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Factors influencing injury severity of motor vehicle–crossing pedestrian crashes in rural Connecticut

Sylvia S. Zajac [a,1], John N. Ivan [b,*]

[a] *Fitzgerald & Halliday, Inc., 157 Oxford Street, Hartford, CT 06105, USA*

[b] *Civil and Environmental Engineering, Connecticut Transportation Institute, University of Connecticut, U-37 Storrs, CT 06269-2037, USA*

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Abstract

The ordered probit model was used to evaluate the effect of roadway and area type features on injury severity of pedestrian crashes in rural Connecticut. Injury severity was coded on the KABCO scale and crashes were limited to those in which the pedestrians were attempting to cross two-lane highways that were controlled by neither stop signs nor traffic signals. Variables that significantly influenced pedestrian injury severity were clear roadway width (the distance across the road including lane widths and shoulders, but excluding the area occupied by on-street parking), vehicle type, driver alcohol involvement, pedestrian age 65 years or older, and pedestrian alcohol involvement. Seven area types were identified: downtown, compact residential, village, downtown fringe, medium-density commercial, low-density commercial, and low-density residential. Two groups of these area types were found to experience significantly different injury severities. Downtown, compact residential, and medium- and low-density commercial areas generally experienced lower pedestrian injury severity than village, downtown fringe, and low-density residential areas.

Keywords: Pedestrian; Injury severity; Rural; Safety; Roadway features; Area type

1. Introduction

Motor vehicle–pedestrian collisions are a serious problem in the United States. In 1998, 5220 pedestrians were killed in the United States and 69,000 were injured. Nationally, 12.6% of traffic fatalities were pedestrian fatalities. Of the pedestrian fatalities, 69% occurred in urban areas and 78% occurred at non-intersection locations (NHTSA, 1998). While most crashes and fatalities occur in urban areas, a higher fraction of rural crashes result in death (Garber and Lienau, 1996). One reason for such higher rates is that vehicle speeds tend to be higher in rural areas than in urban areas.

Because of the low population density, pedestrian crashes in rural areas are rare events, but remain a concern. Pedestrian crashes are highly likely to result in injury to the pedestrian even at low vehicle speeds due to the forces exerted by vehicles on pedestrians. Generally, the severity of injury suffered by a pedestrian struck by a vehicle is least serious at lower collision speeds (Pasanen and Salmivaara, 1993). Due to the difficulty in measuring collision speed for each pedestrian crash, this study provides information about roadway and area features that might influence driving speeds, thereby, influencing pedestrian injury severity.

The influence of roadway and area features on pedestrian injury severity was studied through an analysis of 278 pedestrian crashes occurring on rural Connecticut state-maintained highways over a 10 years period (1989–1998). Crashes included in this study were limited to crashes in which pedestrians were crossing the road at locations where the mainline traffic was controlled by neither signals nor stop signs. Ordered probit models were estimated using the LIMDEP software (Greene, 1992) to determine which roadway and area features significantly influence pedestrian injury severity.

2. Study design

Pedestrian crashes are rare events, especially in rural locations. Therefore, modeling the event of a crash occurring at a specific rural location is difficult. At any given location, it is possible that at most one crash may occur in a 10 years period, but the low frequency of pedestrian crashes does not necessarily mean that a particular location is safe for pedestrians. As a result of the low occurrence of rural

* Corresponding author. Tel.: +1-860-486-0352; fax: +1-860-486-2298.
E-mail addresses: szajac@fhiplan.com (S.S. Zajac), johnivan@engr.uconn.edu (J.N. Ivan).
[1] Tel.: +1-860-236-9369; fax: +1-860-232-7536.

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pedestrian crashes, we need to study factors that influence pedestrian safety without modeling the probability that a crash will occur. An alternative to studying factors that contribute to pedestrian crashes is to study factors that contribute to pedestrian injury severity given that a crash occurred. The roadway and area features that are expected to reduce injury severity are expected to do so through speed reduction, which would also reduce the likelihood of a crash occurring in the first place.

Many human factors and factors describing driving conditions have been previously considered in studying pedestrian injury severity. We control for these factors when modeling injury severity in order to determine the pure effect of our proposed speed-reducing factors, which are discussed in greater detail in Section 3. Following is a list of control variables and the effects we expect them to have on pedestrian injury severity.

- Pedestrian age 65 years or older (PED65): increases severity (Zegeer et al., 1993; Jensen, 1999).
- Pedestrian alcohol use (PED_ALC): increases severity (Jensen, 1999).
- Driver alcohol use (OPER_ALC): increases severity.
- Speed limit (SPEED): increases in speed limit increase severity (Jensen, 1999; Pitt et al., 1990).
- Vehicle type (VEHTYPE): larger vehicles increase severity.
- Annual average daily traffic (AADT): increases in AADT decrease severity (Klop and Khattak, 1999).
- Darkness (DARK): increases severity (Jensen, 1999; Klop and Khattak, 1999; Smeed, 1977).
- Illumination (ILLUM): decreases injury severity (Klop and Khattak, 1999).
- Weather (WEATHER): rain, fog, or snow increase severity (Klop and Khattak, 1999).
- Road surface condition (SURFACE): wet, snowy, or icy conditions increase severity (Klop and Khattak, 1999; Smeed, 1977).

It is doubtful that the above-mentioned variables individually explain all differences in pedestrian injury severity. Collision speed has a strong effect on pedestrian injury severity (Pasanen and Salmivaara, 1993). Collision speed is difficult to collect for pedestrian crashes, but speed limit has been shown to affect injury severity (Jensen, 1999; Klop and Khattak, 1999), which implies that it is a good estimate of collision speed. However, speed limit is not the only factor that may contribute to collision speed. We propose several roadway and area variables that may influence speed: clear roadway width, presence of on-street parking, and area type. These variables are expected to influence driving speeds due to their effects on driver behavior. We expect clear roadway width, presence of on-street parking, and area type to influence the speeds at which drivers feel comfortable traveling.

We define clear roadway width as the entire distance from one side of the road to the other excluding the width occupied by on-street parking. More specifically, shoulder and lane widths are included in the clear roadway width, but the width of road used for on-street parking is not. Increased clear roadway width is expected to increase the comfortable traveling speed for drivers, thereby, increasing injury severity of pedestrians.

The narrowing effect of on-street parking is accounted for by the clear roadway width. However, the presence of on-street parking is expected to cause drivers to further slow down due to intermittent actions such as people getting in and out of their vehicles and vehicles pulling in and out of on-street parking spaces. Presence of on-street parking is expected to decrease pedestrian injury severity because of its slowing effect.

Quantifiable geometric features such as clear roadway width and on-street parking may affect speeds at which drivers feel comfortable driving, and as a result, pedestrian injury severity. We have limited our study to rural areas in Connecticut, but within the rural areas there are different area types that may influence pedestrian injury severity due to differences in speed and driver behavior. Building height, spacing, and distance from the road may influence driver behavior in the sense that taller buildings close together and close to the road create a narrowing feeling and promote an awareness of possible pedestrian activity, as well as visual distractions. These factors are difficult to quantify, so their overall effect has been defined in a qualitative area type variable. We have defined the following seven area types.

1. *Downtown* areas are characterized by larger buildings abutting one another and abutting sidewalks.
2. *Compact residential* areas predominantly have houses close together and these houses are generally visible from the road. Most often there are sidewalks.
3. *Village* areas consist of smaller buildings and residences set back from the road. Sidewalks may or may not be present.
4. *Downtown fringe* areas are similar to village areas, but are slightly more developed and are located within close proximity to downtown areas. Downtown fringe areas may also be similar to medium-density commercial (described in the subsequent sections) areas, except they are more likely to have sidewalks, and buildings are generally spaced closer together making them more similar to village areas. Driver behavior may be different in downtown fringe areas than in village or medium-density commercial areas due to drivers' awareness of the downtown area. On-street parking is common in downtown fringe areas.
5. *Medium-density commercial* areas consist almost entirely of commercial development, often with sidewalks. This area type includes commercial attractions such as gas stations, fast food outlets, and supermarkets. On-street parking is not likely to be found in this type of area.
6. *Low-density commercial* areas have lower density commercial development than that of medium-density commercial areas, and residences are more common. These areas are not likely to have sidewalks or on-street parking.

7. *Low-density residential* areas have houses that are spaced far apart and are often not visible from the road. Sidewalks are rare in these areas. Locations with little to no development are included in this category.

We expect downtown and compact residential areas to experience the lowest injury severity, while low-density residential areas are expected to experience the highest injury severity. Village and downtown fringe areas are expected to experience lower injury severity than medium- and low-density commercial areas because buildings and houses are closer together in village and downtown fringe areas, so drivers will be less comfortable driving faster.

3. Site selection

A database of all of the pedestrian crashes that occurred on state-maintained highways in Connecticut from 1989 to 1998 was obtained from the Connecticut Department of Transportation (ConnDOT) Office of Inventory and Forecasting. Crashes were coded on the KABCO scale (ConnDOT, 1986):

- K: fatality;
- A: disabling injury, cannot leave the scene without assistance (i.e. broken bones, severe cuts, unconsciousness, etc.);
- B: not disabling injury, but visible (i.e. minor cuts, swelling, limping, bruises and abrasions, etc.);
- C: probable injury, but not visible (i.e. complaint of pain or momentary unconsciousness, etc.);
- O: no injury.

Crash events for this research were selected based on pedestrian action, location, number of lanes, population density, and population as explained in the next several paragraphs.

Crashes included in this study were limited to those in which the pedestrian was struck while attempting to cross the road, as opposed to those crashes in which the pedestrian was struck while walking along the road or standing on the side of the road. By including only this type of crash, we reduced the possibility of differences in injury severity as a result of the manner in which pedestrians were struck.

The pedestrian crashes considered for study were further limited to locations with no traffic control on the main road because speeds are expected to be relatively uniform at all times. Traffic signals and stop signs present wider variations in speeds. Locations with no main road traffic control were generally mid-block or at relatively minor intersections. In addition to traffic control, study sites were limited to two-lane highway sections.

While most pedestrian crashes occur in urban areas, rural pedestrian crashes tend to be more severe than pedestrian crashes occurring in urban areas (Garber and Lienau, 1996). Rural areas are difficult to define in Connecticut because much of the state is considered "urbanized," and generally suburban in character. In order to gain a better understanding of an appropriate definition of "rural" for Connecticut, town population densities and total populations were plotted by increasing value as shown in Figs. 1 and 2. Both population density and total population increase somewhat linearly until about 1000 people per square mile and 25,000 people. Using our familiarity with the character

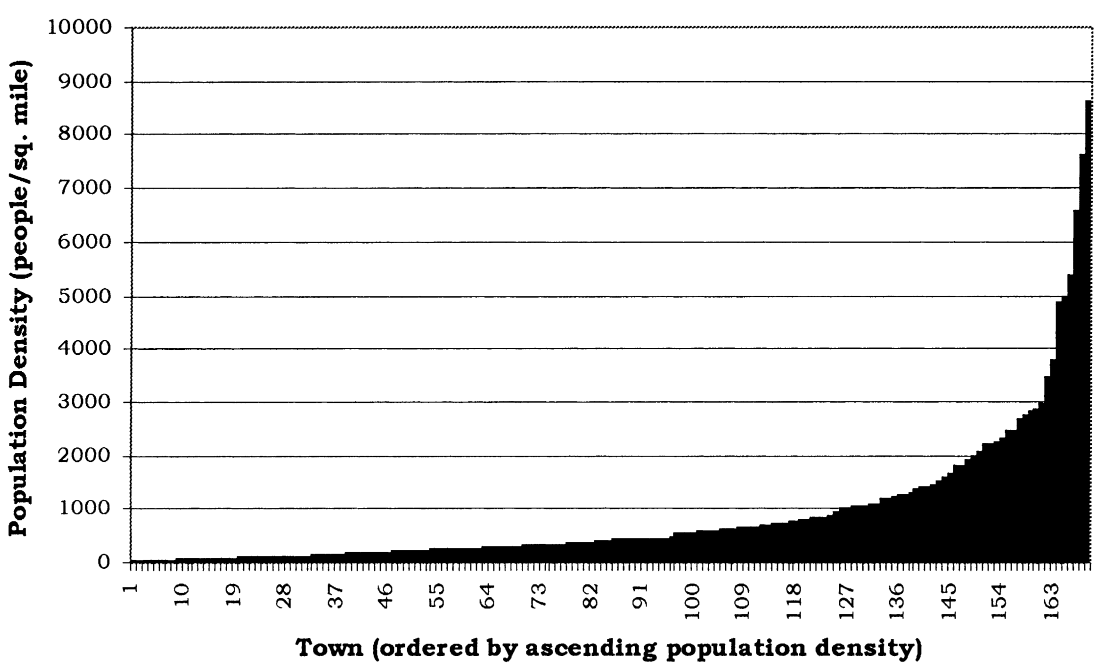

Fig. 1. Connecticut town population densities.

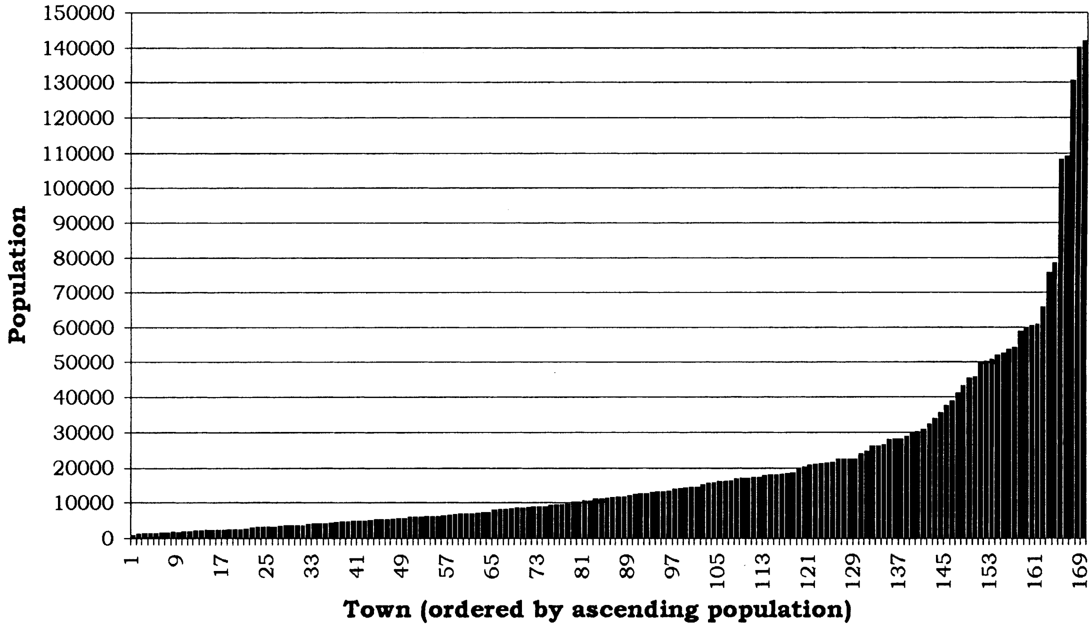

Fig. 2. Connecticut town populations.

of specific Connecticut towns helped us to select these as maximum rural thresholds for population density and total population.

Variables such as pedestrian age, pedestrian alcohol involvement, driver alcohol involvement, vehicle type, light condition, weather, and road surface condition were available from the ConnDOT crash summaries. AADT was obtained using the ConnDOT count locator application developed by ConnDOT's Bureau of Policy and Planning. The count closest to the location of the pedestrian crash was used as an estimate of AADT. The ConnDOT Photolog was used to observe speed limit, clear roadway width, presence of on-street parking, and area type. Each state-maintained highway in Connecticut may be viewed using the Photolog, which consists of images of the roadway taken every 0.01 km (0.006 mile).

4. Methodology

We estimated our models of pedestrian injury severity using ordered probit modeling, which has been used to model injury severity of vehicle occupants as well as bicyclists, but not for pedestrians (Klop and Khattak, 1999; O'Donnell and Connor, 1996; Duncan et al., 1998). Ordered probit models are especially appropriate for this problem because the differences between the ordinal categories of the dependent variable (injury severity level) are not assumed to be equal (Greene, 2000; McKelvey and Zavoina, 1975). For example, the model does not assume that the difference between no injury and probable injury is the same as the difference between disabling injury and death.

The general form of the ordered probit model is

$$y^* = \beta' x + \varepsilon \tag{1}$$

where y^* is an unobserved variable measuring the risk of injury, x the vector of non-random explanatory variables, β' the row vector of unknown parameters, and ε is the random error term. The error term is assumed to have a mean equal to 0, variance equal to 1, and is normally distributed across all observations.

A high risk of injury, y^*, is expected to result in a high level of observed injury, y, in the case of a crash. The relationship between risk of injury and observed injury is defined by thresholds as follows:

$$y = \begin{cases} 0, & \text{if } y^* \le 0 \quad \text{(no injury)} \\ 1, & \text{if } 0 < y^* \le \mu_1 \quad \text{(injury C : injury probable but not visible)} \\ 2, & \text{if } \mu_1 < y^* \le \mu_2 \quad \text{(injury B : injury not disabling but visible)} \\ 3, & \text{if } \mu_2 < y^* \le \mu_3 \quad \text{(injury A : disabling)} \\ 4, & \text{if } \mu_3 < y^* \quad \text{(killed)} \end{cases} \tag{2}$$

where the μ_1, μ_2 and μ_3 are the unknown parameters that are determined with β in estimating the model. The model is estimated using maximum likelihood estimation (Greene, 2000). Models for this research were estimated using the LIMDEP software (Greene, 1992).

5. Model estimation

The continuous variables such as AADT, speed limit, and clear roadway width were scaled to have means between 0 and 1 so the means would be at the same scale as those of the dummy variables. The reason for scaling continuous variables is that ordered probit models may not converge if the variables are not of similar scales (Greene, 1992).

The output from estimating each model indicates which independent variables significantly explain pedestrian injury severity, but it does not indicate whether a given model explains pedestrian injury severity significantly better than another model. The likelihood values of different models estimated from the same set of data were compared using the 'likelihood ratio statistic' (LRS). The LRS was only computed for nested models. For example, a base model may include three variables, and we want to test whether the addition of another variable significantly improves how well pedestrian injury severity is predicted. Then,

$$\mathrm{LRS} = -2[L(\beta_k) - L(\beta_k + \beta_{k+1})] \tag{4a}$$

$$H_0 : \beta_{k+1} = 0 \tag{4b}$$

$$H_\mathrm{A} : \beta_{k+1} \neq 1 \tag{4c}$$

$$\text{Reject } H_0,\ \text{if LRS} > \chi^2_{(\text{d.f.},\,\alpha)} \tag{4d}$$

where α is the selected significance level, $L(\beta_k)$ the likelihood for the restricted model, $L(\beta_k + \beta_{k+1})$ the likelihood for the unrestricted model, and there is 1 d.f. H_0 is the null hypothesis and states that the additional parameter in the unrestricted model does not significantly increase the likelihood (Ben-Akiva and Lerman, 1985).

The 90% significance level was selected for this study because of the relatively small data set of 278 cases including missing values, and 258 excluding missing values. Relationships were expected to exist between pedestrian injury severity and the independent variables, but at a lower significance level than if the data set were very large.

The modeling results are shown in Tables 1–5 and are explained in the sections to follow. The tables report the coefficients and P-values for each variable, the log-likelihood for the null model (i.e. all coefficients are 0), the log-likelihood for each model, the number of free parameters, the LRS and χ^2-value for comparing to the null model, the LRS and χ^2-values for comparing two different models, and the μ thresholds. Our discussion focuses on the sign of the coefficients rather than the numerical value because the sign indicates whether each variable's relationship with pedestrian injury severity is direct or indirect. The P-values indicate the confidence level at which variables are significant (Neter et al., 1993). For example, if we are testing a variable for significance at the 90% confidence level, $\alpha = 0.10$. If the P-value for the variable being tested is equal to 0.045, the variable is significant at a confidence level of at least 90% because $0.045 < 0.10$. In fact, the variable is significant at the 95% confidence interval because α would equal 0.05 and $0.045 < 0.05$. The log-likelihood values and degrees of freedom are used to calculate the LRS-value, which is then used to compare two models as discussed above.

Models were estimated in three steps. First, control variables were tested for inclusion in a base model. Next, roadway variables such as clear roadway width and presence of

Table 1
Results from control variable and roadway variable models

Model	Variable	Coefficient	Significance
First round of estimation (based on 258 cases)			
1	Constant	1.8735	0.00000
	AADT	0.54302	0.45101
2	Constant	1.9100	0.00000
	SPEED	0.27019	0.79009
3	Constant	1.9881	0.29652
	SPEED	−0.19083	0.96744
	SPEEDSQ	0.65685	0.9864
4	Constant	1.9630	0.00000
	SURFACE	0.12307	0.41663
5	Constant	1.9313	0.00000
	DARK	0.22101	0.11727
6	Constant	1.9561	0.00000
	ILLUM	0.1888	0.24806
7	Constant	1.9673	0.00000
	WEATHER	0.11616	0.45449
8	Constant	1.9311	0.00000
	VEHTYPE	0.38243	0.02008
9	Constant	1.9792	0.00000
	OPER_ALC	1.1951	0.00486
10	Constant	1.9017	0.00000
	PED65	0.78042	0.00000
11	Constant	1.9725	0.00000
	PED_ALC	1.2915	0.00014
Second round of estimation (based on 264 cases)			
12	Constant	1.9366	0.00000
	VEHTYPE	0.41082	0.01070
13	Constant	1.9871	0.00000
	OPER_ALC	1.3159	0.00081
14	Constant	1.9110	0.00000
	PED65	0.78874	0.00000
15	Constant	1.9807	0.00000
	PED_ALC	1.3662	0.00002
Roadway variables (based on 264 cases)			
16	Constant	1.3557	0.00233
	WIDTH	1.6407	0.11837
17	Constant	1.6753	0.30393
	WIDTH	0.0690	0.81977
	WIDTHSQ	1.8872	0.99252
18	Constant	2.0149	0.00000
	PARKDRV	0.09431	0.63198
19	Constant	2.0268	0.00000
	PARKOPP	−0.15742	0.38040
20	Constant	2.0320	0.00000
	PARKBOTH	−0.22673	0.28487

Table 2
Results from base model estimation

Variable	I: Base Model 1		II: Alternate base model		III: Base Model 2	
	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
Constant	1.8219	0.00000	1.8217	0.00000	1.1057	0.01173
VEHTYPE	0.35823	0.02944	0.40596	0.01116	0.37460	0.02655
OPER_ALC	1.0025	0.07046	NA	NA	1.0279	0.07004
PED65	0.86978	0.00000	0.87941	0.00000	0.87678	0.00000
PED_ALC	1.4276	0.00001	1.5299	0.3214	1.3957	0.00001
WIDTH	NA	NA	NA	NA	1.8137	0.07677
Log-likelihood (null model)	−358.3511		−358.3511		−358.3511	
Number of free parameters, m	4		3		5	
LRS (null model)	58.58		52.10		61.48	
$\chi^2_{(m,0.90)}$	7.78		6.25		9.24	
μ_1	1.4629		1.4586		1.4683	
μ_2	2.5610		2.5478		2.5721	
μ_3	3.7871		3.7440		3.8100	
Log-likelihood (model)	−329.0603		−332.3016		−327.61	
Number of free parameters (model)	4		3		5	
LRS (comparison of I and II)	6.48					
$\chi^2_{(1,0.90)}$ (comparison of I and II)	2.71					
LRS (comparison of I and III)	2.90					
$\chi^2_{(1,0.90)}$ (comparison of I and III)	2.71					

on-street parking were tested. Finally, area type was modeled. The results and discussion of these models appear in the following three sections.

6. Base model

6.1. Model estimation

In order to determine which control variables significantly affect injury severity by themselves, eleven models were estimated with just one independent variable in each. The results from this first round of estimation are shown in Table 1. The first round of estimation indicated that VEHTYPE, OPER_ALC, PED65, and PED_ALC all significantly explain injury severity level at a 95% confidence level. AADT, speed limit, SURFACE, DARK, ILLUM, and WEATHER were found to be poor predictors. At this point, six cases that contained missing values for SURFACE, DARK, ILLUM, and WEATHER were added back into the database for a total of 264 cases, and the four significant variables (VEHTYPE, OPER_ALC, PED65, and PED_ALC) were tested by themselves again. These results, also shown in Table 1, indicate that the confidence in these four variables increased slightly with the addition of the six cases.

Next, VEHTYPE, OPER_ALC, PED65, and PED_ALC were all included as independent variables in the same model, which we refer to as Base Model 1. OPER_ALC was found to be significant at the 90% confidence level whereas the other three independent variables were significant at the 95% confidence level. An alternative base model was tested in which OPER_ALC was not included. The results of both models are given in Table 2. The LRS for comparing alternative base model to Base Model 1 is greater than the χ^2-value for 1 d.f. at the 90% confidence level. The standard conclusion, then, is to reject the null hypothesis. This means that Base Model 1 predicts pedestrian injury severity significantly better than the restricted alternative

Table 3
Number of crashes by area type and injury severity

Injury severity	Downtown	Compact residential	Downtown fringe	Village	Medium-density commercial	Low-density commercial	Low-density residential
K	1	3	3	6	0	3	6
A	12	10	5	10	7	9	18
B	11	12	7	17	12	13	29
C	13	12	4	9	8	8	10
O	2	0	0	0	1	1	2
Total	39	37	19	42	28	34	65

Table 4
Results from area type model estimation

Variable	III: Base Model 2		IV: Base Model 2 stratified by AREA7		V: Base Model 2 stratified by AREA4		VI: Base Model 2 stratified by AREA2	
	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
Constant	1.1057	0.01173	0.96783	0.03353	0.92598	0.04134	0.99855	0.02217
VEHTYPE	0.37460	0.02655	0.34124	0.04765	0.33833	0.04480	0.33236	0.04521
OPER_ALC	1.0279	0.07004	0.96246	0.13083	0.96305	0.09979	0.99282	0.09074
PED65	0.87678	0.00000	0.93164	0.00000	0.93362	0.00000	0.90986	0.00000
PED_ALC	1.3957	0.00001	1.5631	0.00000	1.5268	0.00000	1.4963	0.00000
WIDTH	1.8137	0.07677	2.1759	0.04997	2.2824	0.03888	2.0965	0.04832
Log-likelihood (null model)	−358.3511		−358.3511		−358.3511		−358.3511	
Number of free parameters, *m*	5		23		14		8	
LRS (null model)	61.48		79.57		76.46		71.76	
$\chi^2_{(m,0.90)}$	9.24		32.01		21.06		13.36	
Log-likelihood (model)	−327.6100		−318.5660		−320.1199		−322.4692	
Number of free parameters (model)	5		23		14		8	
LRS (comparison of III and IV)	18.09							
$\chi^2_{(18,0.90)}$ (comparison of III and IV)	25.99							
LRS (comparison of III and V)	14.98							
$\chi^2_{(9,0.90)}$ (comparison of III and V)	14.68							
LRS (comparison of V and VI)	4.70							
$\chi^2_{(9,0.90)}$ (comparison of V and VI)	10.64							
LRS (comparison of III and VI)	10.28							
$\chi^2_{(6,0.90)}$ (comparison of III and VI)	6.25							

Table 5
Thresholds by area type

Model	Area type	μ_1	μ_2	μ_3
Base Model 2	NA	1.4683	2.5721	3.8100
Base Model 2 stratified by AREA7	Downtown	1.7692	2.5468	4.5585
	Compact residential	1.7137	2.6095	3.9240
	Downtown fringe	1.4475	2.4792	3.3816
	Village	1.3824	2.596	3.5688
	Medium-density commercial	1.5205	2.7345	7.1770[a]
	Low-density commercial	1.5912	2.8784	4.1089
	Low-density residential	1.0969	2.4224	3.6540
Base Model 2 stratified by AREA4	Downtown and compact residential	1.7418	2.5770	4.1513
	Village and downtown fringe	1.4020	2.5573	3.5059
	Low- and medium-density commercial	1.5590	2.8104	2.2462
	Low-density residential	1.0946	2.4195	3.6496
Base Model 2 stratified by AREA2	Downtown, compact residential, low- and medium-density commercial	1.6596	2.6680	4.1746
	Village, downtown fringe, low-density residential	1.2430	2.4798	3.5565

[a] Not statistically significant at 90% confidence level.

base model. More specifically, OPER_ALC does significantly increase the log-likelihood. Therefore, we accept the unrestricted model, Base Model 1.

6.2. Discussion

Many of the control variables were not found to be significant: AADT, speed limit, SURFACE, DARK, ILLUM, and WEATHER. It is possible that AADT is not significant because only rural two-lane state highway crash locations were considered. Vehicle speeds, and thus, pedestrian injury severity, may not be sensitive in this range of AADT.

Speed limit was not expected to be the only predictor of vehicle speed, but it was expected to significantly explain pedestrian injury severity. Speed limit was modeled several different ways to try to determine whether a relationship exists with pedestrian injury severity. Speed limit was modeled as a continuous variable, SPEED, assuming its relationship with injury severity was linear. When the relationship was found to be weak, a non-linear relationship was assumed in which both SPEED and SPEEDSQ were included. While speed limit was expected to influence pedestrian injury severity, our findings imply that, for the crashes we studied, speed limit does not significantly impact pedestrian injury severity. This may imply that drivers tend not to observe lower speed limits in rural areas.

7. Models including roadway variables

7.1. Model estimation

We next tested our hypotheses about clear roadway width and presence of on-street parking. These variables were initially included individually in models in order to determine whether they significantly explain injury severity levels by themselves. The relationship between pedestrian injury severity and clear roadway width (WIDTH) was suspected to possibly be non-linear, so we tested WIDTH alone as well as WIDTH with clear roadway width squared (WIDTHSQ). The on-street parking variables tested were: parking on the driver's side (PARKDRV), parking on the opposite side of the road (PARKOPP), and parking on both sides of the road (PARKBOTH). The results of these models are presented in Table 1. None of the variables tested by themselves were significant at the 90% confidence level. The best results came from the model including only WIDTH, which was significant at a level close to 90%. WIDTH was further tested, but the variables for on-street parking were not further tested because of their weak relationship with injury severity.

WIDTH was next included in a model with VEHTYPE, OPER_ALC, PED65, and PED_ALC. Results of this model estimation are displayed in Table 2. VEHTYPE, PED65, and PED_ALC involvement were significant at the 95% confidence level, while OPER_ALC and WIDTH were significant at the 90% confidence level. All of the variables were significant at an acceptable confidence level, but this less restricted model had to be compared to the restricted Base Model 1 to determine whether the addition of WIDTH significantly improves prediction of injury severity. The null hypothesis may be rejected, which means that the addition of WIDTH to Base Model 1 predicts injury severity significantly better than Base Model 1 alone. So, Base Model 2 includes VEHTYPE, OPER_ALC, PED65, PED_ALC, and WIDTH.

7.2. Discussion

Clear roadway width and presence of on-street parking were expected to influence injury severity due to their possible effects on vehicle speed. However, on-street parking was not found to significantly affect injury severity. As mentioned previously, on-street parking was expected to influence vehicle speeds because of people getting in and out of their vehicles and vehicles pulling in and out of parking spaces. None of the parking variables were found to significantly explain pedestrian injury severity, implying that the presence of on-street parking does not significantly reduce injury severity at the study locations. It is important, however, to remember that the study locations were selected based on the occurrence of a crash. We can state that in the event of a crash, the intermittent actions associated with on-street parking did not significantly affect injury severity, indicating that at crash sites other factors influenced vehicle speeds more.

WIDTH did not significantly influence pedestrian injury severity at the 90% confidence level when included in a model as the only independent variable. When combined with VEHTYPE, OPER_ALC, PED65, and PED_ALC, WIDTH did significantly explain pedestrian injury severity at a confidence level of at least 90%. When compared to Base Model 1, Base Model 2 better predicted pedestrian injury severity at a confidence level of 90%.

8. Area type models

8.1. Model estimation

Area type is the only categorical variable in our database, which means that the values for area type are represented by non-ordinal numbers in the database. In other words, the values for area type are not quantifiable and are in no particular order—they represent the group number to which the area type belongs. To determine the significance of area type in predicting injury severity level, Base Model 2 had to be estimated with area type as a stratifying variable. Table 3 gives a summary of the number of crashes that occurred in each area type by injury severity level. When stratifying by area type, the coefficients for the continuous and dummy variables are the same for each area type, but a different set of μ thresholds is estimated for each area type. The value for the risk of injury is the same for given conditions regardless of area type, and the threshold values determine the most likely observed injury for each area type. For example, if μ_3 (the threshold for being killed) is much lower for one area type than another, a pedestrian is more likely to die if struck by a vehicle in that area type than the other.

Results from modeling Base Model 2 stratified by all seven area types (AREA7) are shown in Table 4 and the threshold values are shown in Table 5. All threshold values were significant, except for μ_3 for medium-density commercial areas. This may be attributed to no fatalities having occurred in any of the medium-density commercial areas. Had even one fatality occurred in a medium-density commercial area, the μ_3 threshold for medium-density commercial areas would have been significant.

As shown in Table 4, the LRS-value is lower than the χ^2-value, so the null hypothesis cannot be rejected. Base Model 2 stratified by AREA7 does not predict injury severity significantly better than Base Model 2.

Stratifying by all seven area types does not produce significantly better results than the restricted Base Model 2. There are, however, groupings of area types that may produce more significant results. The number of free parameters when stratifying by seven area types is high and grouping the area types will require fewer μ thresholds to be estimated, reducing the degrees of freedom lost to estimation.

Note that the μ thresholds shown in Table 5 were similar for some area types: downtown and compact residential, village and downtown fringe, and medium- and low-density commercial. The implication is that pedestrian injury severity may not be significantly different in area types with similar μ thresholds. Area type was redefined in four groups as AREA4:

- downtown and compact residential;
- village and downtown fringe;
- low- and medium-density commercial;
- low-density residential.

Another model was estimated in which the stratifying variable was AREA4. The results for Base Model 2 stratified by AREA4 are also given in Table 4 and the threshold values are presented in Table 5. The LRS-value is slightly greater than the χ^2, which means that the null hypothesis may be rejected. Base Model 2 stratified by AREA4 significantly better predicts injury severity than Base Model 2.

After area types were grouped and defined above as AREA4, we again noticed similarities in threshold values (shown in Table 5) for groups of area types. The threshold values for downtown and compact residential areas were similar to those of low- and medium-density commercial areas, and the threshold values for village and downtown fringe areas were similar to those of low-density residential areas. Area types were then further grouped and defined as AREA2:

- downtown, compact residential, medium-density commercial, and low-density commercial areas;
- village, downtown fringe, and low-density residential areas.

To test whether the four groups were significantly explaining injury severity better than only two groups of area types, another model was tested in which Base Model 2 was stratified by AREA2. Results from this model were compared to those of Base Model 2 stratified by AREA4 as shown in Table 4, and the thresholds are shown in Table 5. The null hypothesis may not be rejected, indicating that there are only two area types that are significantly different from one another.

We have determined that only two groups of area types are significantly different from each another in predicting pedestrian injury severity. For completeness, it is necessary to test whether Base Model 2 stratified by AREA2 is significantly better at predicting injury severity than Base Model 2.

The comparison of these two models is shown in Table 4. The null hypothesis may be rejected, and we conclude then that stratification by AREA2 significantly improves prediction of injury severity over Base Model 2 alone.

8.2. Discussion

The models stratified by AREA4 and AREA2 both explained pedestrian injury severity significantly better than Base Model 2 at the 90% confidence level. Base Model 2 stratified by AREA4 does not predict injury severity significantly better than Base Model 2 stratified by AREA2, which means that only two groups of area types are needed in predicting pedestrian injury severity. Our original hypothesis was that downtown and compact residential areas would experience the lowest injury severity, while low-density residential would experience the highest injury severity. Additionally, low- and medium-density commercial areas would experience higher injury severity than village and downtown fringe areas. Our hypothesis was partly correct in that downtown and compact residential areas experienced lower injury severity than low-density residential areas. However, we did not expect low- and medium-density commercial areas to experience lower injury severity than village and downtown fringe areas since the buildings were further apart and further off the road in low- and medium-density commercial areas.

The two area type groups significantly different from one another were: (1) downtown and compact residential combined with low- and medium-density commercial, and (2) village and downtown fringe combined with low-density residential. A possible explanation for low- and medium-density commercial areas experiencing lower pedestrian injury severity than village and downtown fringe areas is that drivers may be traveling at lower speeds in low- and medium-density commercial areas due to a greater number of driveways and commercial attractions. Many vehicles turning in and out of commercial driveways may keep vehicle speeds low, while vehicles driving through villages and downtown fringe areas may maintain the same speeds at which they were traveling through low-density residential areas. Speeds may be higher in village and downtown fringe areas due to fewer commercial attractions and more residences than in downtown, low-density commercial, and medium-density commercial areas. Our findings imply that compact residential areas may be significantly safer than village and downtown fringe areas because the close spacing of residences and closeness to the road may increase driver awareness of pedestrians as well as lower vehicle speeds.

Consequently, vehicle speeds in village and downtown fringe areas are of concern. We expect pedestrian activity to be greater in village and downtown fringe areas than in low-density residential areas. Crosswalk treatments may improve pedestrian safety in these areas, but many pedestrians choose to cross at locations other than crosswalks and few of the crashes studied in village and downtown fringe areas occurred at crosswalks. In village and downtown fringe areas, efforts should be made to slow vehicles passing through. On-street parking does not seem to significantly affect pedestrian injury severity, but clear roadway width does significantly influence injury severity for pedestrians struck while crossing the road. In village and downtown areas with speeding traffic, narrowing the roadway width with appropriate traffic calming devices in the area with most pedestrian activity is likely to reduce pedestrian injury severity. For example, “slow points” are a traffic calming design that narrows the roadway width in short intervals and may effectively slow vehicular traffic (Fehr and Peers, 2000). Lower clear roadway width may also reduce the likeliness of a pedestrian crash occurring due to the reduced distance required for the pedestrian to travel, but we have not shown this to be the case. We have shown that higher clear roadway widths generally result in higher pedestrian injury severity and that village, downtown fringe, and low-density residential areas tend to result in higher injury severity than downtown, compact residential, low-density commercial, and medium-density commercial areas.

9. Conclusions

This study focused on roadway and area features that may influence vehicle speeds, and as a result affect injury severity for pedestrians struck while crossing rural two-lane state highways in Connecticut. Through a literature review, control variables were identified based on factors shown to increase or decrease pedestrian injury severity. The ordered probit model was used for model estimation. The control variables that proved significant were included in a base model, which was then compared to subsequent models including roadway and area features.

The control variables found to significantly increase pedestrian injury severity were vehicle type, driver alcohol involvement, pedestrian age 65 years and older, and pedestrian alcohol involvement. Of the speed influencing variables, clear roadway width significantly explained pedestrian injury severity, while the presence of on-street parking did not significantly influence injury severity. Area type significantly influenced pedestrian injury severity, but only the groupings of area types defined by AREA2 were significantly different from one another in influencing injury severity. Downtown, compact residential, low-density commercial, and medium-density commercial areas tended to experience lower pedestrian injury severity while village, downtown fringe, and low-density residential areas tended to experience higher pedestrian injury severity.

The study results may be useful in understanding which types of areas tend to experience more severe injury for pedestrians crossing the road. Our findings indicate that speed-reducing measures should be considered for village and downtown fringe areas with speeding vehicles since they experience higher pedestrian injury severity than other area types, such as downtown, compact residential, medium-density commercial, and low-density commercial. Also, village and downtown fringe areas are expected to have more pedestrian activity than medium-density commercial, low-density commercial, and low-density residential areas. The modeling results indicate that lowering roadway widths could be considered in an effort to reduce pedestrian injury severity in the event that they are struck while crossing the road. Roadway designs in village and downtown fringe areas should be more similar to those in downtown and compact residential areas to make drivers more aware of potential pedestrian activity.

Other estimates of speed should be considered for future research of pedestrian injury severity. One such estimate is the average driving speed at a crash location over a 24 h period. The time at which a crash occurred is available in the crash summary from ConnDOT. The average driving speed at a crash location for the time of day the crash occurred may better explain pedestrian injury severity than speed limit at the crash location.

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References

Ben-Akiva, M., Lerman, S.R., 1985. Discrete Choice Analysis: Theory and Application to Travel Demand. The MIT Press, Cambridge, MA.

Connecticut Department of Transportation (ConnDOT), 1986. Coding Manual: Motor Vehicle and Traffic Collision Analysis on Connecticut Streets and Highways.

Duncan, C.S., Khattak, A.J., Council, F.M., 1998. Applying the ordered probit model to injury severity in truck-passenger car rear-end collisions. Transport. Res. Record 1635, 63–71.

Fehr and Peers Associates, Inc., 2000. Guide to Traffic Calming. http://www.trafficcalming.org; accessed May 2000.

Garber, N.J., Lienau, T.K., 1996. Traffic and Highway Geometric Characteristics Associated with Pedestrian Crashes in Virginia. Report VTRC 96-R29. Virginia Transportation Research Council, March 1996.

Greene, W.H., 1992. LIMDEP User's Manual and Reference Guide. Version 6.0, Econometric Software, Inc., Bellport, NY.

Greene, W.H., 2000. Econometric Analysis, 4th Edition. Prentice Hall, Upper Saddle River, NJ.

Jensen, S., 1999. Pedestrian safety in Denmark. Transport. Res. Record 1674, 61–69.

Klop, J.R., Khattak, A.J., 1999. Factors influencing bicycle crash severity on two-lane, undivided roadways in North Carolina. Transport. Res. Record 1674, 78–85.

McKelvey, R.D., Zavoina, W., 1975. A statistical model for the analysis of ordinal level dependent variables. J. Math. Sociol. 4, 103–120.

Neter, J., Wasserman, W., Whitmore, G.A., 1993. Applied Statistics, 4th Edition. Allyn and Bacon, Boston, MA.

National Highway Traffic Safety Administration (NHTSA), 1998. Pedestrian Safety Facts. http://www.nhtsa.dot.gov; accessed May 2000.

O'Donnell, C.J., Connor, D.H., 1996. Predicting the severity of motor vehicle accident injuries using models of ordered multiple choice. Accident Anal. Prev. 28 (6), 739–753.

Pasanen, E., Salmivaara, H., 1993. Driving speeds and pedestrian safety in the City of Helsinki. Traffic Eng. Control 34 (6), 308–310.

Pitt, R., Guyer, B., Hsieh, C., Malek, M., 1990. The severity of pedestrian injuries in children: an analysis of the pedestrian injury causation study. Accident Anal. Prev. 22 (6), 549–559.

Smeed, R.J., 1977. Pedestrian accidents. In: Proceedings of the International Conference on Pedestrian Safety, Vol. II. pp. 7–21.

Zegeer, C.V., Stutts, J.C., Huang, H., Zhou, M., Rodgman, E., 1993. Analysis of elderly pedestrian accidents and recommended countermeasures. Transport. Res. Record 1405, 56–63.