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Identifying Factors Explaining Pedestrian Crash Severity: A Study of Austin, Texas

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Identifying Factors Explaining Pedestrian Crash Severity: A Study of Austin, Texas

by

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Abstract

Identifying Factors Explaining Pedestrian Crash Severity: A Study of Austin, Texas

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From the Federal Highway Administration to local departments of transportation, traffic safety is a persistent concern for transportation planners and engineers. Pedestrians are among the most vulnerable road users and require consideration beyond typical analysis of vehicle safety. This study has two objectives: to identify environmental, demographic, and behavioral factors explaining crash severity, and to compare methods for determining the significance of these factors. Binary and ordered logistic regression models were developed and compared to assess factor significance. Environmental and local factors, such as lighting and speed limit, had the strongest correlation with crash severity in all cases. However, inclusion of driver and pedestrian behavior and demographic characteristics improved the fit of the model and, in some cases, predictive ability. The two model types identified the same significant variables in traffic safety, but the magnitudes of the effects differed by model. This finding demonstrates that while the simpler method may yield the same overall results, combining methods can differentiate factors which contribute to the most severe crashes.

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Chapter 1: Introduction

Since 2004, the Federal Highway Administration Office of Safety has identified numerous cities and states as Pedestrian Focus Cities or States. There are currently 35 focus cities, including Austin, Texas, which are encouraged to analyze trends in pedestrian crashes, injuries, and fatalities to develop Pedestrian Safety Action Plans (PSAPs) toward reducing traffic injuries and deaths (*1*). These plans evaluate a wide range of variables, culminating in recommendations for engineering, education, enforcement, and policy solutions toward reducing or eliminating pedestrian injuries and fatalities.

Some cities have already completed a pedestrian safety study and action plan, including New York City and Chicago (*2,3*). Many others have used FHWA guidance to produce an action plan toward increased pedestrian safety, but they have not published comprehensive studies of pedestrian safety trends (*4,5,6*). Each study includes examination of those most affected by traffic injuries and fatalities and many include behavioral contributors, such as impairment, speeding, or failure to yield. However, the only attribute of the built environment studied consistently is location at an intersection. Presence of sidewalks, bicycle lanes, land use, or lighting are not often studied. This trend suggests that cities could augment their analysis by conducting a holistic analysis of the surrounding environment, demographic influences, and human behavior.

The motivation of this research is to conduct such an analysis and to identify explanatory variables for injury severity in pedestrian crashes in Austin, Texas. The expected outcome of this research is the basis for a Pedestrian Safety Action Plan for the City of Austin and recommendations for approaching modeling of pedestrian safety data. In addition, many practicing planners look to peer cities, leading cities, and their own experiences for direction when creating plans. This work will provide a connection between the literature on safety as it pertains to design and pedestrian vulnerability and the work of practicing planners and engineers as well as a methodology to enhance datasets without extensive data enhancement.

Chapter 2: Literature Review

Existing research has found that a wide range of factors may contribute to the incidence and severity of traffic injuries, including behavioral, roadway, and environmental factors. Impact speed is logically the most important predictor of the outcome of a crash involving a pedestrian. Likelihood of fatality at various impact speeds has been studied repeatedly. Stoker et al summarized four studies which reported exponential increase in likelihood of fatality between 20 and 40 mph (*7*). Rosen and Sander challenge commonly reported probabilities, citing underreporting of non-severe injuries as one mechanism by which sampling bias is introduced (*8*). While the likelihood of pedestrian fatality at any given impact speed is not certain, all research concludes that the trend is nonlinear, and that significant improvements in safety can be made in small speed reductions.

Factors contributing to speed, including roadway design and the surrounding environment, have been studied to determine what designs or interventions may most effectively reduce pedestrian injuries and fatalities. Studies in rural contexts found that an increased number of lanes and increased lane widths were negatively correlated with traffic safety and specifically pedestrian safety (*9,10*). Dambaugh and Li found that within urban contexts, miles of arterial roadways in an area contributed to reduced pedestrian safety (*11*).

The same study identified environments typical of urban sprawl to reduce pedestrian safety, such as arterial roadways, big box retail stores, strip commercial land uses, and long block lengths. Conversely, pedestrian-scaled retail uses were found to be positively correlated with pedestrian safety (*11*). Typical urban and pedestrian friendly environments with higher population densities, greater mix of land use, and more transit access have been found to have a higher incidence of pedestrian crashes; however, the exposure rate may still be lower due to the increased pedestrian volume in these areas (*13*).

Characteristics of the pedestrian may also increase the risk of a severe or fatal injury when a pedestrian crash occurs. Age, race, and socioeconomic status have all been shown to be associated with the likelihood of a fatality in the event a pedestrian is involved in a crash (*7,10,12*).

While many studies have catalogued the numerous factors influencing pedestrian safety, cities continue to struggle with prioritizing safety interventions pertaining to engineering, education, enforcement, and policy. This research seeks to use empirical data from the City of Austin to determine the significance and relative importance of these many factors in service of developing a Pedestrian Safety Action Plan.

Chapter 3: Methods and Data

METHODOLOGY

Ordinal outcomes such as injury severity have been modeled used many techniques, including ordered logit models, ordered probit models, and multinomial logit models (*10,16,17,18,19*). Ordered logit models have been found to be more flexible in their assumptions and more capable of modeling traffic injury severities and health outcomes, which have a similar ordinal nature, than probit models by some studies and were used in this study (*17,18,19*). Crash data were analyzed with ordinal response variables for injury (no injury, minor injury, severe injury, or fatal injury) as well as with a binary response variable (no/minor injury or severe/fatal injury). The binary analysis was included in light of analyses conducted by the City of Austin and New York City which used the ratio of severe/fatal crashes to total crashes as an measure of when, where, and to whom the most severe crashes occurred (*2*). This is one method of normalizing crash data in lieu of robust pedestrian volume data. The addition of ordinal logistic models enables understanding of factors contributing to an increase in severity across all levels which may not be the same as the top contributors for severe and fatal injuries.

Models were developed by first creating a model of each explanatory variable individually, similar to the methodology employed by Zajac et al (*10*). This analysis illuminated which attributes of a crash were significantly correlated to injury severity and attempted to explain whether observed differences in environmental, roadway, behavioral, or personal attributes were significant. Variables were then added to a model constructed to predict crash severity based on explanatory variables. Insignificant variables were not removed to understand the relative significance of all variables. The aggregate predictions of each model were compared to the actual aggregate outcomes as a measure of accuracy.

DESCRIPTION OF INPUTS

Data from the Texas Department of Transportation (TxDOT) Crash Record Information System (CRIS) database were the basis of this study. Data from 2010-2015 included 1,562 crash records involving pedestrians that could be geocoded (*20*). The records for crashes, individuals involved, and vehicles involved were combined into a single file for regression analysis using a crash identifier. The data were then spatially joined with geographic data from the City of Austin to obtain data for environmental justice areas (as determined by the Capital Area Metropolitan Planning Organization) and bicycle infrastructure present at the time of the crash (*21*).

Contributing factors can be reported by an officer in the crash record. For the records with this information (n=911), six binary variables were coded that correspond to the dangerous behaviors identified in the Vision Zero Action Plan adopted by the Austin City Council in May 2016: Distraction, Failure to Stop, Failure to Yield, Impairment, Improper Maneuvers, and Speeding/Unsafe Speed (*22*). Table 1 describes the data available for each variable and summarizes the values present for each.

Table 1: Summary of Dataset

Variable	Values	Range	Size	Average
Environmental Factors				
Environmental Justice Area	No (0), Yes (1)	0-1	1562	0.677
Lighting	Light	0	894	
	Dark, Lit	1	483	N/A*
	Dark, unlit	2	167	
Site Specific Factors				
Bike Lanes	No (0), Yes (1)	0-1	865	0.165
At Intersection	No (0), Yes (1)	0-1	1562	0.446
Speed Limit	Continuous	5-80	1338	37.821
Contributing Behavior				
Distraction	No (0), Yes (1)	0-1	911	0.397
Failure to Stop	No (0), Yes (1)	0-1	911	0.041
Failure to Yield (by Driver)	No (0), Yes (1)	0-1	911	0.408
Failure to Yield (by Pedestrian)	No (0), Yes (1)	0-1	911	0.111
Impairment	No (0), Yes (1)	0-1	911	0.093
Improper Maneuver	No (0), Yes (1)	0-1	911	0.076
Speeding/Unsafe Speed	No (0), Yes (1)	0-1	911	0.061
Driver Factors				
Commercial Vehicle	No (0), Yes (1)	0-1	1562	0.02
Driver under 20	No (0), Yes (1)	0-1	1303	0.044
Driver 65 or over	No (0), Yes (1)	0-1	1303	0.072
Male Driver	No (0), Yes (1)	0-1	1361	0.584
Driver Race/Ethnicity	White	1	679	
	Latino/a	2	395	
	African American	3	191	N/A
	Asian American	4	48	
	Other	5	23	
Pedestrian Factors				
Pedestrian under 16	No (0), Yes (1)	0-1	1478	0.097
Pedestrian 65 or over	No (0), Yes (1)	0-1	1478	0.061
Male Pedestrian	No (0), Yes (1)	0-1	1557	0.605
Pedestrian Race/Ethnicity	White	1	786	
	Latino/a	2	420	
	African American	3	269	N/A
	Asian American	4	38	
	Other	5	16	

Chapter 4: Model Results

Individual Binary Model Results

A binary logistic model was used to predict which factors increase the likelihood of a severe or fatal injury in a pedestrian crash, commonly referred to as a KSI crash or a KSI injury. This measure is used due to the relative infrequency of fatal accidents as a method to better understand the factors contributing to the most severe outcomes. Each variable was modeled independently to test assumptions of association between a variable and the outcomes of crashes. Three combined models representing different hypotheses about the factors associated with crash severity were developed and compared to actual values.

Environmental and Site-Specific Factors

Factors related to the environment surrounding a pedestrian crash were studied to identify features that may contribute to increased risk of severe or fatal injury. Environmental justice areas were included due to the disproportionate injury sustained by people of color when compared to the total population. For example, African Americans comprised 7.5% of Austin's population in 2014 and were victims of 24.3% of pedestrian fatalities during the 2010-2015 study period (*20,23*). This variable and the subsequent testing of variation by race test assumptions of correlation between race, environmental justice communities, and crash severity. Darkness was expected to increase crash severity due to reduced visibility and consequential shortened reaction time. Bicycle lanes provide additional buffer space between a pedestrian in the sidewalk area and vehicle travel lanes. Installation of bicycle lanes may also result in a reduced crossing distance (across vehicle lanes) compared to a similar road without this feature. In areas without constructed sidewalks, this space may also provide a path for pedestrians who would otherwise move in the street, particularly those with limited mobility or in wheelchairs. For these reasons, bicycle lanes were hypothesized to reduce risk of severe or fatal pedestrian injury. Extensive documentation of the association between higher speeds and more severe crash outcomes exists (*4,7,8*). In lieu of actual speed data, roadway speed limit was used and was predicted to be positively correlated with crash severity.

Table 2: Individual Models of Environmental and Site-Specific Factors

Factor	Coefficient	z	p(z)	Chi2	p(Chi2)
EJ area	0.340	2.580	0.010	6.830	0.009
Constant	-1.396	-12.500	0.000		
Lighting				86.180	0.000
1-Dark, Lit	1.072	8.060	0.000		
2-Dark, Unlit	1.250	6.800	0.000		
Constant	-1.701	-18.370	0.000		
Bike Lanes	-0.640	-2.840	0.005	8.800	0.003
Constant	-0.773	-9.660	0.000		
At Intersection	-0.734	-5.840	0.000	35.670	0.000
Constant	-0.867	-11.630	0.000		
Speed Limit	0.066	9.530	0.000	98.410	0.000
Constant	-3.594	-12.780	0.000		

Each of these variables was significant at the 95% confidence, indicating a strong connection between surrounding conditions and pedestrian crash severity. Each of the hypotheses were confirmed, with the following change in risk of KSI injury for each variable. This model indicates that crashes occurring in an environmental justice area were 40% more likely to result in a severe or fatal injury. Crashes occurring at night can be 3-3.5 times more likely to result in a KSI injury, depending on whether the area is artificially lit or not. For midblock crashes, presence of bicycle facilities on the street was associated with a 47% reduction in likelihood of a severe or fatal crash. Crashes occurring at an intersection were associated with a 52% reduction in KSI crash outcomes. Finally, one mile-per-hour increase in speed limit was associated with a 6.8% increase in severe or fatal injury risk. Multiplied, this can be interpreted as nearly doubling risk for a 10 mph increase in speed limit (93% increase). This finding is consistent with trends observed in literature and provides an additional data point among the many predicting the relationship between speed and crash severity.

Contributing Behavior

Behavioral factors documented in the CRIS dataset were selected to align with those studied in the recently adopted Vision Zero Action Plan in Austin, Texas: speeding or unsafe speed, improper maneuver, distraction, impairment, failure to stop, and failure to yield by either driver or pedestrian. Peace officers code these factors based on the officer's assessment of the crash conditions, and these factors may not be uniformly documented. Each of the contributing factors identified is an illegal or dangerous behavior, and each was hypothesized to be associated with an increase in crash severity.

Table 3: Individual Models of Behavioral Factors

Factor	Coefficient	z	p(z)	Chi2	p(Chi2)
Speeding/Unsafe Speed	1.108	3.880	0.000	13.820	0.000
Constant	-1.469	-16.750	0.000		
Improper Maneuver	0.370	1.290	0.198	1.580	0.210
Constant	-1.412	-16.260	0.000		
Distraction	-0.404	-2.310	0.021	5.480	0.019
Constant	-1.232	-12.070	0.000		
Impairment	1.334	5.640	0.000	29.600	0.000
Constant	-1.547	-16.910	0.000		
Failure to Stop	0.097	0.240	0.812	0.060	0.814
Constant	-1.385	-16.380	0.000		
Driver Failure to Yield	-0.813	-4.420	0.000	21.100	0.000
Constant	-1.096	-11.030	0.000		
Pedestrian Failure to Yield	0.366	1.500	0.134	2.140	0.143
Constant	-1.425	-16.040	0.000		

Four factors were significant at the 95% confidence level: speeding or unsafe speed, distraction, impairment, and driver failure to yield. Speeding or travelling an unsafe speed for conditions increases the force imparted to a pedestrian and unsurprisingly associates strongly with severe or fatal injuries (3 times as likely). This analysis indicates that distraction is associated with 33% lower risk of severe or fatal injury. More investigation into this topic is needed to understand this finding. Distracted driving may occur a lower speeds, reducing crash injury. A bias may also be introduced as distracted driving is difficult to detect by law enforcement. Distraction as a documented crash factor may to an extent rely on self-reporting and could be underreported in the event of severe outcomes. This limitation could also apply to unsafe speeds.

Impairment by drivers or pedestrians reduces reaction time and alters judgement, likely leading to the observed association with higher crash severity. Independent modeling of this factor indicated that crashes caused in part by impairment were 3.8 times as likely to result in a KSI injury. Finally, failure to yield can apply to either pedestrians or drivers, but this analysis indicates that only driver failure to yield was associated with a significant change in crash severity. Crashes where the driver failed to yield were found to be 55% less likely to result in a KSI crash. This could be related to the finding of reduced severity at intersections, as intersections are the primary location where drivers are expected to yield the right-of-way to pedestrians.

Sociodemographic Factors

Education campaigns and policies proposed often target specific audiences, such as Safe Routes to Schools programs for children, policies increasing driver license renewal frequency, or graduated driver license programs for new drivers (*4,24*).

Characteristics of drivers and pedestrians involved in crashes were studied to determine whether differences across groups were statistically significant. Driver age was predicted to be associated with a change in crash severity due to experience and ability differences across drivers, and no other factors related to drivers were predicted to be significant. Similarly, pedestrian age was hypothesized to be associated with a change in crash severity due to differences in ability and fragility throughout the lifespan. Race or ethnicity was predicted to be statistically different across groups due to observed trends in the data, with people of color hypothesized to be associated with higher crash severities.

Driver gender was the only driver factor significant at the 95% confidence level, with male drivers 56% more likely than female drivers to be involved in a KSI crash. The hypothesis that driver age would be associated with crash severity was disproven; neither young nor aging drivers were associated with a change in crash severity.

Pedestrian age and gender were found to be significant at the 95% confidence level. Younger pedestrians were associated with a lower risk of severe or fatal injury, while older pedestrians are positively correlated with injury severity (-51% and +91% likelihood, respectively). This could be due to the lower speed roads traveled by young pedestrians such as neighborhood streets. However, many multifamily residences are located on busy streets, and a disparity may exist between high and low income children. Additional research is necessary to determine the nature of this relationship. Male pedestrians were 61% more likely to be involved in a KSI crash, similar to the increased odds for male drivers (56%). This may have to do with differences in risk aversion, but these potential differences are beyond the scope of this work.

Table 4: Individual Models of Driver and Pedestrian Factors

	Coefficient	z	p(z)	Chi2	p(Chi2)
Commercial Vehicle Driver	0.525	1.390	0.164	1.820	0.177
Constant	-1.171	-19.470	0.000		
Driver under 20	-0.044	-0.140	0.891	0.020	0.891
Constant	-1.175	-17.610	0.000		
Driver 65 or over	-0.435	-1.540	0.123	2.570	0.109
Constant	-1.149	-17.080	0.000		
Male Driver	0.443	3.300	0.001	11.150	0.001
Constant	-1.468	-13.620	0.000		
Driver Race/Ethnicity				5.780	0.216
2-Latino/a	0.143	0.960	0.336		
3-African American	0.075	0.390	0.699		
4-Asian American	-0.694	-1.560	0.120		
5-Other	-0.645	-1.030	0.303		
Constant	-1.252	-13.560	0.000		
Pedestrian under 16	-0.727	-2.920	0.004	9.830	0.002
Constant	-1.090	-17.280	0.000		
Pedestrian 65 or over	0.647	2.840	0.005	7.590	0.006
Constant	-1.193	-18.780	0.000		
Male Pedestrian	0.479	3.790	0.000	14.800	0.000
Constant	-1.459	-14.150	0.000		
Pedestrian Race/Ethnicity				8.310	0.081
2-Latino/a	-0.114	-0.790	0.432		
3-African American	0.165	1.020	0.307		
4-Asian American	-0.716	-1.470	0.142		
5-Other	-1.537	-1.480	0.138		
Constant	-1.171	-13.960	0.000		

COMBINED BINARY MODELS

Three models were developed combining the variables discussed so far. These test three hypotheses about the nature of pedestrian crash severity.

Environmental and Site-Specific Factors

A first model consisted only of environmental and site-specific factors. Two versions of Model 1 test the hypothesis that environment and design are the primary determinants of crash severity. Due to limitations in the data, bicycle lane attributes were populated for midblock locations. Therefore, for each record with a bicycle lane attribute, the intersection variable is “0.” Two variations test both variables separately.

In this model, environmental justice areas and bicycle facilities were not significant predictors of severe or fatal crashes at the 95% confidence level, leaving lighting, location at an intersection, and speed limit as significant environmental variables predicting crash severity. Due to the similar goodness of fit, increased number of records, and significance of all variables, Model 1a was selected as the basis for all further analysis of the binary regression. Crashes occurring after dark, whether in a lit area or not, were associated with approximately twice the chance of resulting in a severe or fatal injury. Higher speed limits were also correlated with higher odds of severe or fatal injury, with each mile per hour increase associated with 5.5% increase in risk of KSI injury. See Table 5 for all results.

Addition of Human Factors

Two models were developed to test the hypothesis that human factors significantly explain pedestrian crash severity when controlling for environmental factors. Education campaigns and policies proposed often target specific audiences, such as Safe Routes to Schools programs for children, policies increasing driver license renewal frequency, or graduated driver license programs for new drivers (*4,24*). Characteristics of drivers and pedestrians involved in crashes were studied to determine whether differences across groups were statistically significant when considering environmental and behavioral factors. Finally, driver and pedestrian behavior were added to a composite model.

Table 5: Results of Models 1a and 1b: Environment and Local Design

	1a - With Intersections			1b - With Bicycle Lanes		
	Coefficient	z	p(z)	Coefficient	z	p(z)
EJ area	0.166	1.130	0.257	0.051	0.270	0.787
Lighting						
1-Dark, Lit	0.832	5.770	0.000	1.076	5.750	0.000
2-Dark, Unlit	0.773	3.680	0.000	0.907	3.700	0.000
Speed Limit	0.054	7.480	0.000	0.051	6.090	0.000
At Intersection	-0.473	-3.370	0.001	-*	-	-
Bicycle Lanes	-*	-	-	-0.237	-0.980	0.328
Constant	-3.449			-3.320		
McFadden's R2	0.100			0.114		
Chi2	153.030			107.490		
p(Chi2)	0.000			0.000		
n	1323			755		

**- = omitted due to model specifications*

Model 2 tests the association between demographic factors and crash severity using variables for both drivers and pedestrians in addition to factors included in Model 1a. Driver age was predicted to be associated with a change in crash severity due to experience and ability differences across drivers, and no other factors were predicted to be significant. Similarly, pedestrian age was hypothesized to be associated with a change in crash severity due to differences in ability and fragility throughout the lifespan. Race and ethnicity was predicted to be statistically different across groups, with people of color hypothesized to be associated with higher crash severities due to differences observed in aggregate data.

As shown in Table 6, environmental and site-specific factors remained significant at the 95% confidence level when demographic data were added to the explanatory model. Dark, lit and dark, unlit conditions were correlated with a 150% and 140% increase in severe or fatal crash outcomes, respectively. Crashes at an intersection were modeled to be 44% less likely to result in a KSI injury. Only one demographic factor was associated with increased crash severity: pedestrians 65 years of age or older. Older pedestrians demonstrated a 179% increase in association with severe or fatal crashes compared to those under the age of 65.

Behavioral factors documented in the CRIS dataset were selected to align with those studied in the recently adopted Vision Zero Action Plan in Austin, Texas: speeding or unsafe speed, improper maneuver, distraction, impairment, failure to stop, and failure to yield by either driver or pedestrian. Peace officers code these factors based on the officer's assessment of the crash conditions, and these factors may not be uniformly applied. Each of the contributing factors identified is an illegal or dangerous behavior, and each was hypothesized to be associated with an increase in crash severity.

Model 3 iterates upon Model 1a through the addition of these pedestrian and driver behaviors. Without removing any previously considered factors, the third model has few significant variables. The sample size is also significantly reduced from previous models (n=1,031 in Model 2, n=591 in Model 1) which may introduce a sampling bias based on documentation preferences and practices. Crashes occurring in higher speed limits and those occurring in dark, artificially lit places were still associated with higher crash severities. Older pedestrians were correlated with severe or fatal crashes at nearly the same rate as in Model 2 (154% more than younger than 65). Two behavioral factors emerged: speeding or unsafe speed was associated with a 260% increase in severe or fatal crash outcomes, and impairment was associated with a 113% increase. Location at an intersection was not a statistically significant factor at the 95% confidence interval. See Table 6 for all results.

Table 6: Results of Models 2 and 3: Environmental and Human Factors

	Model 2			Model 3		
	Coefficient	z	p(z)	Coefficient	z	p(z)
EJ area	0.103	0.580	0.563	0.086	0.340	0.735
Lighting						
1-Dark, Lit	0.919	5.310	0.000	0.688	2.770	0.006
2-Dark, Unlit	0.880	3.460	0.001	0.631	1.560	0.118
At Intersection	-0.575	-3.440	0.001	-0.206	-0.770	0.439
Speed Limit	0.052	6.070	0.000	0.045	3.460	0.001
Commercial Vehicle Driver	0.889	1.780	0.075	1.377	2.030	0.042
Driver under 20	-0.108	-0.290	0.773	-0.700	-1.000	0.316
Driver 65 or over	-0.300	-0.890	0.371	-0.065	-0.140	0.887
Male Driver	0.137	0.750	0.401	0.167	0.700	0.482
Driver Race/Ethnicity						
2-Latino/a	0.019	0.100	0.918	-0.038	-0.140	0.886
3-African American	-0.075	-0.310	0.759	-0.164	0.440	0.661
4-Asian American	-0.983	-1.910	0.056	-0.937	-1.410	0.158
5-Other	-1.183	-1.520	0.129	-1.008	-0.890	0.373
Pedestrian under 16	-0.195	-0.610	0.524	-0.565	-0.870	0.384
Pedestrian 65 or over	1.026	3.600	0.000	0.933	2.370	0.018
Male Pedestrian	0.194	1.170	0.263	0.087	0.370	0.713
Pedestrian Race/Ethnicity						
2-Latino/a	-0.165	-0.850	0.393	-0.386	-1.340	0.180
3-African American	-0.117	-0.540	0.588	-0.275	-0.860	0.388
4-Asian American	-0.805	-1.380	0.165	-1.628	1.500	0.134
5-Other	-1.172	-1.070	0.286	N/A**		
Speeding/Unsafe Speed	-*	-	-	1.284	2.950	0.003
Improper Maneuver	-	-	-	0.203	0.500	0.618
Distraction	-	-	-	-0.235	-0.910	0.364
Impairment	-	-	-	0.756	2.280	0.022
Failure to Stop	-	-	-	0.293	0.540	0.590
Pedestrian Failure to Yield	-	-	-	0.372	1.040	0.300
Driver Failure to Yield	-	-	-	-0.362	-1.210	0.228
Constant	-3.467			-3.329		
McFadden's R2	0.130			0.154		
Chi2	152.330			93.550		
p(Chi2)	0.000			0.000		
n	1031			591		

** - = omitted due to model specification; ** N/A = Not applicable; no records included in model*

Binary Model Comparison

Models 1, 2, and 3 were compared to determine which best predicted the actual crash severity distribution (Table 7). Model 2 best predicted the proportion of crashes that would result in a severe or fatal injury in the aggregate. However, the pseudo-R2 value for Model 3 indicated the best fit occurred when environmental, demographic, and behavioral factors are all considered, suggesting that inclusion of some human factors improves the predictive ability of a model for pedestrian crash severity compared to a purely environmental model (Model 1). This model was developed based on a limited sample size compared to others, and included many insignificant variables. To arrive at a strong predictive model, the purpose of the model should be considered when determining which insignificant variables to remove.

Table 7: Comparison of Binary Model Predictions

	Actual	Model 1a	Model 1b	Model 2	Model 3
Ratio No/Minor Injury	0.761	0.735	0.679	0.746	0.790
Ratio Severe/Fatal Injury	0.239	0.265	0.321	0.254	0.210
McFadden's R2	-	0.100	0.114	0.130	0.154

INDIVIDUAL ORDINAL MODEL RESULTS

Ordinal or ordered logistic models predict associations with moving to a higher crash severity, such as increasing from "minor" to "severe" or from "severe" to "fatal." This type of model may provide more granular insight into factors contributing to crash severity. For example, the binary models developed in this research identified factors that increase likelihood of severe or fatal injury, but they do not consider whether factors increase likelihood of fatal compared to severe injury, or minor injury compared to none. Models were developed using the same two-phased approach: modeling each factor individually before combining into a predictive model.

Environmental Factors

Environmental factors were first assessed to determine associations between factors and higher crash severity. As in the individual binary models, all factors were significant at the 95% confidence level. Environmental justice areas were associated with a 23% increase in likelihood of moving to an increased severity category compared to 40% increased risk in the binary model. This finding indicates that these areas are particularly at higher risk for the most severe injuries in addition to escalated outcomes in general. Similarly, crashes occurring at night under lit or unlit situations are 2-2.4 times more likely to result in increased injury severity compared to 3-3.5 times in the binary model. Higher severity injuries were modeled to be 32% less likely when bicycle lanes are present (47% in the binary model). The influence of location at an intersection and of speed limit were similar in the binary and ordinal models. Intersections were associated with approximately 44% reduction in risk of higher severity and speed limits were associated with a 6% increase of more severe injuries per mile per hour. The differences between the binary and ordinal models suggest that for many environmental factors influence is not uniform between different injury levels, and these factors may play a stronger role in KSI injuries.

Contributing Behavior

As in the binary models of behavioral factors, speeding or unsafe speed, impairment, and driver failure to yield were found to be associated with a change in crash severity at the 95% confidence interval. However, distraction was significant at the 90% confidence level. This suggests that when looking at all injury levels, distraction is less likely to be associated with crash outcomes than the other three. Again, reporting bias could be present for any of the behavioral factors examined here due to the collection method.

Table 8: Individual Models of Environmental and Site-Specific Factors

Factors	Coefficient	z	p(z)	Chi2	p(Chi2)
EJ area	0.204	1.990	0.047	3.960	0.047
Cutoff Minor	-1.082	-1.259	-0.906		
Cutoff Severe	1.299	1.118	1.480		
Cutoff Fatal	2.846	2.597	3.094		
Lighting				57.070	0.000
1-Dark, Lit	0.713	6.480	0.000		
2-Dark, Unlit	0.876	5.150	0.000		
Cutoff Minor	-0.960	-1.095	-0.824		
Cutoff Severe	1.476	1.327	1.625		
Cutoff Fatal	3.059	2.829	3.290		
Bike Lanes	-0.389	-2.310	0.021	5.380	0.020
Cutoff Minor	-1.483	-1.664	-1.302		
Cutoff Severe	0.801	0.645	0.957		
Cutoff Fatal	2.211	1.977	2.444		
At Intersection	-0.589	-6.010	0.000	36.650	0.000
Cutoff Minor	-1.509	-1.664	-1.354		
Cutoff Severe	0.909	0.769	1.049		
Cutoff Fatal	2.472	2.256	2.689		
Speed Limit	0.064	10.630	0.000	113.720	0.000
Cutoff Minor	0.905	0.463	1.347		
Cutoff Severe	3.477	3.002	3.953		
Cutoff Fatal	5.123	4.587	5.660		

Speeding or unsafe speed was correlated with over double the risk of increased injury severity, compared to triple risk for KSI injury in the binary model. Impairment of the driver or the pedestrian resulted in 175% increase in likelihood of higher crash severity, compared to 280% increase of KSI injury. Finally, driver failure to yield was associated with a 32% reduction in likelihood of increased crash severity compared to 56% in the binary model. The larger odds magnitudes in the binary model compared to the ordinal model suggest that, as in environmental factors, these behaviors may not have a linear relationship with crash severity.

Table 9: Individual Models of Behavioral Factors

Factor	Coefficient	z	p(z)	Chi2	p(Chi2)
Speeding/Unsafe Speed	0.806	2.890	0.004	8.250	0.004
Cutoff Minor	-1.050	-1.201	-0.899		
Cutoff Severe	1.433	1.266	1.601		
Cutoff Fatal	3.202	2.872	3.531		
Improper Maneuver	0.356	1.470	0.141	2.170	0.141
Cutoff Minor	-1.061	-1.214	-0.908		
Cutoff Severe	1.410	1.243	1.577		
Cutoff Fatal	3.165	2.837	3.493		
Distraction	-0.214	-1.650	0.098	2.740	0.098
Cutoff Minor	-1.175	-1.360	-0.991		
Cutoff Severe	1.297	1.107	1.486		
Cutoff Fatal	3.053	2.716	3.391		
Impairment	1.012	4.420	0.000	19.250	0.000
Cutoff Minor	-1.021	-1.173	-0.869		
Cutoff Severe	1.486	1.314	1.659		
Cutoff Fatal	3.274	2.940	3.609		
Failure to Stop	0.363	1.170	0.241	1.370	0.242
Cutoff Minor	-1.071	-1.222	-0.920		
Cutoff Severe	1.399	1.233	1.564		
Cutoff Fatal	3.152	2.826	3.479		
Driver Failure to Yield	-0.381	-2.950	0.003	8.760	0.003
Cutoff Minor	-1.258	-1.448	-1.067		
Cutoff Severe	1.226	1.035	1.416		
Cutoff Fatal	2.991	2.653	3.328		
Pedestrian Failure to Yield	0.229	1.090	0.276	1.190	0.276
Cutoff Minor	-1.063	-1.217	-0.908		
Cutoff Severe	1.405	1.237	1.573		
Cutoff Fatal	3.160	2.832	3.489		

Sociodemographic Factors

Characteristics of drivers and pedestrians were not predicted to be different when considering all severity levels rather than only severe or fatal injuries. Consistent with this hypothesis, the only significant driver characteristic was gender with male drivers associated with higher severity crashes.

Table 10: Individual Models of Driver Factors

Factor	Coefficient	z	p(z)	Chi2	p(Chi2)
Commercial Vehicle Driver	0.541	1.590	0.111	2.510	0.113
Cutoff Minor	-1.207	-1.326	-1.088		
Cutoff Severe	1.171	1.054	1.289		
Cutoff Fatal	2.718	2.512	2.923		
Driver under 20	0.144	0.570	0.569	0.320	0.569
Cutoff Minor	-1.188	-1.318	-1.057		
Cutoff Severe	1.184	1.054	1.314		
Cutoff Fatal	2.669	2.448	2.890		
Driver 65 or over	-0.156	-0.780	0.433	0.610	0.433
Cutoff Minor	-1.206	-1.339	-1.074		
Cutoff Severe	1.166	1.035	1.297		
Cutoff Fatal	2.652	2.430	2.873		
Male Driver	0.251	2.400	0.016	5.770	0.016
Cutoff Minor	-1.077	-1.246	-0.908		
Cutoff Severe	1.342	1.167	1.517		
Cutoff Fatal	2.873	2.618	3.127		
Driver Race/Ethnicity				3.120	0.539
2-Latino/a	-0.006	-0.050	0.962		
3-African American	-0.075	-0.470	0.636		
4-Asian American	-0.349	-1.250	0.211		
5-Other	-0.495	-1.230	0.217		
Cutoff Minor	-1.237	-1.400	-1.075		
Cutoff Severe	1.195	1.034	1.356		
Cutoff Fatal	2.764	2.514	3.015		

Only two of four pedestrian characteristics were found to be associated with higher injury severities: aging pedestrians and male pedestrians. Pedestrians under 16 years of age were not significantly associated with lower severity injuries, in contrast to the binary model. No correlation between race and ethnicity and crash severity was found in the ordinal model. This finding paired with the significance of location in an environmental justice area suggests that roadway and environmental factors in communities of color contribute more to the observed disparity than inherent difference of a demographic block, as observed in the NYC PSAP (*2*).

Table 11: Individual Models of Pedestrian Factors

	Coefficient	z	p(z)	Chi2	p(Chi2)
Pedestrian under 16	-0.162	-1.010	0.312	1.020	0.312
Cutoff Minor	-1.253	-1.380	-1.126		
Cutoff Severe	1.131	1.008	1.255		
Cutoff Fatal	2.630	2.423	2.837		
Pedestrian 65 or over	0.463	2.150	0.031	4.610	0.032
Cutoff Minor	-1.212	-1.336	-1.088		
Cutoff Severe	1.176	1.053	1.298		
Cutoff Fatal	2.677	2.470	2.885		
Male Pedestrian	0.320	3.250	0.001	10.610	0.001
Cutoff Minor	-1.044	-1.205	-0.883		
Cutoff Severe	1.349	1.182	1.516		
Cutoff Fatal	2.901	2.662	3.141		
Pedestrian Race/Ethnicity				4.650	0.325
2-Latino/a	-0.077	-0.670	0.502		
3-African American	0.185	1.370	0.171		
4-Asian American	-0.150	-0.490	0.621		
5-Other	-0.496	-1.090	0.278		
Cutoff Minor	-1.220	-1.372	-1.068		
Cutoff Severe	1.199	1.048	1.351		
Cutoff Fatal	2.790	2.556	3.024		

COMBINED ORDINAL MODELS

The approach taken for binary models was repeated for ordinal to provide a comparison between the efficacies of the two types.

Environmental and Site-Specific Factors

The first ordinal model tested the hypothesis that environment and design are the primary determinants of crash severity and included factors found to be associated with a change in crash severity in initial screening. As in the binary analysis, two models were developed to account for the relationship between bicycle lanes and intersections in the dataset. The same significant variables were identified as in the binary model, indicating a significant effect for both the most severe injuries and across the spectrum of severity. Again, Model 1a was the basis of the subsequent analysis of factors.

Crashes occurring after dark, in both lit and unlit scenarios, were approximately 75% more likely to results in a higher crash severity. One mile per hour increase in speed limit is associated with a 5.7% increase in odds for a higher severity crash (compared to 5.5% in the binary model). Location at an intersection was correlated with a 34% reduction in likelihood of increased crash severity.

Table 12: Results of Models 1a and 1b: Environment and Local Design

	1a - With Intersections			1b - With Bicycle Lanes		
	Coefficient	z	p(z)	Coefficient	z	p(z)
EJ area	0.099	0.870	0.386	-0.089	-0.580	0.559
Lighting						
1-Dark, Lit	0.565	4.720	0.000	0.757	4.730	0.000
2-Dark, Unlit	0.569	3.020	0.002	0.663	3.030	0.002
Speed Limit	0.056	9.050	0.000	0.054	7.640	0.000
At Intersection	-0.426	-3.890	0.000	-*	-	-
Bicycle Lanes	-*	-	-	-0.038	-0.210	0.836
Cutoff Minor	0.659			0.628		
Cutoff Severe	3.292			3.162		
Cutoff Fatal	4.989			4.749		
McFadden's R2	0.052			0.060		
Chi2	159.230			109.100		
p(Chi2)	0.000			0.000		
n	1323			755.0		

*- = *omitted due to model specifications*

Addition of Human Factors

Characteristics and behavior of drivers and pedestrians were not predicted to be different when considering all severity levels rather than only severe or fatal injuries. Consistent with this hypothesis, aging pedestrian was the only demographic factor associated with a change in risk for higher injury in Model 2. Pedestrians 65 or over were found to have 120% higher likelihood of increased crash severity, compared to 179% higher likelihood of severe or fatal injury observed in the binary model. This finding may indicate heightened vulnerability to the most severe injuries in particular.

In addition to the three behavioral factors identified in the binary model development, a fourth, distraction, was found to be significant at the 90% confidence level. Distraction by drivers or pedestrians can result in delayed reaction time or inability to perceive others on the roadway, but it can be difficult to detect by law enforcement and may to an extent rely on self-reporting. This could be one reason why distraction was not significantly associated with severe or fatal injuries but was when all injury levels are considered.

Consistent with the binary model, speeding or unsafe speed and impairment were the two significant factors once behavioral factors were added to create Model 3. Again, sample size was reduced substantially by the introduction of these factors and few variables were significant. Speeding or unsafe speed was associated with 175% higher odds of increased crash severity, compared to a 260% increase observed in the binary model. Impairment correlated to an 86% increase in odds of higher crash severity, compared to 113% in the binary model. These findings suggest that the increased risk of higher crash severity due to these behaviors is more pronounced for the most severe injuries.

Table 13: Results of Models 2 and 3: Environmental and Human Factors

	Model 2			Model 3		
	Coefficient	z	p(z)	Coefficient	z	p(z)
EJ area	0.139	1.030	0.303	0.068	0.380	0.704
Lighting						
1-Dark, Lit	0.672	4.770	0.000	0.359	1.850	0.064
2-Dark, Unlit	0.560	2.470	0.014	0.111	0.340	0.733
At Intersection	-0.497	-3.900	0.000	-0.314	1.670	0.094
Speed Limit	0.054	7.670	0.000	0.046	4.480	0.000
Commercial Vehicle Driver	0.790	1.780	0.075	1.366	2.500	0.019
Driver under 20	0.131	0.470	0.641	-0.027	-0.070	0.945
Driver 65 or over	-0.097	-0.410	0.682	-0.241	-0.760	0.447
Male Driver	0.114	0.920	0.359	-0.003	-0.020	0.985
Driver Race/Ethnicity						
2-Latino/a	-0.096	-0.660	0.509	-0.145	-0.730	0.463
3-African American	-0.230	-1.180	0.238	-0.397	-1.460	0.144
4-Asian American	-0.576	-1.810	0.071	-0.404	-1.060	0.288
5-Other	-0.576	-1.350	0.176	-0.478	-0.780	0.438
Pedestrian under 16	0.186	0.890	0.376	0.074	0.220	0.824
Pedestrian 65 or over	0.635	2.530	0.011	0.292	0.880	0.379
Male Pedestrian	0.085	0.670	0.502	-0.014	-0.080	0.935
Pedestrian Race/Ethnicity						
2-Latino/a	-0.185	-1.230	0.217	-0.280	-1.360	0.174
3-African American	-0.056	-0.330	0.742	-0.106	-0.450	0.656
4-Asian American	-0.235	-0.680	0.495	-0.203	-0.470	0.636
5-Other	-0.415	-0.750	0.452	-0.688	-1.060	0.287
Speeding/Unsafe Speed	-	-	-	1.011	2.640	0.008
Improper Maneuver	-	-	-	-0.130	-0.390	0.693
Distraction	-	-	-	0.018	0.100	0.922
Impairment	-	-	-	0.622	2.110	0.035
Failure to Stop	-	-	-	0.552	1.390	0.166
Pedestrian Failure to Yield	-	-	-	0.393	1.350	0.178
Driver Failure to Yield	-	-	-	-0.036	-0.180	0.858
Cutoff Minor	0.674			0.246		
Cutoff Severe	3.337			3.106		
Cutoff Fatal	5.015			4.862		
McFadden's R2	0.062			0.056		
Chi2	146.670			73.590		
p(Chi2)	0.000			0.000		
N	1031			600		

Comparing Ordinal Models

Ordinal Models 1, 2, and 3 were compared to determine which best predicts crash severity. Model 2 most closely predicts minor injuries and fatalities, and is near to Model 3's performance in predicting severe injuries. The pseudo-R2 value for Model 2 is the highest of the ordinal models, though it is notably lower than the binary models. Based on this analysis, models with consideration of human characteristics and behavior will perform better than those with environmental variables only. However, as with the binary analysis, these models should be refined to include only variables of interest to the application to increase the predictive power and better understand the relationship between variables.

Table 14: Comparing Ordinal Models

	Actual	Model 1a	Model 1b	Model 2	Model 3
Ratio No Injury	0.2286	0.192	0.169	0.202	0.217
Ratio Minor Injury	0.5327	0.532	0.497	0.532	0.571
Ratio Severe Injury	0.1761	0.201	0.227	0.192	0.162
Ratio Fatality	0.0627	0.074	0.107	0.073	0.050
McFadden's R2	-	0.052	0.060	0.062	0.056

Chapter 5: Conclusions

Binary and ordinal models developed here tested the hypothesis that the addition of human factors to models of pedestrian safety would improve performance. In both cases, the purely environmental model had the lowest predictive value. In both binary and ordinal cases, the addition of driver and pedestrian characteristics revealed that aging pedestrians are the only demographic group associated with increased odds of higher injury severity when controlling for other factors.

Behavioral factors were associated with a larger increase in odds of high severity injury in the binary model than in the ordinal model. This may explain why addition of behavior increased the goodness of fit for the binary model but not for the ordinal model. Speeding or unsafe speed and impairment may be factors in higher severity injuries, or reporting may change across the range of injuries. More research on the reporting and attribution of these factors is needed to determine the cause of the difference.

This research suggests that while education and enforcement regarding behavioral contributors to pedestrian crash severity are important components of severity reduction, a focus on improving the built environment is more likely to be associated with positive results. Similarly, citywide studies of the types of people involved may or may not reveal significant differences across demographic groups, but for most groups no inherent susceptibility exists.

Another finding of this research is the similarity between the binary and ordinal models. The same variables were significant for both the most severe injuries and for differences between tiers of injuries, but the magnitude of their effects differs between model types. Depending on the objective of modeling crash severity, cities may seek to simplify analysis by looking at factors contributing to the most severe injuries. However, a combination of both binary and ordinal models can reveal the difference in effect magnitude and identify factors which contribute most strongly to severe and fatal injuries.

This study focused on crash severity in the interest of understanding and eliminating the most severe injuries. Additional research on crash incidence and its nexus with severity are necessary to form comprehensive recommendations for Austin and other cities. For example, the FHWA has reported pedestrian crashes as the leading cause of death and injury for children, reporting that crashes frequently occur on neighborhood streets near their homes (*4*). However, this research did not suggest increased risk of high severity for children in the event of a crash. This gap supports the argument for combined frequency and severity modeling.

Crash severity modeling provides one tool for understanding how cities can approach reducing and eliminating traffic crashes. Models such as the ones developed here can provide insight into the environmental and individual factors contributing to traffic injuries and fatalities with minor enhancements to existing data sources such as local police reports. Each crash is unique, and creating a perfect model to predict human behavior may not be attainable. However, it is also not necessary. Patterns in transportation infrastructure, the built environment, and affected populations exist and provide a path forward toward improving the safety of cities and of people.

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