration (NHTSA) reported that 68,000 pedestrians were injured in traffic collisions. In 2005, 4,881 pedestrians died as a result of being struck by automobiles (up from 4,641 in 2004), accounting for more than 10 percent of total traffic-related fatalities (NHTSA 2006)

In Washington State, 1,769 pedestrians were involved in collisions in 2004 (WSDOT and TDO N.D.), and 60 died within three weeks of the collisions (NHTSA 2006), representing 10.6 percent of total traffic-related fatalities in the state.

Traffic safety enhancement programs seek to reduce both the frequency of collisions and the severity of injuries sustained in these collisions. Collision frequency is at issue because collision events, even if they do not entail human injury, are disruptive and costly. They produce inefficiencies in transportation and induce loss of productivity and significant property damage. Strategies for preventing injury and loss of life also seek to reduce "societal costs," which include personal and social trauma, medical and legal bills, and loss of productivity and property damage (Council, Zaloshnja et al. 2005).

Objectives

The study focused on the severity of injuries and fatalities related to pedestrian travel. It used all recorded collisions involving pedestrians (1999-2004) on the state routes (SR) of King County, Washington. The study sought to examine the effects of multiple levels of factors influencing injury and loss of life. To inform transportation safety policies and programs, the study considered correlates of injury severity at both the individual and the environmental levels. Understanding the relative effects of factors at these two levels is important because it corresponds to two different types of safety interventions: those aimed at changing the behavior of individual pedestrians and drivers (typically focusing on education and enforcement programs) and those aimed at providing an environment that supports safe behavior (typically focusing on facility design and targeting areas with high pedestrian exposure to traffic).

A secondary objective of the study was to test various ways to model injury severity and fatalities and, specifically, to examine the possible effects of different injury classification systems on highlighting explanatory variables.

Conceptual Framework

To meet our objectives, we conceptualized that a collision event and the resulting severity of injury were affected by factors functioning at both individual and environmental levels (Figure 1). Furthermore, we reckoned that these factors could belong to different domains. ("Domain" is a term used in the social sciences to define fields, areas, or realms of information or data documenting a phenomenon; these information or data are in turn characterized by variables and measures that serve to model the phenomenon.) Domains that had figured prominently in past research at the individual level were pedestrian and driver sociodemographic characteristics and their behaviors or actions. At the environmental level, both the road and the neighborhood environments might help explain the occurrence of collisions and the severity of injury. The road environment captures variables related to what can be called the micro level of the collision environment, including road design, traffic characteristics, weather, and light conditions. The neighborhood environment captures meso-level variables of the collision environment, which are known to be related to pedestrian travel in terms of both exposure (or volumes of pedestrians) and behavior. Neighborhood environment variables include population densities, land uses that may attract pedestrians, and income or wealth, which have been related to non-motorized travel and population sociodemographic characteristics.

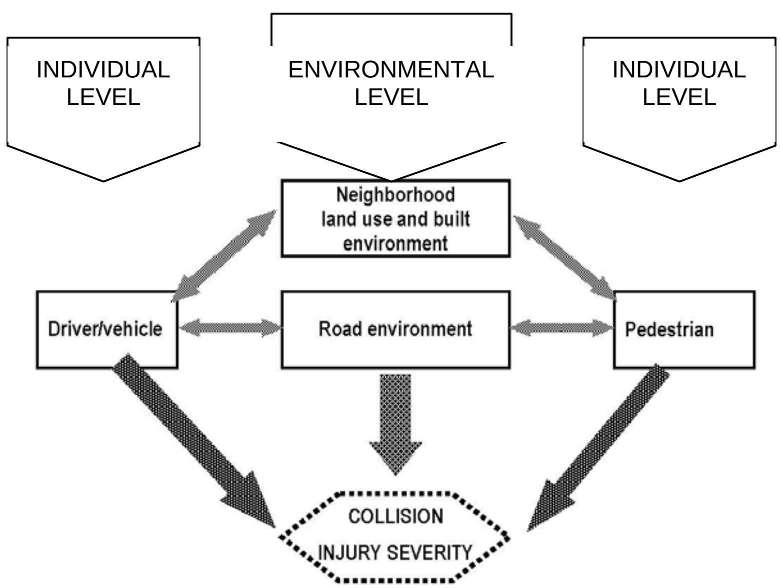

Figure 1: Framework used to conceptualize the severity of injury in pedestrian-motor-vehicle collisions: levels and domains

The study hypothesized that transportation safety policies and injury prevention approaches intended to reduce the severity of pedestrian injuries must rely on understanding the relative importance of all factors known or suspected to affect injury severity. Sound transportation safety policies depend on the appropriate knowledge to assess the potential effectiveness of individual-level programs such as pedestrian and driver safety education, as well as law enforcement, or, alternatively, of environmentally based programs such as road design or re-design. This study focused on identifying correlates of injury severity and on measuring their effect in order to address these issues and to support future transportation safety policies and standards.

Literature Review

An extensive literature on pedestrian injury exists in the fields of transportation and injury prevention. Most studies address specific dimensions of pedestrian collisions and related injuries, ranging from risks associated with special populations to the effects of vehicle design on injury. This literature review followed this study's conceptual model and classified past research in three areas:

- that focusing primarily on the characteristics of individual pedestrians
- that looking at the effects of the road environment
- that examining the role of the neighborhood environment in predicting the severity of injury.

Individual-Level Research

Previous studies have shown that age, gender, and state of inebriety are consistently related to the severity of injury sustained by pedestrians. Pedestrians aged 65 or older are significantly more likely than younger people to be severely injured or to die as a result of a collision with an automobile (Kong, Lekawa et al. 1996; Peng and Bongard 1999; Zajac and Ivan 2003; Demetriades, Murray et al. 2004; Lee and Abdel-Aty 2005). In 2000, the fatality rate of male pedestrians was twice that of female pedestrians (US DOT, NHTSA 2001). A recent study found that male drivers were more likely to be at fault in pedestrian crashes than female drivers (Lee and Abdel-Aty 2005).

Alcohol consumption has been associated with higher injury severity. Pedestrians under the influence of alcohol have been shown to engage in risky road-crossing behaviors (Oxley, Lenne et al. 2006; Wootton, Spainhour et al. 2006).

Inebriation of both driver and pedestrian was found to increase the severity of injury in rural Connecticut (Zajac and Ivan 2003). In collisions involving pedestrians or bicyclists, a high alcohol level has been associated with the need for more complicated treatment of injuries and longer hospital length of stay (Plurad, Demetriades et al. 2006). Another study found that intoxicated pedestrians crossing streets at intersections ran a high risk of being severely injured (Lee and Abdel-Aty 2005).

The large mass differential between vehicles and people makes driving speed and types of vehicles involved in collisions obvious determinants of pedestrian injury severity (Garder 2004; Lee and Abdel-Aty 2005). At impact speeds of higher than 30 mph and 40 mph, 45 percent and 85 percent of the collisions, respectively, have been shown to result in pedestrian fatality (Figure 2) (Leaf and Preusser 1999). A recent study examined the relationship between pre-crash vehicle movement (e.g., driving straight or turning) and the severity of pedestrian injury. It found that after adjustment for pedestrian's age, pre-crash movement was a significant predictor of injury severity and case fatality. However, pre-crash movement was no longer significant when impact speed was included in the model, suggesting that vehicle movement or driver action is related to impact speed (Roudsari, Kaufman et al. 2006).

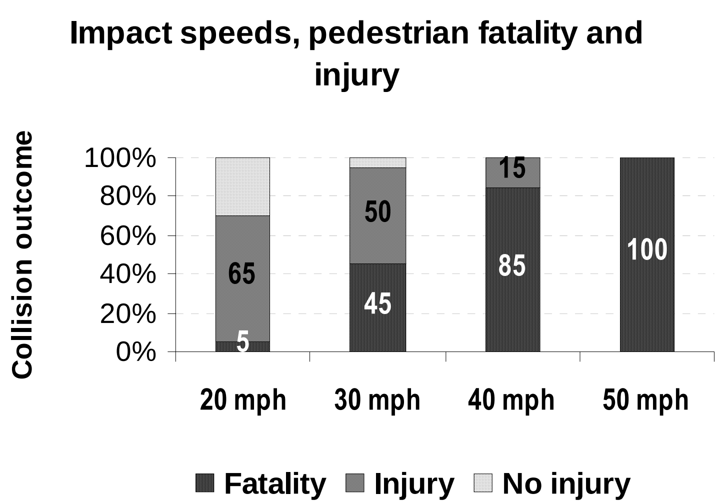

Figure 2: Effect of impact speed on pedestrian fatality and injury (U.S. Department of Transportation, Leaf WA, Preusser DF 1999)

Large or heavy vehicles such as sport utility vehicles, pickups, and vans, have been implicated in higher rates of severe injury and fatal pedestrian collisions than conventional passenger cars (Ballesteros, Dischinger et al. 2004). Children under eight years of age were most vulnerable to the size of the vehicle with which they collided (Starnes and Longthorne 2003). The NHTSA's Fatality Analysis Reporting System (FARS) studied the risks of killing pedestrians associated with different types of vehicles. Normalizing the number of pedestrian fatalities per billion miles of travel by vehicle type, the study showed risk ratios of killing a pedestrian to be 7.97 for buses, 1.93 for motorcycles, 1.45 for light trucks, and 0.96 for heavy trucks. (The risk ratio is also called the relative risk. It measures the probability of a fatal collision in each vehicle group http://www.childrensmercy.org/stats/journal/oddsratio.asp) (Paulozzi 2005). Furthermore, in comparison with cars, buses were 11.85 times and motorcycles were 3.77 times more likely per mile of travel to kill children zero to fourteen years old, while buses were 16.70 times more likely to kill adults age 85 or older than were cars. Importantly, these figures correspond to the risk of drivers of different vehicles killing pedestrians per mile driven. They do not represent the risk of pedestrians being killed by drivers traveling in different types of vehicles. The study's author concluded that light trucks were associated with the highest mortality rates of U.S. pedestrians.

Another study showed major differences in types of pedestrian injury by different classes of vehicles: chest and abdomen injuries were more common in pedestrians struck by light trucks than in those hit by passenger vehicles. The major sources of injury were hood surfaces and windshields for pedestrian collisions with passenger cars, and hood surfaces and edges for collisions with light trucks (Roudsari, Mock et al. 2005).

Finally, car manufacturer studies have shown that the design and construction of a vehicle exterior can help mitigate the effects of a collision on a pedestrian (Holt 2004).

Research on the Road Environment

Traffic volumes have been correlated with traffic collisions and injury severity. One study of rear-end collisions involving light trucks found that high annual average daily traffic volumes (AADT) per lane of highway were associated with significantly reduced injury severity (Duncan, Khattak et al. 1998). Recent research based on all collisions in Greater London examined whether congested traffic conditions, which typically increase the number of vehicle crashes, were associated with lower levels of injury severity. The findings were inconclusive but pointed to some evidence that traffic congestion may mean lower severity of injury to pedestrians on roadways, ostensibly because congestion reduces vehicular speed (Noland and Quddus 2005).

Weather conditions, which have been known to affect the road surface and the driver's ability to break for pedestrians, have not been shown to affect the risk of injury (DiMaggio and Durkin 2002).

Several studies looked into the effects of road design characteristics such as street width, intersection locations, and the presence of crosswalks, sidewalks, and traffic signals on injury severity. The width of a street was found to be positively related to pedestrian collision severity (Zajac and Ivan 2003). Another study found the child pedestrian injury rate to be 2.5 times higher on one-way than on two-way streets—46.4 per 100,000 children aged zero to fourteen per 100 km of one-way street versus 19.6 per 100,000 children on two-way streets (Wazana, Rynard et al. 2000). The severity of injury in collisions occurring at the intersections of two-lane roads was found to not differ significantly whether crosswalks were marked or unmarked (Zegeer, Steward et al. 2002). However, on multi-lane roads fatal pedestrian collisions were found to be more frequent at marked than at unmarked crosswalks. a Swedish study found that on streets with a posted speed of under 30 km/h, marked crosswalks increased vehicular yield rates for pedestrians. Speed cushions situated at a two-car-length distance from the marked crosswalk was also found to increase yield rates for pedestrians and cyclists in comparison to speed cushions located closer to the marked crosswalk (Leden, Garder et al. 2006).

Research on injury severity at intersections has provided varied results. Crashes involving driver violations at an intersection have been found to result in relatively fewer severe outcomes, as opposed to along the roadway, suggesting that vehicular speed plays a role in injury severity (Hunter, Stutts et al. 1996). Younger children have been found to be more likely to be struck mid-block and during daylight hours, whereas adolescents are more likely to be struck at intersections and at night (DiMaggio and Durkin 2002). A study examined the crash severity levels of all traffic collisions at signalized intersections. The authors stated that crashes involving a pedestrian or a bicyclist and a motor vehicle turning left had a high probability of resulting in severe injury (Abdel-Aty and Keller 2005). A recent study of pedestrian crossing found that the probability of a pedestrian dying after being struck by a vehicle was higher at mid-block locations than at intersections for any light condition on the roadway (Guttenplan, Chu et al. 2006). The study included 58,202 pedestrian crashes in Florida (reported in Long Form Police Accident Reports [PARs] from 1986 through 2003). Of all those crashes, 36.35 percent (or 160,119 collisions) involved a pedestrian crossing the street. The same study explored the effects of speed limits on injury severity. Results were inconclusive. Another study found that sidewalks were non-existent in 57 percent of the 353 fatal pedestrian crashes involving a pedestrian walking along the roadway (Wootton, Spainhour et al. 2006).

An evaluation of the effects of engineering treatments to improve the safety of pedestrians crossing high traffic volume and high-speed roads in marked crosswalks showed that red signal or beacon devices (displaying a circular red indicator to motorists at the pedestrian crossing location) were effective. Rates of yielding to pedestrians were above 94 percent for all 45 marked crosswalks observed (Turner, Park et al. 2006). Another study of elderly pedestrian travel and road infrastructure in urban corridors found that the greatest risk of pedestrian collision and injury was related to the presence of center turning lanes, traffic signal spacing exceeding 0.5 miles, and low roadway illumination (Shankar, Sittikariya et al. 2006). This study reviewed 153 elderly pedestrian collisions from a sample of 440 1-mile sections along corridors in Washington State (1991-1994).

Roadway daylight and lighting conditions have been shown to have an effect on pedestrian injury severity. Relative to dark conditions or no street lighting, daylight has been shown to reduce the odds of a fatal injury by 75 percent at mid-block locations and by 83 percent at intersections. Street lighting has been shown to reduce the same odds by 42 percent at mid-block locations and by 54 percent at intersections (Guttenplan, Chu et al. 2006). The study suggested that light conditions are more important at intersections than at mid-block, where, presumably, drivers are less cognizant of the potential presence of a pedestrian than at intersections and where, perhaps, vehicular speed is higher.

Research on the Neighborhood Environment

A study showed that the characteristics of the local environment in England had a significant influence on pedestrian casualty rates (Graham and Glaister 2003). Specifically, the incidence of pedestrian casualties and serious injuries was found to be higher in residential than in “economic zones” (areas dominated by commercial land uses). A quadratic relationship was found between urban density (measured as population and employment density) and pedestrian casualties, with incidents diminishing for the most extremely dense “wards” (neighborhoods or districts). Another study examining the built environment and pedestrian-vehicular crashes near public schools found that the presence of a driveway (defined as a throughway or loop located on the school property and accessing the school building) decreased crash occurrence and severity (Clifton and Kreamer Fults 2006). However, the presence near schools of recreational facilities such as playgrounds, courts, fields, pools, or tracks was shown to increase crash occurrence and severity.

Other studies found associations between levels of deprivation and rates of casualty of child pedestrians involved in crashes, with child pedestrian injury rates being three times higher in poor than in wealthier neighborhoods (Wazana, Rynard et al. 2000; Hewson 2004).

Literature on Traffic Law Enforcement

Little research has been carried out on the potential effectiveness of traffic violation enforcement programs at reducing collisions and decreasing injuries and fatalities. One study tested the association between traffic citations and fatalities in motor-vehicle crashes. Using a case-crossover design to analyze the protective effect of citations in Ontario, Canada, the study found that traffic law enforcement effectively reduced the frequency of fatal motor-vehicle crashes (Redelmeier, Tibshirani et al. 2003).

Another study in the Australian state of Victoria evaluated the effectiveness of law enforcement and publicity campaigns on cases of speeding and driving under the influence of alcohol. It found that speed-related enforcement and publicity campaigns had no independent effect but that their interactive effect was significant in reducing serious crashes involving young male drivers (Tay 2005).

A recent study evaluated an aggressive traffic violation enforcement program in Fresno, California, carried out in 2003 and 2004. Pre- and post-data were collected and analyzed. The study found that the program produced significant increases in citations issued, with marked decreases in motor vehicle crashes, injury collisions, fatalities, and fatalities related to speed. These changes were not detected during the same period outside the area of increased enforcement (Davis, Bennink et al. 2006).

Summary

Overall, the literature provides guidance on the effects of pedestrian age, gender, and actions on injury severity. Also, the effects of intersection design and pedestrian crossing behaviors have been consistently researched. Vehicle type and driver's behavior have been studied as well but little information has been provided on the effects of driver's inattention or distraction on pedestrian injury severity. Research has shown that cell phone use while driving increases the risk of crashes as much as 38 percent (Laberge-Nadeau, Maag et al. 2003). Little seems to be known as well on pre-crash driver and pedestrian behaviors and their effects on injury severity.

Finally, further research is needed on the impacts of the neighborhood and built environment on pedestrian fatalities and injury severity. Also, the one study on the negative effects of the presence of recreational facilities near schools, such as playgrounds, courts, fields, pools, or tracks, suggested the need for focusing on neighborhoods around schools.

METHODS

Study Design

This study was based on the conceptual model discussed earlier and focused on pedestrian collisions on the state routes (SR) of King County, Washington. It used collision records and objective environmental data. Individual-level data served to capture the characteristics and behaviors of pedestrians and drivers. Road and neighborhood environment data related to the location of each collision. The use of individual level and disaggregate data facilitated analyses and interpretation of results (Hewson 2005; Lee, Moudon et al. 2006a).

In the State of Washington, state routes, as a road class, and King County, as a geographic area, have high numbers and rates of collisions and a high proportion of severe injuries and fatalities. State routes experienced more than 26.5 percent of all pedestrian collisions in the State of Washington, whereas 64.5 percent of the collisions occurred on city streets. However, state routes have a disproportionate percentage of fatalities and disabling injuries. Statewide, 7.8 percent of pedestrian collisions on state routes end in a fatality, in comparison to 2.0 percent on city streets and 3.9 percent on all roads and streets. Statewide as well, 17.6 percent of pedestrian collisions on state routes end in a disabling injury, in comparison to 12.5 percent on city streets and 14.5 percent on all streets and roads.

King County is the most urbanized county of the State of Washington. With slightly more than 28 percent of the State population (almost 1.8 million estimated in 2005), the county has 44.0 percent of all statewide pedestrian collisions. It has 34.4 percent of the pedestrian fatalities and 41.7 percent of the disabling injuries in the state. Furthermore, King County has only 7 percent of the total miles of Washington state routes (506 out of 7,080 miles), yet the county hosts 37.7 percent of the pedestrian collisions on these routes, 32.9 percent of the fatalities, and 35.4 percent of the disabling injuries (figures 3, 4 and 5). Between 1999 and 2004, state routes in King County had an average of 1.5 collisions per mile, whereas state routes throughout the entire state had an average of 0.04 collisions per mile. The figures for pedestrian collisions resulting in a fatality or disabling injury are 0.4 per mile of state route in King County, in comparison to 0.07 per mile of state route in Washington State.

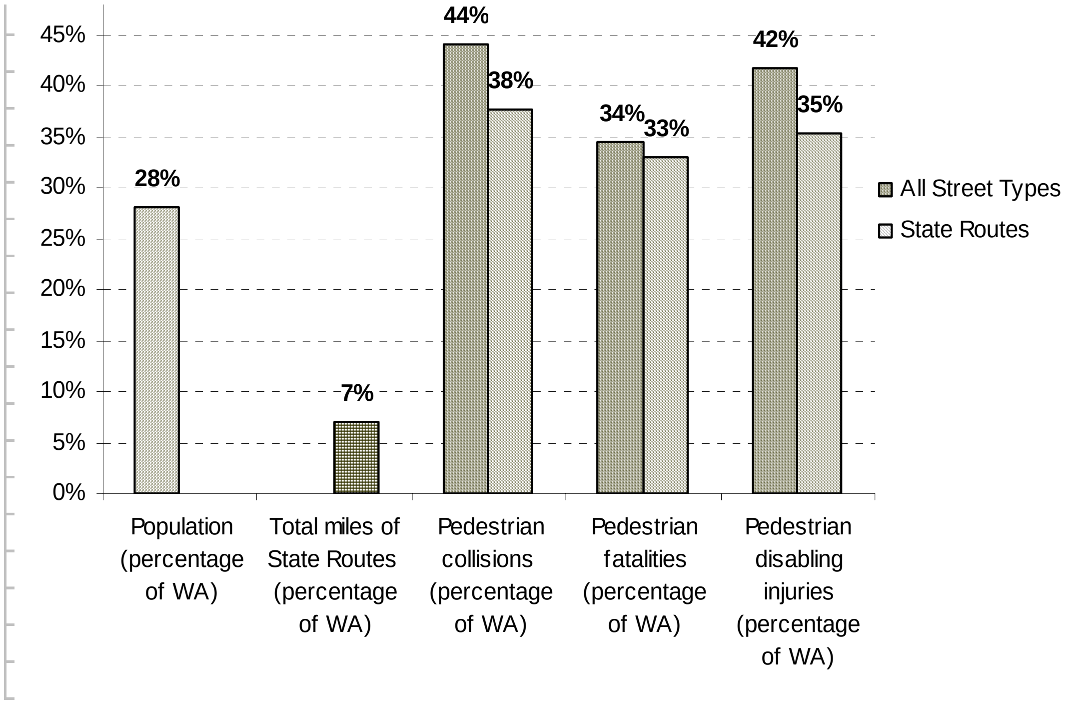

Figure 3: King County pedestrian collisions on state routes compared to pedestrian collisions on state routes in the State of Washington

Of the pedestrian collisions on state routes within King County, 6.8 percent end in a fatality and 16.6 percent in a disabling injury. This compares to 1.8 percent of pedestrian collisions on city streets in the county ending in a fatality and 12.6 percent ending in a disabling injury.

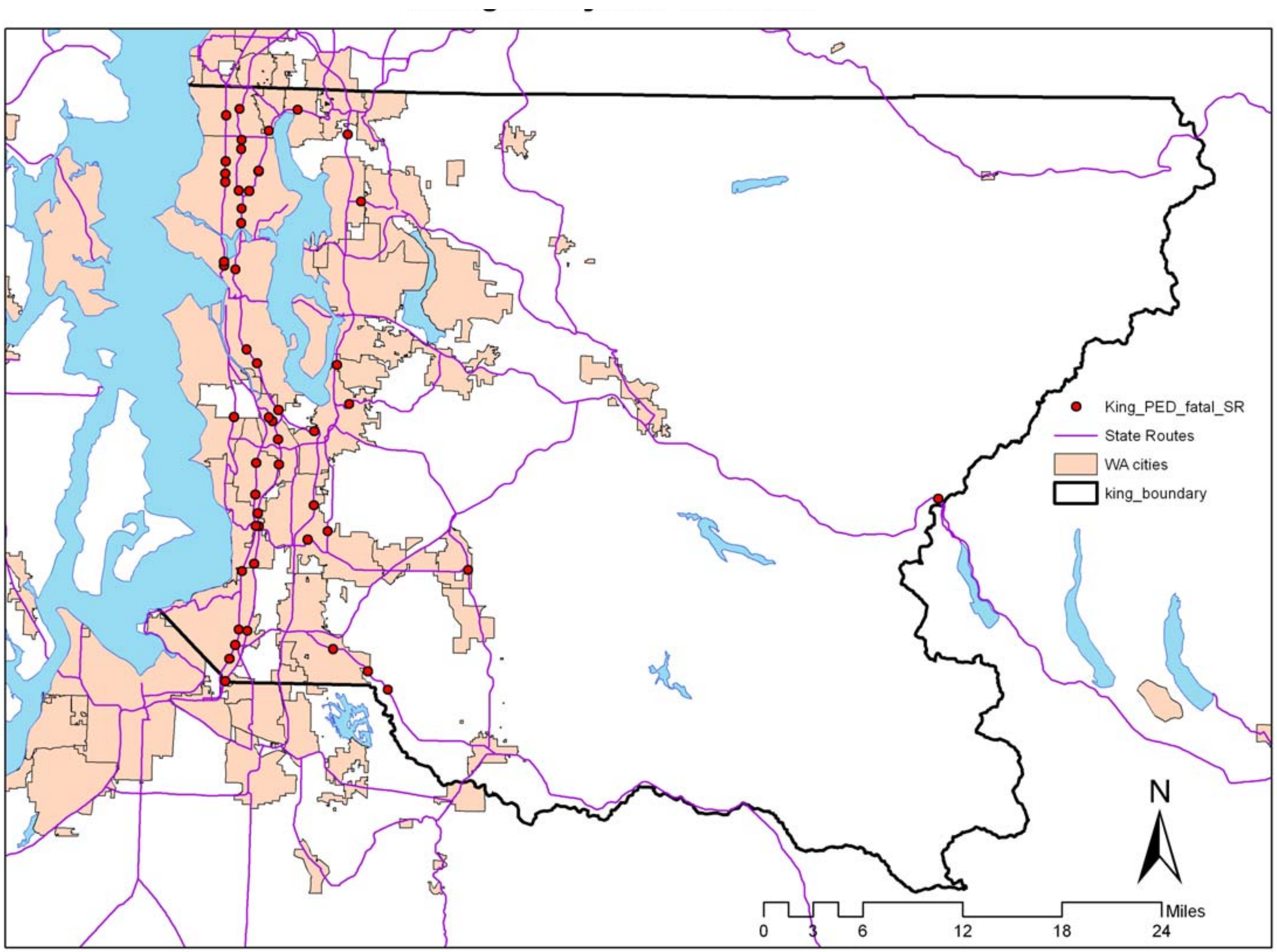

Figure 4: Locations of fatal pedestrian collisions on state routes in King County (1999-2004)

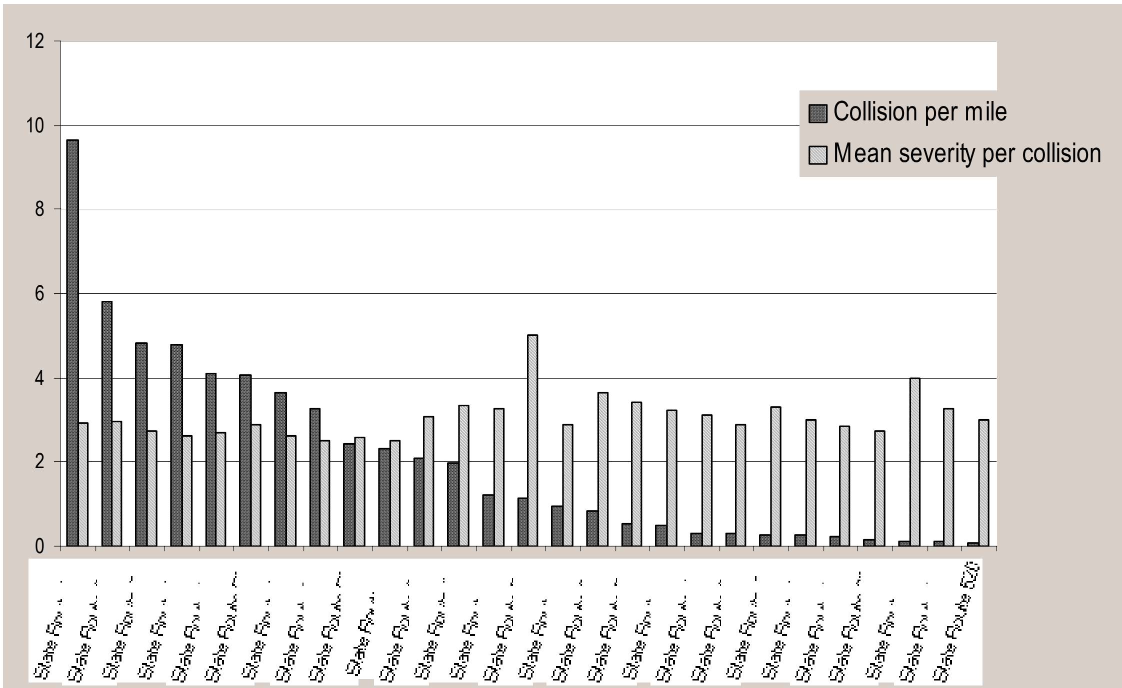

Figure 5: Mean severity of collisions and collisions per mile of state route in King County (five KABCO classes with 5 = fatal; county mean = 2.97; and state mean = 2.02)

Data Sources

The collision data comprised all collisions involving pedestrians on state routes in King County, Washington, recorded over a period of six years (1999 to 2004). These data came from the Transportation Data Office (TDO) of the Washington State Department of Transportation's (WSDOT) Strategic Planning and Programming Division. The TDO is responsible for collecting, processing, analyzing, and disseminating traffic, roadway, and collision data pertaining to all roadways in Washington State. These collision data originated from collision reports submitted by police officers and citizens. They are made available to the regions and divisions within WSDOT, the Federal Highway Administration (FHWA), the Washington Traffic Safety Commission, other Washington State government agencies, and public or private organizations. The data used for this study covered sociodemographic and behavioral characteristics of individual pedestrians and drivers, road class and design characteristics of the road where the collision occurred, time of day and year when the collision occurred, and weather conditions. Individual collision records were compiled in a geocodable flat file containing milepost information.

Objective data on the road environment came from the Puget Sound Regional Council (PSRC), which provided average daily traffic figures (ADT is EMME2 modeled data) and estimated speed on state routes; from King County Metro, which provided bus ridership data; and from WSDOT, which provided traffic signals, intersections, crosswalks, sidewalk, and number of lanes.

Objective data on the neighborhood environment came from the US population Census (2000), and from the King County Assessor's office, which provided land use, property assessment values, and residential density data at the parcel or tax lot level. Employment data were generated at the Urban Form Lab on the basis of the assessor's land-use data and by combining several sources of data on employment (Moudon and Sohn 2005).

Measurements

Collision Reports

Ninety percent of the collisions involving pedestrians on King County's SRs (711 out of a total of 790 pedestrian collisions) could be geocoded by using milepost data with a spatial resolution of 1/10th of a mile. The statistical distribution of geocoded and total collisions was similar; however, with 94 percent of the collisions involving one pedestrian, 5 percent involving two pedestrians, and about 1 percent involving three pedestrians (Table 1).

Table 1: Pedestrians involved in a collision and collision frequency in King County

	Collisions from TDO		Geocoded Collisions	
Number of pedestrians involved in a collisions	**Number of collisions**	**Percentage**	**Number of collisions**	**Percentage**
1	741	93.80%	670	94.23%
2	39	4.94%	36	5.06%
3	10	1.27%	5	0.70%
Total Collisions	790	100%	711	100%
Total Pedestrians	849		757	

The dependent variable was the degree of severity of injury, including death, sustained by a pedestrian involved in a collision with a motor vehicle. Police records on pedestrian injury contain seven categories of severity: no injury, possible injury, evident injury, disabling injury, died at hospital, dead on arrival, and dead at scene. For modeling purposes, injury severity was aggregated into two, three, and five classes. The five classes were those of the KABCO classification system used in other studies (KABCO collapses the three subcategories of fatality used in the police records into one).

The KABCO injury recording system defines injury as “bodily harm to a person” (Hauer 2006) (citing ANSI D16.1-1996 American National Standard, 1996 Manual on Classification of Motor Vehicle Traffic Accidents, Section 2.3). KABCO stands for the following:

- “fatal injury” (code **K** = “an injury that results in death”)
- “incapacitating injury” (code **A** = “any injury, other than a fatal injury, which prevents the injured person from walking, driving or normally continuing the activities the person was capable of performing before the injury occurred”)
- “non-incapacitating evident injury” (code **B** = “any injury, other than a fatal injury or an incapacitating injury, which is evident to observers at the scene of the accident in which the injury occurred”)
- “possible injury” (code **C** = “any injury reported or claimed which is not a fatal injury, incapacitating injury or non-incapacitating evident injury” and includes “claim of injuries not evident”)
- “no injury” (coded as **O**)

In the two-injury class models, categories K and A above were combined into one class, and B, C, and O into another. These two classes were called fatal/high injury severity and low/no injury severity

In the three-injury class models, categories K and A above were combined into one class; category B was the second class; and C and O formed the third class. These three classes were called fatal/high, medium, and low/no injury severity (Table 2, Figure 6).

The KABCO classification system has been a standard way of ordering injury severity in transportation. It has been used in quite a few studies (Duncan, Khattak et al. 1998; Zajac and Ivan 2003; Lee and Abdel-Aty 2005; Guttenplan, Chu et al. 2006). Some studies have used four levels of injury severity measures, which have included no `injury, possible injury, evident injuries, and severe/fatal injury (Abdel-Aty 2003; Khorashadi, Niemeier et al. 2005; de Lapparent 2006). Some have also used the binary system of fatality/severe injury and not severe injury (Shankar, Sittikariya et al. 2006).

Table 2: Distribution of pedestrian collisions by fatality and injury severity class in King County

Injury severity classifications			Police records [BASE]	Frequency of pedestrian collisions by injury class (n = 757)					
2 classes	3 classes	5 classes		5 classes		3 classes		2 classes	
				Frequency	Percent	Frequency	Percent	Frequency	Percent
Low injury severity	Low injury	1 No Injury	Unknown No injury	25	3.30				
		2 Possible Injury	Possible injury	241	31.84	266	35.14		
	Medium injury	3 Evident Injury	Evident Injury	291	38.44	291	38.44	557	75.20
Fatal/High injury severity	Fatal/High injury	4 Disabling Injury	Disabling Injury	144	19.02				
		5 Fatal	Died at hospital, Dead on arrival, Dead at scene	56	7.40	200	26.42	200	24.80
		Total		757	100	757	100	757	100

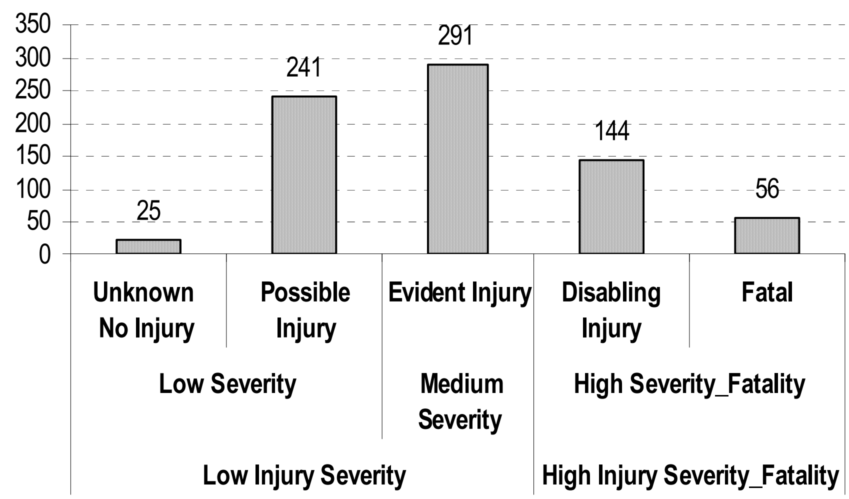

Figure 6: Fatal and injury severity classes and frequency of pedestrian collisions (n = 757)

Environmental Data

Table 3 summarizes the environmental variables and corresponding measures considered for the different identified domains. Variables portraying the road environment corresponded to those found to be significant in the literature. Additional variables were considered to capture the potential effects of transit because of its association with pedestrian travel (Hess, Moudon et al. 2004; Lee, Moudon et al. 2006). Variables describing the neighborhood environment included the social and the physical dimensions of neighborhood related to pedestrian travel patterns and exposure to vehicular traffic. Neighborhood wealth and neighborhood destinations, shown to attract significantly more walking in King County (Moudon AV 2007), constituted the majority of these variables.

Table 3: Objective environmental variables and measures considered

Variables			Measures Buffer measures (0.5 km, 1 km, and 1.5 km buffers)	Distance Measures Closest to collision measure
Road environment	Road design characteristics'	Crosswalks	Count	Euclidean distance to the closest
		Intersections	Count	Euclidean distance to the closest
		Traffic signals	Count	Euclidean distance to the closest
		Number of lanes	Count	
		Sidewalks	Linear feet	
	Traffic conditions	Bus stops	Count	Euclidean distance to the closest
		Bus ridership (within 250 feet)	Count	
		Traffic ADT	Count	
		Estimated speed from EMME2	Mean	
		Speed limit	Meanrs	
		Pedestrian collisions	Count	
		Pedestrian Accident Collisions (PALS)*	Count	Euclidean distance to the closest
Neighborhood environment	Transportation network	Block size	Median	
	Density of development	Population density (gross)	People per census block per acre of residential parcels	
		Residential density (net)	Residential units per net acre of residential parcels	
		Employment density (net)	Employees per net acre of employment parcels	
	Neighborhood wealth	Assessed residential property values	Median home values	
	Land uses (potential destinations and attractors of pedestrian travel)	Office	Count of parcels	Euclidean distance to the closest
		Grocery stores	Count of parcels	Euclidean distance to the closest
		NC_2 **	Count	Euclidean distance to the closest
		Retail	Count of parcels	Euclidean distance to the closest
		Eating/drinking establishments	Count of parcels	Euclidean distance to the closest
		Elementary school	Count of parcels	Euclidean distance to the closest
		Middle school	Count of parcels	Euclidean distance to the closest
		High school	Count of parcels	Euclidean distance to the closest
		Private school	Count of parcels	Euclidean distance to the closest
		College	Count of parcels	Euclidean distance to the closest

* The Washington State Department of Transportation (WSDOT) defines a PAL as four or more collisions over a six-year period along a 0.10-mile section of roadway (528 feet).
** NC_2 is a measure of neighborhood commercial center, which is defined as a cluster of at least one grocery store, one restaurant, and one retail outlet within 50 m of each other.

Objective measures of the road environment were taken at the collision location by using routines in geographic information systems that have been developed in previous projects (Lee C and Moudon AV 2006b). Measures of neighborhood environment were also taken in GIS by using three airline buffer radii (0.5 km, 1 km, and 1.5 km) from each collision point. The three buffer sizes corresponded to pedestrian travel catchment areas that have been used in previous research. Some of the neighborhood-level measures represented the distance from the closest neighborhood environment feature to the point of collision.

Analyses

The unit of analysis in this study was an individual pedestrian who was involved in a collision from 1999-2004 on state routes in King County, Washington. There were 757 pedestrians involved in the 711 geocoded collisions.

Independent Variable Selection

Three criteria were used to select independent variables:

- theoretical importance based on previous studies that had found the variables to be significantly associated with pedestrian injury severity
- significant in bivariate analyses with the dependent variables (0.05 level)
- availability, quality, or completeness of the data.

Bivariate analyses with the dependent variables used one-way ANOVA for continuous independent variables, Kendall's tau-c for ordinal variables, and contingency coefficients for categorical and dummy variables.

Table 4 summarizes the independent variables selected from the collision reports. These variables covered both the individual level of influence on injury severity and the road environment surrounding the collision, as reported in the police report and transferred to the collision database.

Table 4: Independent variables selected for the base model (from the collision report data)

LEVEL	Domain	Variable Name	Definition	Measurement and number of observations for each category	Type
Individual Level	**Pedestrian** Socio-demographic characteristics	P_AGE_square	(Square of Age)/100	Min: 0, Max: 84.64, Mean: 16.50, SD: 12.25	Continuous
		P_SEX	Gender	Male:188 , female: 115, unknown: 454	Categorical
	Pedestrian Behavior characteristics (action)	P_ALC	Inebriety	Have NOT been drinking: 665, Have been drinking: 92	Dummy
		P_ACT	Action and location	Walking along roadway: 73, Xing-Non intersection: 207, Xing - at intersection with signal: 253, Xing - at intersection without signal: 92, Other actions: 132	Categorical
		PED_N_d	Number of pedestrians	one pedestrian Involved: 670, more than one pedestrian involved: 87	Dummy
	Driver Behavior characteristics	DRIV_ALC	Inebriety	Have NOT been drinking: 721, Have been drinking: 36	Dummy
	Driver Vehicle action	V_ACT	Action and location	Going straight ahead: 419, Making right turn: 188, Making left turn: 96, other actions: 54	categorical
		VEH_N_d	Number of vehicles	One vehicle involved: 316, More than one vehicle involved: 441	Dummy
Road Environment	Temporal characteristics of collision	PEAK_TIME	Day time of collision (and traffic volumes)	Morning peak(6-9am): 87 Morning off-peak (9am-12pm): 88 Afternoon off-peak (12-4pm): 181 Afternoon peak(4-7pm): 177 Evening off-peak(7pm-6am): 224	categorical
		LIGHT		daylight/dawn/dusk: 402, dark/unknown/other: 355	Dummy
	Road characteristics	SR_Function	Road functional class	Principal arterial: 583, Minor arterial: 93, Interstate highway: 81	categorical
		JUNCTION	Location	At roadway (non-intersection): 329, At intersection/intersection: 428	Dummy

Table 5 summarizes the independent variables selected from the objective data on the road and the neighborhood environments. Only measures taken in the 0.5-km airline buffer were used in the models because bivariate analyses showed that measures in the different buffers had similar relationships with the dependent variables and because more variables were significantly related to the dependent variables in the 0.5-km buffer than in the larger buffers.

Table 5: Independent variables from the objective environmental data retained in the one-by-one testing

LEVEL	Domain	Name	Definition	Measurement and number of observations for each category	Type*
Road Environment	Road characteristics	ln_chmile_DIST_INTER	Distance to the closest intersection (Log) (feet)	Min:-7.88, Max: -0.6, Mean:-4.17, SD:1.36	Continuous
		ln_chmile_DIST_SIGN	Distance to the closest traffic signal (log) (feet)	Min:-6.09, Max: -0.13, Mean:-3.4, SD:1.14	Continuous
		N_LANES_dich	Number of lanes at collision site	Two lanes or fewer:50 More than 2 lanes:707	dichotomized
		cat_N_SIGN_05	Count of traffic signals in 0.5-km buffer	11 0-2 traffic signals: 91, 12 3-5 traffic signals: 75, 13 6-8 traffic signals: 121, 14 9-12 traffic signals: 214, 15 13-15 traffic signals: 103, 16 16-25 traffic signals: 101, 17 26+ traffic signals: 52	Ordinal
		Cat_L_SWLK_T05	Total length of sidewalk in 0.5-km buffer	11 0 mile: 70, 12 <=1 mile: 68, 13 1-2 miles: 123, 14 2-3 miles: 121, 15 3-4 miles: 112, 16 4-5 mile: 77, 17 5-6 miles: 62, 18 6-8 miles: 70, 19 >8 miles: 54	Ordinal
	Traffic conditions	ln_DIST_BUSST	Distance to the closest bus stop (log) (feet)	Min:2.48, Max: 8.57, Mean:5.35, SD:1.18	Continuous
		Cat2_N_RIDE_M05	Median daily bus ridership in 0.5-km buffer (Boardings and Alightings)	11 0 ridership: 138, 12 1-5 ridership: 185, 13 6-10 ridership: 132, 14 11-20 ridership: 140, 15 21-50 ridership: 106, 16 50+ ridership: 56	Ordinal
		ln_AVE_ADT_05	Average daily traffic in 0.5-km buffer (log) (number of cars)	Min:3.85, Max: 11.4, Mean:8.92, SD:1.36	Continuous
		SPEED_E_05	Estimated speed in 0.5-km buffer (mph)	Min:23, Max: 70, Mean:35.03, SD:6.97	Continuous
		cat_N_COLI_05	Count of collisions in 0.5-km buffer	11 collision 1-2: 136, 12 collision 3-5: 102, 13 collision 6-10: 187, 14 collision 11-15: 122, 15 collision 16-20: 91, 16 collision 21-25: 66, 17 collision 26+: 53	Ordinal

Table 5 (cont'd): Independent variables from the objective environmental data retained in one-by-one testing

		ln2_RESDEN_N05	Net residential density in 0.5-km buffer (log) (dwellings per acre)	Min:0, Max: 5.63, Mean:2.32, SD:0.93	Continuous
Neighborhood Environment	Density	ln2_EMPDEN_N05	Net employment density in 0.5-km buffer (log) (employees per acre)	Min:0, Max: 7.09, Mean:3.08, SD:0.95	Continuous
		Ln2_EMPTOT_N05	Sum of employment in 0.5-km buffer (log) (number of employees)	Min:0, Max: 11.45, Mean:6.79, SD:1.86	Continuous
	Land use_ Destinations	Cat2_N_OFF_05	Count of office parcels in 0.5-km buffer	11 0 office parcels: 94, 12 1-2 office parcels: 88, 13 3-5 office parcels: 84, 14 6-8 office parcels: 135, 15 9-11 office parcels: 111, 16 12-14 office parcels: 68, 17 15-20 office parcels: 85, 18 21-30 office parcels: 48, 19 31+ office parcels: 44	Ordinal
		dich_N_GRO_05	Count of grocery store parcels in 0.5-km buffer	Have NO grocery store parcels in 0.5 km buffer: 397, Have at least one grocery store parcel in 0.5 km buffer: 360	dichotomized
		dich_S_NC2_L_05	Count of NC2 in 0.5-km buffer	Have NO NC2 in 0.5 km buffer: 345, Have NC2 in 0.5 km buffer: 412	dichotomized
		Cat2_S_RET_L_05	Acres of retail parcels in 0.5-km buffer	11 0 acre retail parcels: 81, 12 less than 0.5 acre retail parcels: 70, 13 0.5-1 acre retail parcels: 67, 14 1-2 acres retail parcels: 85, 15 2-3 acres retail parcels: 72, 16 4-5 acres retail parcels: 74, 17 5-7 acres retail parcels: 64, 18 7-10 acres retail parcels: 50, 19 10-12 acres retail parcels: 59, 20 12-13 acres retail parcels: 80, 21 13+ acres retail parcels: 55	Ordinal
		Cat2_S_RES_L_05	Acres of drinking and eating establishments in 0.5-km buffer	11 0 acre drinking and eating establishments: 143, 12 less than 0.5 acres drinking and eating establishments: 115, 13 0.5-1 acres drinking and eating establishments: 164, 14 1-3 acres drinking and eating establishments: 125, 15 3-10 acres drinking and eating establishments: 131, 16 10+ acres drinking and eating establishments: 79	Ordinal
	Neighborhood wealth	cat_HOMEVAL_05	Median home value in 0.5-km buffer (dollars)	11 0 -6,000 dollars of median home: 76, 12 6,001 – 28,000 dollars of median home r: 100, 13 28,001 – 34,000 dollars of median home: 109, 14 34,001 – 47,000 dollars of median home: 182, 15 47,001 – 68,000 dollars of median home: 123, 16 68,001 – 120,000 dollars of median home: 105, 17 120,001+ dollars of median home: 62	Ordinal

Statistical Models

Binary logistic regression was applied to the model with fatal/high and low/no injury pedestrian injury severity categories, and ordinal logistic regressions were used in the models with three and five categories of injury severity.

Many studies have used ordered probit regression models to analyze traffic injury severity because the models account for the ordinal nature of injury categories and discern the unequal differences between ordinal categories in the dependent variable. Specifically, ordinal logistic regressions do not assume that, given a unit change in the explanatory variable, the difference between, for example, no injury and a minor injury is the same as the difference between a severe injury and a fatality. A traffic injury study first used this model in the mid-1990s to investigate the severity of motor vehicle injury (O'Donnell and Connor 1996). Subsequent applications of the model in traffic safety have included the following studies:

- truck-passenger car collision injury severity (Duncan, Khattak et al. 1998)
- motorcycle injury severity and vehicle damage severity (Quddus, Noland et al. 2002)
- driver injury severity (Abdel-Aty 2003)
- older occupant injury severity (Austin and Faigin 2003);
- injury severity of pedestrians crossing streets (Zajac and Ivan 2003)
- severity of injury for all traffic crash severity at signalized intersections (Abdel-Aty and Keller 2005)
- injury severity of pedestrian collisions at intersections (Lee and Abdel-Aty 2005)
- on pedestrian injury severity (Guttenplan, Chu et al. 2006).

Modeling Process

The same three-step modeling process was used for all three models. First, a base model was developed by using the individual level and road environment-related independent variables from the collision report database. This base model included data and variables that have been commonly used in previous transportation research. Second, the objective environmental variables of the road and neighborhood environment were added to the base model and tested one at a time. The goal was to systematically compare and select the environmental variables new to transportation research that were most likely associated with pedestrian injury severity. In the third step, final models were developed that combined all the variables in the base model and those objective environmental variables that showed statistical significance in the one-by-one testing step. This modeling process was developed to examine and identify objective built environmental variables that affected pedestrian injury severity, while controlling for other variables that have been found to be associated with pedestrian crashes and have been commonly used in transportation planning.

RESULTS

Descriptive Statistics

In King County, about one quarter of the pedestrians involved in collisions with automobiles were severely injured or died as a result of the collision. More than 38 percent suffered incapacitating or evident injury. And slightly more than 35 percent sustained possible injury, no injury, or did not have a record of being injured.

Of the 757 pedestrians included in the analysis, 29 (3.8 percent) records did not include information on age. There were 93 (12.3 percent) pedestrians between the ages of 0 and 14, 68 (9.0 percent) pedestrians 65 and older, and 547 (74.9 percent) pedestrians between the ages of 15 and 64. Of the pedestrians who were 65 and older, 11.8 percent died, while 1.1 percent those ages of 0 to 14 died and 8.3 percent of those between 15 and 64 died. One quarter of the pedestrians 65 and older suffered disabling injury, in comparison to 16.1 percent of pedestrians between 0 and 14, and 18.7 percent of those between 15 and 64.

There was no information on gender for 454 (60.0 percent) pedestrians. Of the remaining 40 percent, 115 were females and 188 were males. Bivariate analyses showed no significant gender-based differences in injury severity.

Principal state routes (excluding interstate highways) had 583 (77.0 percent) pedestrians involved in collisions, in comparison to 93 (12.3 percent) on minor arterials and had 81(10.7 percent) on interstate highways. Of the pedestrians involved in collisions on principal arterials (excluding interstate highways), 5.5 percent died, whereas 4.3 percent died on minor arterials and 24.7 percent died on interstate highways. Bivariate analyses showed significant differences in injury severity among state route functional classes (see Appendix 1).

Fifty (6.6 percent) pedestrians had collisions on two-lane streets, and 707 (93.4 percent) had collisions on streets with more than two lanes. There are approximately 200 miles of two-lane state roads in King County (or 2/5 of the county's state routes; lanes in this context exclude turning lanes). Of the pedestrians involved in collisions on two-lane streets, 4.0 percent died and 36.0 percent had a disabling injury. This compares to 7.6 percent dying and 17.8 percent suffering a disabling injury in collisions on streets with more than two lanes. Bivariate analyses showed significant differences in injury severity between two-lane streets and streets wider than two lanes.

Seventy (9.2 percent) pedestrians had collisions within a 0.5-km-radius of major streets that had no sidewalks (from PSRC GIS based data). For the more than 90 percent of pedestrians involved in a collision in an area whose major streets had sidewalks, the area mean length of sidewalks was 3.8 miles (range 0.1 to 16 miles). Furthermore, 37.1 percent of pedestrians at locations without sidewalks sustained severe injuries, in comparison to 25.3 percent of pedestrians at locations with some sidewalks.

Also, 227 (30 percent) pedestrians were involved in a street collision where a marked crosswalk was within 0.5 km, and 530 (70 percent) were involved in street collisions where no marked crosswalk was within a 0.5-km radius.. Of those pedestrians in areas with marked crosswalks, 24.2 percent died or sustained severe injury, in comparison to 27.4 percent in areas without marked crosswalks. Bivariate analyses showed no significant relationship between injury severity and the presence of marked crosswalks within 0.5 km of the collision location.

With respect to the proximity of the collision location to an intersection, 198 (26.2 percent) pedestrians were involved in a collision within 10 meters of an intersection, 322 (42.5 percent) were within 10 to 50 meters of an intersection, and 237 (31.3 percent) were more than 50 meters away from an intersection. Injury severity increased with the collision location distance from an intersection: 16.2 percent of the pedestrians who died or sustained severe injury were at locations that were 10 meters from an intersection, 26.7 percent were 10 to 50 meters from an intersection, and 34.6 percent were more than 50 meters away from an intersection. Bivariate analyses showed that distance to an intersection was significantly and negatively related to injury severity (from PSRC GIS data).

Overall Fit of the Base and Final Models

The binomial logit base model had a –2 log likelihood value of 700.026, capturing approximately 26 percent of the variation (Nagelkerke pseudo R-square value). The ordinal regression base models had a –2 log likelihood value of 1430.340 and 1811.083, for the three levels and five levels of injury severity, respectively, and Nagelkerke pseudo R-square values of 0.195 (Table 6).

Table 6: Base model results

			High_Low Severity			High_Medium_Low Severity			5 categories		
			B	Sig.	Odds ratio		Est.	Sig.		Est.	Sig.
		Constant	-2.198	**0.002**	0.111	[P_INJ_3cat = 0]	-0.958	**0.004**	[P_INJ_5cat = 0]	-2.424	**0.000**
						[P_INJ_3cat = 1]	0.199	0.553	[P_INJ_5cat = 1]	-0.880	**0.005**
									[P_INJ_5cat = 2]	0.268	0.396
									[P_INJ_5cat = 3]	1.212	**0.000**
Individual Level	Pedestrian	**P_AGE_square (square of age/100)**	0.027	**0.000**	1.027		0.009	**0.001**		0.010	**0.000**
		P_SEX [male]	-0.071	0.840	0.931		-0.033	0.843		0.068	0.665
		P_SEX [female]	-0.113	0.774	0.893		0.051	0.780		0.139	0.421
		P_SEX [unknown] ♦									
		P_ALC[Have NOT been drinking]					-0.311	**0.029**		-0.387	**0.004**
		P_ALC [Have been drinking] ♦	0.578	**0.036**	1.783						
		P_ACT_recode[Walking along roadway]	0.207	0.577	1.230		0.039	0.821		-0.012	0.942
		P_ACT_recode[Xing-Non intersection]	0.237	0.448	1.268		0.162	0.279		0.245	0.083
		P_ACT_recode[Xing - at intersection with signal]	0.601	0.149	1.825		0.100	0.545		0.093	0.548
		P_ACT_recode[Xing - at intersection without signal]	1.142	**0.007**	3.132		0.375	**0.041**		0.308	0.073
		P_ACT_recode[Other actions] ♦					0.000	.			
		PED_N_d [one pedestrian involved]					-0.196	0.157		-0.087	0.502
		PED_N_d [more than one pedestrian involved] ♦	0.663	**0.026**	1.941						
	Driver	DRIV_ALC [Have NOT been drinking]					0.061	0.770		0.012	0.951
		DRIV_ALC [Have been drinking] ♦	0.345	0.388	1.412		0.000	.			
		V_ACT [Going straight ahead]	0.851	**0.026**	2.342		0.304	0.078		0.382	**0.020**
		V_ACT [Making right turn]	-1.235	**0.010**	0.291		0.546	**0.004**		-0.291	0.102
		V_ACT [Making left turn]	-0.666	0.199	0.514		0.326	0.123		-0.139	0.488
		V_ACT [Others] ♦					0.000	.			
		VEH_N_d [one vehicle involved]					0.014	0.931		-0.056	0.712
		VEH_N_d [more than one vehicle involved] ♦	-0.117	0.736	0.890						
Road environment	time	PEAK_TIME [Morning peak]	0.142	0.711	1.152		0.036	0.835		-0.070	0.668
		PEAK_TIME [Morning off-peak]	-0.585	0.199	0.557		0.369	0.059		-0.337	0.065
		PEAK_TIME [Afternoon off-peak]	-0.209	0.568	0.811		-0.345	**0.038**		-0.411	**0.008**
		PEAK_TIME [Afternoon peak]	-0.372	0.185	0.689		0.247	0.062		-0.224	0.072
		PEAK_TIME [Evening off-peak] ♦									
		LIGHT [daylight/dawn/dusk]	-0.203	0.484	0.817		0.028	0.827		0.023	0.847
		LIGHT [dark/unknown/other] ♦									
	junction	**JUNCTION [at roadway]**	0.795	**0.021**	2.215		0.136	0.366		0.104	0.462
		JUNCTION [at intersection/related] ♦									
	SR Function	SR_Function [Principal arterial]	-0.200	0.517	0.818		0.162	0.295		-0.352	**0.015**
		SR_Function [Minor arterial]	-0.177	0.646	0.838		0.129	0.493		-0.329	0.063
		SR_Function [Interstate] ♦									
		-2 Log Likelihood	700.026				1430.340			1811.083	
		Cox & Snell R Square	0.180				0.173			0.182	
		Nagelkerke R Square	0.262				0.195			0.195	

♦ Reference; **bold** = significant < 0.05

The –2 log likelihood value for the binomial logit final model was 684.065 (Nagelkerke pseudo R-square = 0.29). The ordinal regression models with three levels and five levels of injury severity had –2 log likelihood values of 1422.163 and 1803.793, respectively, and a Nagelkerke pseudo R-square equal to 0.22 (Table 7).

Table 7: Final model results

			High_Low Severity			High_Medium_Low Severity			5 categories		
			B	Sig.	Odds ratio		Est.	Sig.		Est.	Sig.
		Constant	-0.397	0.801	0.673	[P_INJ_3cat = 0]	-1.545	**0.038**	[P_INJ_5cat = 0]	-2.736	**0.000**
						[P_INJ_3cat = 1]	-0.372	0.618	[P_INJ_5cat = 1]	-1.174	0.092
									[P_INJ_5cat = 2]	-0.012	0.986
									[P_INJ_5cat = 3]	0.956	0.171
Individual Level	Pedestrian	**P_AGE_square (square of age/100)**	0.028	**0.000**	1.029		0.009	**0.001**		0.010	**0.000**
		P_SEX [male]	-0.132	0.715	0.876		-0.096	0.572		0.004	0.979
		P_SEX [female]	-0.049	0.902	0.952		0.031	0.870		0.120	0.496
		P_SEX [unknown] ♦									
		P_ALC[Have NOT been drinking]					-0.279	**0.052**		-0.364	**0.006**
		P_ALC [Have been drinking] ♦	0.524	0.064	1.689						
		P_ACT_recode[Walking along roadway]	0.407	0.294	1.502		0.015	0.933		0.029	0.860
		P_ACT_recode[Xing-Non intersection]	0.575	0.085	1.777		0.292	0.060		0.365	**0.012**
		P_ACT_recode[Xing – at intersection with signal]	0.820	0.060	2.270		0.162	0.333		0.148	0.343
		P_ACT_recode[Xing – at intersection without signal]	1.381	**0.002**	3.980		0.444	**0.018**		0.382	**0.030**
		P_ACT_recode[Other actions] ♦									
		PED_N_d [one pedestrian involved]					-0.185	0.192		-0.077	0.562
		PED_N_d [more than one pedestrian involved] ♦	0.684	**0.028**	1.981						
	Driver	DRIV_ALC [Have NOT been drinking]					-0.045	0.832		0.042	0.832
		DRIV_ALC [Have been drinking] ♦	0.342	0.407	1.407						
		V_ACT [Going straight ahead]	0.800	**0.040**	2.226		0.280	0.111		0.367	**0.028**
		V_ACT [Making right turn]	-1.257	**0.010**	0.285		-0.528	**0.006**		-0.261	0.147
		V_ACT [Making left turn]	-0.756	0.155	0.470		-0.332	0.123		-0.116	0.567
		V_ACT [Others] ♦									
		VEH_N_d [one vehicle involved]					0.054	0.744		0.012	0.938
		VEH_N_d [more than one vehicle involved] ♦	-0.165	0.639	0.848						
Road environment	time	PEAK_TIME [Morning peak]	0.207	0.597	1.230		-0.018	0.917		-0.059	0.719
		PEAK_TIME [Morning off-peak]	-0.659	0.158	0.517		-0.375	0.058		-0.337	0.068
		PEAK_TIME [Afternoon off-peak]	-0.183	0.626	0.833		-0.333	**0.049**		-0.390	**0.013**
		PEAK_TIME [Afternoon peak]	-0.359	0.215	0.699		-0.231	0.085		-0.202	0.107
		PEAK_TIME [Evening off-peak] ♦									
		LIGHT [daylight/dawn/dusk]	-0.214	0.473	0.807		0.044	0.734		0.051	0.675
		LIGHT [dark/unknown/other] ♦									
	junction	JUNCTION [at roadway]	0.430	0.258	1.538		0.007	0.967		0.001	0.995
		JUNCTION [at intersection/related] ♦									
	SR Function	SR_Function [Principal arterial]	0.038	0.910	1.039		-0.025	0.883		-0.221	0.161
		SR_Function [Minor arterial]	-0.154	0.731	0.857		-0.094	0.656		-0.280	0.153
		SR_Function [Interstate] ♦									
	road features	ln_chmile_DIST_INTER	0.184	0.056	1.202		0.042	0.327		0.029	0.468
		N_LANES_dich [2 lanes or fewer]					0.127	0.511		-0.013	0.942
		N_LANES_dich [more than 2 lanes] ♦	-0.588	0.154	0.555						
	traffic conditions	**ln_AVE_ADT_05**	-0.188	**0.018**	0.829		-0.081	**0.030**		-0.070	**0.044**
		cat_N_COLI_05	0.003	0.971	1.003		-0.022	0.536		-0.017	0.594
Neighborhood Environment	neighborhood wealth	**cat_HOMEVAL_05**	0.074	0.204	1.077		0.054	**0.047**		0.059	**0.019**
	NC2	NC2 [NO NC2]					0.058	0.598		0.112	0.277
		NC2 [At least one NC2] ♦	-0.139	0.578	0.870						
	Office	Cat2_N_OFF_05	-0.002	0.967	0.998		-0.025	0.266		-0.028	0.190
		-2 Log Likelihood	682.065			1422.163			1803.793		
		Cox & Snell R Square	0.199			0.194			0.205		
		Nagelkerke R Square	0.290			0.219			0.220		

♦ Reference; **bold** = significant < 0.05

All final models improved the base models by approximately 2 percent to 3 percent. BIC tests (model selection criteria tests) for all models showed that the final binomial logit model was significantly better than the base binomial model. However, the two ordinal regression final models did not show significant improvements over their base models.

Model Results

Base Models

Seven variables were significant ($p < 0.05$) in the binomial model, and five were significant in each of the ordinal models. Significant variables in all models included the age of the pedestrian and his or her state of inebriety. One variable was significant in the two ordinal models: the collision occurring in the afternoon off-peak period, with a negative association relative to collisions occurring at evening off-peak periods. Significant variables in the binomial and one of the ordinal models included the collision occurring when the pedestrian crossed the road at an unsignalized intersection, the vehicle going straight on the roadway, and the vehicle making a right turn. Two variables were significant in the binomial model only: having more than one pedestrian involved in the collision and the collision occurring along the roadway at a non-intersection location. One variable was significant in only one of the ordinal models: the collision not occurring on a principal state route.

Base and Final Models

A few variables in the base models became insignificant after introducing the road and neighborhood environmental variables were introduced in the final models. As mentioned, the state of the pedestrian's inebriety was significant in all base models ($p < 0.05$), showing in the binomial model that a pedestrian under the influence of alcohol was 1.78 more likely to sustain severe injury than a sober pedestrian. Yet the relationship became insignificant in the final binomial model ($p = 0.064$). One other variable became insignificant in the final models: the collision taking place along the roadway (and being non-intersection related ($p = 0.910$). On the other hand, one variable became significant in the five-category final ordinal model: the pedestrian being hit while crossing at an unsignalized intersection, relative to all other crossing situations or to walking along the roadway ($p = 0.030$).

One-by-One Testing

Several of the road and neighborhood environment variables selected (Table 5) were insignificant in the one-by-one testing. Insignificant road characteristic variables included traffic signalization, presence of sidewalks, bus stops, bus ridership, and estimated traffic speed within the buffer. Insignificant neighborhood characteristics included all measures of development density (residential and employment based) and measures of land uses, except for offices and such neighborhood commercial variables as grocery stores, retail outlets, restaurants, and NC2. Of the significant neighborhood commercial variables that were highly correlated with the dependent variables, only NC2 measures were included in the final models because they represent clusters of at least one grocery store, one retail outlet, and one restaurant, all within 50 m of each other. They were found to be positively and significantly related to pedestrian activity (Moudon AV 2007).

Final Models

The binomial logit model estimated that six variables were significantly associated with the severity of pedestrian injury ($p < 0.05$). The ordinal regression models of three-class and five-class injury severity yielded seven and eight significant variables, respectively (Table 7).

Variables that were significant in all models involved the individual level of influence on injury severity and the road environment level. They included a positive association with the age of the pedestrian and the pedestrian crossing at an unsignalized intersection, as well as a negative association with the average daily traffic (ADT) volume where the collision occurred. The relationship between severity and age of the pedestrian was quadratic in form, with older pedestrians being more likely to sustain more severe injuries as a result of a collision with a motor vehicle. Pedestrians crossing a road or street at a unsignalized intersection were almost four times more likely to sustain severe injuries or to die than when crossing at other locations or walking along the roadway.

Variables that were significant in two of the models straddled all three levels of influence: individual, road, and neighborhood environment. Positive associations with injury severity, including fatality, were the striking vehicle moving straight ahead on the roadway and the average home value of the neighborhood 0.5 km from where the collision occurred. Negative associations were found with pedestrians being sober, with vehicles making a right turn, and with the collision occurring at the afternoon non-peak period. Pedestrians colliding with a vehicle that was moving straight ahead on the roadway were almost four times more likely to suffer severe injury or to die than those colliding with vehicles making a right or a left turn on the roadway (data not shown).

Variables found significant in one of the three models included a positive relationship with having more than one pedestrian involved in the collision, and with the pedestrian crossing at a non-intersection. Having more than one pedestrian in the collision increased the risk of sustaining severe injury or fatality by 98 percent.

DISCUSSION

Consistent results across models attested to the models' robustness. Strongly significant correlates of injury severity or fatality emerged at the individual level and at the level of the road environment, providing direction for effective future safety policies and injury prevention.

The introduction of objective environmental variables at the road and neighborhood level rendered the report data on the collision location (junction and SR function) insignificant. It increased and strengthened the significance of the variable capturing pedestrians crossing at unsignalized intersections. But it made the pedestrian state of inebriety insignificant in the multinomial model. It is important to limit the interpretation of these results strictly within the confines of estimating injury severity and NOT collision frequency.

The general lack of significance of environmental variables was not surprising. Pedestrian injury severity is conditioned by the fact that a collision has taken place. While the occurrence of a collision would expectedly be influenced by the characteristics of the road and neighborhood environment around the collision, the influence of the environment on the severity of injury may be less determining. However, the limited associations found between injury severity and environment raised interesting issues. One would have expected the severity of injury to *decrease* in areas with high density development or in areas with neighborhood commercial activity: these areas should be "safer" because they are likely to have large numbers of pedestrians. Similarly, one would have expected a decrease in severity of injury where speed limits were low and there were sidewalks, crosswalks, signals, and many bus riders.

Also interesting was the lack of association between injury severity and collision frequency at or near the same location. The one-by-one testing showed a significant negative association between the number of collisions within the 0.5-km buffer and pedestrian injury severity. This result suggests that the locations of collisions with high severity injury are not necessarily the same locations as those with high collision frequency. Thus safety programs addressing high frequency collision locations would not necessarily help reduce the severity of injury when collisions did occur. Furthermore, combining the lack of relationship between collision frequency and injury severity and the finding that injury severity was related to very few attributes of the surrounding environment suggests that injury severity on state routes might be explained primarily by driver or pedestrian actions and behaviors.

Individual-Level Influences

Vehicle actions stood out as important correlates of injury severity. Turning vehicles were shown to be much less threatening to pedestrians than vehicles moving along the roadway. This finding differed from results of research focusing on collision frequency, which has pointed to an increased risk of collisions when vehicles are making turns, ostensibly capturing the fact that drivers pay attention to their own actions at the expense of pedestrians crossing the right of way.

The strong association between vehicles moving straight along the roadway and injury severity likely captured the effect of speed on injury; vehicles traveling straight ahead are likely to be moving faster than those that are turning. Yet none of the vehicular speed measures turned out to be significant in the models. This finding was unexpected because vehicular speed, and especially speed at impact, has been recognized as the single most important predictor of pedestrian injury severity or fatality. One would have expected other measures of vehicular speed, which are necessarily correlated to impact speed, to be associated with injury severity. At the same time, the finding was hardly surprising: data on measures such as speed limit or modeled speed were taken within areas that were larger than the localized point of collision and likely did not capture the driver’s actual actions. It is also possible or even likely that drivers involved in high injury collisions with pedestrians were traveling at higher speeds than those modeled or posted.

Unfortunately, police records were incomplete regarding the type of vehicle involved in collisions with one or more pedestrians, which is another known determinant of injury severity.

Road Environment Influences

The finding that intersections without signals were high risk locations for pedestrian safety added to previous research (Koepsell, McCloskey et al. 2002; Zegeer, Steward et al. 2002). It points to the fact that such intersections have been strongly associated not only with increased risk of collision but also with increased risk of severe injury. The lessons seem clear: all intersections that pedestrians are expected to use should be signalized. What represents a “signal,” however, needs immediate further research. Collision records do not consistently report the type of signal existing at collision locations. Likewise, objective data on signalization at intersections are sketchy because they do not distinguish among the many varieties of traffic lights and stop signs. In the short run, pedestrians must be educated to understand the high risks they take in crossing roadways at any unsignalized location.

The finding that ADT was negatively related to injury severity suggests that facilities with low traffic volumes, and perhaps little or no congestion, harbor a higher risk of severe injury or fatality whenever a collision does occur. This finding suggests that ADT may be a proxy for vehicular speed. Similar effects of ADT were found in a study on injury severity in rear-end collisions involving truck-passenger cars (Duncan, Khattak et al. 1998). A UK study examining the association between congestion and traffic safety found inconclusively that traffic congestion may increase pedestrian safety (Noland and Quddus 2005). These studies suggested that ADT has an effect on both automobile and non-automobile safety. Roads or streets with high traffic volumes produce high congestion, leading to traffic moving more slowly and resulting in less severe injury when collisions do occur. Correlation analyses of speed and ADT did show that higher ADT was associated with a lower speed limit or estimated speeds. Also, the ADT data were limited in that they did not take into account differences between peak and off-peak traffic.

The lack of significance of variables capturing road width could be explained by the few observations collected on two-lane state routes. Similar research on city streets might reveal associations between road width and pedestrian injury.

Neighborhood Environment Influences

It made sense to find stronger correlations between injury severity and the objective environmental measures in the small 0.5-km buffer rather than the larger buffers. Only the environment immediately proximate to the collision location would have an influence on the severity of injury. However, we expect that this result will not hold in future analyses of collision frequency, in which the characteristics of the larger geographic environment are likely to influence the number of collision events.

Residential property values were the only feature of the social and built environments that remained significant in the final models. The positive, but weak, association with injury severity was not easily explained. On the one hand, it could indicate a relationship between injury severity and residential areas, as opposed to commercial areas. In the one-by-one testing of objective built environmental variables, the presence of grocery stores, offices, retail establishments, and restaurants decreased pedestrian injury severity. Bivariate analyses showed higher median home values to be significantly associated with fewer grocery stores, retail, and restaurants in a 0.5-km buffer around a collision location. On the other hand, residential areas with higher property values could be a proxy measure for car-oriented roads with fewer pedestrians and /or higher vehicular speeds. We found a weak association between home value and estimated speed, with higher home value being associated with higher estimated speed within the 0.5-km buffer. As well, bivariate analyses showed ADT and property values to be moderately (low coefficient 0.163) but significantly (p-value<0.01) and positively correlated. Because vehicular speed is higher in areas with no pedestrians, it is possible that when a collision did occur, vehicular speed was high, thus resulting in higher injury severity. (Collisions with impact speeds of higher than 30 mph have a 50 percent chance of resulting in a fatality.)

Other interesting aspects of home values included a weak association with the age of the pedestrian involved in a collision. There were more senior pedestrian (65 and above) collisions than young pedestrian (age zero to fourteen) collisions in areas where home values were high. Secondly, as noted, in the one-by-one testing, the number of collisions within the 0.5-km buffer was negatively associated with pedestrian injury severity. The bivariate analysis result also showed that home value was negatively associated with the number of collisions.

Note that most of the neighborhood environment variables considered had a significant relationship with the dependent variable in the bivariate analyses, with the exception of the presence of schools and educational facilities near collision locations. The latter land uses were not associated with injury severity even without controlling for individual-level variables. One likely explanation is that speed limits in schools zones are effective means for preventing severe injury or death when collisions do occur near schools.

Further research would be needed to probe the effect of neighborhood-level measures of population, including the age and density of the area population.

Limitations

This study was limited to state routes in King County, Washington. The results apply to major roads in metropolitan areas and are not generalizable to all road or street types or to the entire state. State routes have a disproportionate number of collisions ending in fatality and severe injury. Similar research on city streets may yield different results, including possible associations between injury and the neighborhood environment.

The study relied on uniquely detailed data on road design and traffic characteristics and on the attributes of land uses along the roads. These data could be improved, especially, and as noted earlier, in including more precise measures of vehicular speed.

The study was based on police records in Washington State. These data were unique and a powerful basis for this research, given the systematic and coordinated methods by which they were collected and recorded, the large geographic extent they covered, and their long temporal extent. However, limitations to such data remain, which have been noted in the literature. The Transportation Research Board recently published a circular summarizing the need for improving safety data collection, quality and accuracy (Transportation Research Board 2006). Several studies have already noted the limitations of data collected in a similar fashion, arguing that not all reportable motor vehicle accidents were actually reported (Hauer 2006). A study comparing police reports of pedestrian collisions and records of pedestrians treated at San Francisco General Hospital for 2000 and 2001 found that police collision reports underestimated the number of injured pedestrians by 21 percent (Sciortino, Vassar et al. 2005). It noted that police collision reports were also likely to miss pedestrians who had minor injuries. A study using the National Electronic Injury Surveillance System All-Injury Program operated by the U.S. Consumer Product Safety Commission identified a much greater annual number of school bus-related injuries to children than reported previously (McGeehan, Annest et al. 2006).

Another study reviewed 18 studies in which researchers examined police, hospital, and insurance sources for common entries. It concluded that the police missed some 20 percent of injuries that required hospitalization and perhaps up to half of the injuries that did not. Also suggested was the fact that perhaps 60 percent of reportable property damage-only accidents were not reported (Hauer and Hakkert 1988). A comprehensive meta-analysis (Elvik and Mysen 1999) found the probability of reporting a collision to be 70 percent for serious injuries, 25 percent for slight injuries, and 10 percent for very slight injuries. Another study concluded that, on average, estimates of unreported injuries varied by injury severity, with nearly one quarter of all minor injuries and almost half of all property-damage-only (PDO) crashes remaining unreported (Blincoe, Seay et al. 2002).

By contrast, there was agreement that all critical or fatal injuries were reported. The inclination to report an accident to the police was found to increase with the age of the injured person and with the number of vehicles involved. Injuries to non-occupants were less completely reported than injuries to passengers in vehicles, and these, in turn, were less likely to be reported than injuries to drivers.

CONCLUSIONS AND RECOMMENDATIONS

Table 8 summarizes the findings of this research. These need to be understood as limited to state routes, which, on average, have higher traffic volumes and higher speeds than city streets. Most significant associations emerged between injury severity or fatality and variables at the individual and the road environment levels. And most significant variables came from the police record data, suggesting that objective environmental data might better serve analyses of collision frequency. However, given the likely underreporting of low injury collisions, police record data should likely be complemented with medical records.

Table 8: Summary of model results

Level		Variable	Data Source*	Association with Injury Severity	
				Direct-ion	Strength
Individual level	Pedestrian	Age of the pedestrian	PR	+	[quadratic]
		Pedestrian being inebriated	PR	+	
		More than one pedestrian involved in the collision	PR	+	almost 2 times more likely to sustain severe injuries or to die than a single pedestrian
		Pedestrian crossing at a non-intersection vs all other intersections or locations along roadway	PR	+	
		Pedestrian crossing at an intersection without a signal	PR	+	4 times more likely to sustain severe injuries or to die than when crossing at other locations or walking along roadway
	Driver/Vehicle	Striking vehicle moving straight ahead on the roadway	PR	+	almost 4 times more likely to suffer severe injury or to die than colliding with vehicles making a right or a left turn on the roadway
		Vehicle making right turn vs all other vehicle actions	PR	-	
Environment	Road	Afternoon off-peak vs evening off-peak	PR	-	
		Average Daily Traffic (ADT) volume within 0.5 km of the collision	O	-	
	Neigh-borhood	Average home values within 0.5 km of the collision.	O	+	

* PR = Police records; O = objective GIS-based data

The significance of the relationship of ADT to injury severity, combined with the strength of association with vehicles moving straight along the roadway as opposed to making turns, suggests that accurate data on vehicular speed would greatly improve the prediction of the risk of injury severity. In order to predict injury outcomes, vehicular speed should be estimated and recorded both precisely and at the exact time and location of the collision. These two requirements could not be met with current data, highlighting several lessons to be drawn from these findings. First, because police records routinely analyze and estimate vehicular speed in fatal and severe injury cases, it would be useful to record estimated speed at impact as an integral part of official records of collisions. Pre-crash vehicle movements would also be interesting to know, though likely not as directly useful as impact speeds (Roudsari, Kaufman et al. 2006). Second, both drivers and pedestrians should be educated about the effects of vehicular speed on injury severity. Third, speed limits should be strictly enforced on state routes running through populated areas where pedestrians are expected to use the roadway (Davis, Bennink et al. 2006).

Data on the types of vehicles involved in collisions with pedestrians need to be recorded for all collisions, not only those with severe injury or fatal outcomes. These data would be essential in supporting research on vehicle design to enhance driver's awareness and perception of pedestrians and to minimize harm to pedestrians who are hit by vehicles. Such data would help vehicle safety research and development to be expanded and to consider the risk that motor vehicles confer to all people, not only occupants (Holt 2004).

Lessons from the finding that intersections without signals were high-risk locations for pedestrian safety and injury severity seem clear: all intersections expected to be used by pedestrians should be signalized. Furthermore, research to improve the understanding of the type of signalization that effectively reduces both collision frequency and severity of injury is urgently needed.

The relatively weak association between the neighborhood environment and injury severity suggests that transportation safety and injury prevention programs seeking to lower injury severity should be directed to individuals, pedestrians, and drivers, as well as to the design and utilization of roads and streets affecting such behaviors. However, such limited programs might shortchange attempts to lower the risk of collision all together. This was suggested by the lack of association between injury severity and collision frequency at or near the same location—and the significant but negative association between them in bivariate analyses. Parallel models of collision frequency using the same data are being developed to address this very issue.

REFERENCES

Abdel-Aty, M. (2003). "Analysis of driver injury severity levels at multiple locations using ordered probit models." J Safety Res **34**(5): 597-603.

Abdel-Aty, M. and J. Keller (2005). "Exploring the overall and specific crash severity levels at signalized intersections." Accid Anal Prev **37**(3): 417-25.

Austin, R. A. and B. M. Faigin (2003). "Effect of vehicle and crash factors on older occupants." J Safety Res **34**(4): 441-52.

Ballesteros, M. F., P. C. Dischinger, et al. (2004). "Pedestrian injuries and vehicle type in Maryland, 1995-1999." Accid Anal Prev **36**(1): 73-81.

Blincoe, L. J., A. G. Seay, et al. (2002). The Economic Impact of Motor Vehicle Crashes, 2000, National Highway Traffic Safety Administration**:** 94 p.

Clifton, K. J. and K. Kreamer Fults (2006). Role of Environmental Attributes in Explaining Pedestrian-Vehicular Crashes near Public Schools. Transportation Research Board 85th Annual Meeting, Transportation Research Board**:** 15p.

Council, F., E. Zaloshnja, et al. (2005). Crash Cost Estimates by Maximum Police-Reported injury Severity Within Selected Crash Geometries, US Department of Transportation Federal Highway Administration**:** 71.

Davis, J. W., L. D. Bennink, et al. (2006). "Aggressive traffic enforcement: a simple and effective injury prevention program." J Trauma **60**(5): 972-6; discussion 976-7.

de Lapparent, M. (2006). "Empirical Bayesian analysis of accident severity for motorcyclists in large French urban areas." Accid Anal Prev **38**(2): 260-8.

Demetriades, D., J. Murray, et al. (2004). "Pedestrians injured by automobiles: relationship of age to injury type and severity." J Am Coll Surg **199**(3): 382-7.

DiMaggio, C. and M. Durkin (2002). "Child pedestrian injury in an urban setting: descriptive epidemiology." Acad Emerg Med **9**(1): 54-62.

Duncan, C. S., A. J. Khattak, et al. (1998). "Applying the Ordered Probit Model to Injury Severity in Truck-Passenger Car Rear-End Collisions." Transportation Research Record **1635**: 63-71.

Elvik, R. and A. B. Mysen (1999). "Incomplete Accident Reporting: Meta-Analysis of Studies Made In 13 Countries." Transportation Research Record **1665**: p. 133-140.

Garder, P. E. (2004). "The impact of speed and other variables on pedestrian safety in Maine." Accid Anal Prev **36**(4): 533-42.

Graham, D. J. and S. Glaister (2003). "Spatial Variation in Road Pedestrian Casualties: The Role of Urban Scale, Density and Land-use Mix." Urban Studies **40**(8): 1591-1607.

Guttenplan, M., X. Chu, et al. (2006). Crossing Locations, Light Conditions, and Pedestrian Injury Severity. Transportation Research Board 85th Annual Meeting, Transportation Research Board**:** 18p.

Hauer, E. (2006). "The frequency--severity indeterminacy." Accid Anal Prev **38**(1): 78-83.

Hauer, E. and A. S. Hakkert (1988). "Extent and Some Implications of Incomplete Accident Reporting." Transportation Research Record **1185**: p. 1-10.

Hess, P., A. V. Moudon, et al. (2004). "Pedestrian Safety and Transit Corridors." Journal of Public Transportation **7**(2): 73-93.

Hewson, P. (2004). "Deprived children or deprived neighbourhoods? A public health approach to the investigation of links between deprivation and injury risk with specific reference to child road safety in Devon County, UK." BMC Public Health **4**: 15.

Hewson, P. J. (2005). "Epidemiology of child pedestrian casualty rates: can we assume spatial independence?" Accid Anal Prev **37**(4): 651-9.

Holt, D. J., Ed. (2004). Pedestrian Safety. Warrendale, PA, Society of Automotive Engineers, Inc.

Hunter, W., J. Stutts, et al. (1996). Pedestrian and Bicycle Crash Types of the Early 1990's. Washington, DC, Federal Highway Administration.

Khorashadi, A., D. Niemeier, et al. (2005). "Differences in rural and urban driver-injury severities in accidents involving large-trucks: an exploratory analysis." Accid Anal Prev **37**(5): 910-21.

Koepsell, T., L. McCloskey, et al. (2002). "Crosswalk markings and the risk of pedestrian-motor vehicle collisions in older pedestrians." The Journal of the Amercian Medical Association **288**(17): 2136-2143.

Kong, L. B., M. Lekawa, et al. (1996). "Pedestrian-motor vehicle trauma: an analysis of injury profiles by age." J Am Coll Surg **182**(1): 17-23.

Laberge-Nadeau, C., U. Maag, et al. (2003). "Wireless telephones and the risk of road crashes." Accid Anal Prev **35**(5): 649-60.

Leaf, W. and D. Preusser (1999). Literature Review on Vehicle Speeds and Pedestrian Injuries. Washington, DC, US Dept of Transportation.

Leden, L., P. Garder, et al. (2006). "Safe pedestrian crossings for children and elderly." Accid Anal Prev **38**(2): 289-94.

Lee C and Moudon AV (2006b). "The 3Ds + R: Quantifying land use and urban form correlates of walking." Transportation Research Part D: Transport and Environment **11**(3): 204-215.

Lee, C. and M. Abdel-Aty (2005). "Comprehensive analysis of vehicle-pedestrian crashes at intersections in Florida." Accid Anal Prev **37**(4): 775-86.

Lee, C., A. V. Moudon, et al. (2006). "Built environment and behavior: spatial sampling using parcel data." Ann Epidemiol **16**(5): 387-94.

Lee, C., A. V. Moudon, et al. (2006a). "Built environment and behavior: spatial sampling using parcel data." Ann Epidemiol **16**(5): 387-94.

McGeehan, J., J. L. Annest, et al. (2006). "School bus-related injuries among children and teenagers in the United States, 2001-2003." Pediatrics **118**(5): 1978-84.

Moudon AV, L. C., Cheadle AD, Garvin CW, Johnson DB, Schmid TL, Weathers RD (2007). "Attributes of environments supporting walking." A J of Health Prom **21**(3): in press.

Moudon, A. V. and D. W. Sohn (2005). Transportation-Efficient Land Use Mapping Index (TELUMI) Phase 3 of Integrating Land Use and Transportation Investment Decision-Making, Washington State Transportation Center, Washington State Department of Transportation, Federal Highway Administration.

NHTSA (2006). Traffic Safety Facts 2005: Overview Washington, DC, National Highway Traffic Safety Administration, National Center for Statistics and Analysis**:** 12p.

Noland, R. B. and M. A. Quddus (2005). "Congestion and Safety: A Spatial Analysis of London." Transportation Research. Part A: Policy and Practice **39**(7): pp 737-754.

O'Donnell, C. J. and D. H. Connor (1996). "Predicting the severity of motor vehicle accident injuries using models of ordered multiple choice." Accid Anal Prev **28**(6): 739-53.

Oxley, J., M. Lenne, et al. (2006). "The effect of alcohol impairment on road-crossing behaviour." Transportation Research Part F: Traffic Psychology and Behaviour **9**(4): 258-268.

Paulozzi, L. J. (2005). "United States pedestrian fatality rates by vehicle type." Inj Prev **11**(4): 232-6.

Peng, R. Y. and F. S. Bongard (1999). "Pedestrian versus motor vehicle accidents: an analysis of 5,000 patients." J Am Coll Surg **189**(4): 343-8.

Plurad, D., D. Demetriades, et al. (2006). "Pedestrian injuries: the association of alcohol consumption with the type and severity of injuries and outcomes." J Am Coll Surg **202**(6): 919-27.

Quddus, M. A., R. B. Noland, et al. (2002). "An analysis of motorcycle injury and vehicle damage severity using ordered probit models." J Safety Res **33**(4): 445-62.

Redelmeier, D. A., R. J. Tibshirani, et al. (2003). "Traffic-law enforcement and risk of death from motor-vehicle crashes: case-crossover study." Lancet **361**(9376): 2177-82.

Roudsari, B., R. Kaufman, et al. (2006). "Turning at intersections and pedestrian injuries." Traffic Inj Prev **7**(3): 283-9.

Roudsari, B. S., C. N. Mock, et al. (2005). "An Evaluation of the Association Between Vehicle Type and the Source and Severity of Pedestrian Injuries." Traffic Injury Prevention **6**(2): pp 185-192.

Sciortino, S., M. Vassar, et al. (2005). "San Francisco pedestrian injury surveillance: mapping, under-reporting, and injury severity in police and hospital records." Accid Anal Prev **37**(6): 1102-13.

Shankar, V. N., S. Sittikariya, et al. (2006). "Some Insights on Roadway Infrastructure Design for Safe Elderly Pedestrian Travel." IATSS Research **30**(1): pp 21-26.

Starnes, M. and A. Longthorne (2003). Child Pedestrian Fatality Rates by Striking Vehicle Body Type: A Comparison of Passenger Cars, Sport Utility Vehicles, Pickups, and Vans, National Center for Statistics and Analysis.

Tay, R. (2005). "The effectiveness of enforcement and publicity campaigns on serious crashes involving young male drivers: Are drink driving and speeding similar?" Accid Anal Prev **37**(5): 922-9.

Transportation Research Board (2006). Safety Data Analysis and Evaluation: Research Problem Statements Transportation Research Circular E-C094. R. TRB Safety Data, and Analysis Committee. Washington, DC, Transportation Research Board.

Turner, S. M., E. S. Park, et al. (2006). Motorist Yielding to Pedestrians at Unsignalized Intersection: Findings from National Study on Improving Pedestrian Safety. Transportation Research Board 85th Annual Meeting, Transportation Research Board**:** 19p.

Wazana, A., V. L. Rynard, et al. (2000). "Are child pedestrians at increased risk of injury on one-way compared to two-way streets?" Can J Public Health **91**(3): 201-6.

Wootton, I. A., L. K. Spainhour, et al. (2006). Causative Factors and Trends in Florida Pedestrian Crashes. Transportation Research Board 85th Annual Meeting, Transportation Research Board**:** 21p.

WSDOT and TDO (N.D.). Transportation Data Office of the Washington State Department of Transportation,.

Zajac, S. S. and J. N. Ivan (2003). "Factors influencing injury severity of motor vehicle-crossing pedestrian crashes in rural Connecticut." Accid Anal Prev **35**(3): 369-79.

Zegeer, C. V., J. R. Steward, et al. (2002). Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines. McLean, VA, Office of Safety Research and Development, Federal Highway Administration**:** 33.

APPENDIX: FUNCTIONAL CLASSIFICATION OF HIGHWAYS

RCW 47.05.021: Functional classification of highways.

All designated state highways are sub-classified into the following three functional classes:

(a) The "principal arterial system" shall consist of a connected network of rural arterial routes with appropriate extensions into and through urban areas, including all routes designated as part of the interstate system, which serve corridor movements having travel characteristics indicative of substantial statewide and interstate travel;

(b) The "minor arterial system" shall, in conjunction with the principal arterial system, form a rural network of arterial routes linking cities and other activity centers which generate long distance travel, and, with appropriate extensions into and through urban areas, form an integrated network providing interstate and interregional service; and,

(c) The "collector system" shall consist of routes which primarily serve the more important intercounty, intracounty, and intraurban travel corridors, collect traffic from the system of local access roads and convey it to the arterial system, and on which, regardless of traffic volume, the predominant travel distances are shorter than on arterial routes.

More information could be found at http://www.wsdot.wa.gov/mapsdata/tdo/PDF_and_ZIP_Files/RCW_47_05_021.pdf