Finding Strategies to Improve Pedestrian Safety in Rural Areas

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DISCLAIMER

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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 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 severity levels. 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.

INTRODUCTION

Motor-vehicle-pedestrian collisions are a serious problem in the United States. In 1998, 5,220 pedestrians were killed in the United States and 69,000 were injured. Nationally, 12.6 percent of traffic fatalities were pedestrian fatalities. Of the pedestrian fatalities, 69 percent occurred in urban areas and 78 percent occurred at non-intersection locations [1]. While most crashes and fatalities occur in urban areas, a higher fraction of rural crashes result in death [2]. 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 [3]. 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 ten-year period (1989-1998). Crashes included in this study were limited to those 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 package [4] to determine which roadway and area features significantly influence pedestrian injury severity.

By limiting the types of pedestrian crashes to those mentioned previously, our data set is too small for high-level significance. Relationships do exist, but not all are significant at the 95 percent confidence level; a larger study may obtain results at the 95 percent significance level. As a result, our study may be used as a prototype for future research.

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 ten-year 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 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 the next section. Following is a list of control variables and the effects we expect them to have on pedestrian injury severity:

- Pedestrian Age 65 or Older (PED65) – increases severity [5,6],
- Pedestrian Alcohol Use (PED_ALC) – increases severity [6],
- Driver Alcohol Use (OPER_ALC) – increases severity,
- Speed Limit (SPEED) – increases in speed limit increase severity [6,7],
- Vehicle Type (VEHTYPE) – larger vehicles increase severity,
- Annual Average Daily Traffic (AADT) – increases in AADT decrease severity [8],
- Darkness (DARK) – increases severity [6,8,9],
- Illumination (ILLUM) – decreases injury severity [8],
- Weather (WEATHER) – rain, fog, or snow increase severity [8], and
- Road Surface Condition (SURFACE) – wet, snowy, or icy conditions increase severity [8,9].

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 [3]. Collision speed is difficult to collect for pedestrian crashes, but speed limit has been shown to affect injury severity [6,8], implying 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 below) 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.

SITE SELECTION

A database of all pedestrian crashes occurring on state-maintained highways in Connecticut from 1989 through 1998 was obtained from the Connecticut Department of Transportation (ConnDOT) Office of Inventory and Forecasting. Crashes were coded on the KABCO scale [10]:

- K: Fatality,
- A: Disabling injury, cannot leave the scene without assistance (i.e., broken bones, severe cuts, unconsciousness, etc.),
- B: Non-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.), and
- 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 because speeds are expected to be relatively uniform at all times. Traffic signals and stop signs present wider variations in speeds. Locations with no 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 [2]. 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 Figures II-1 and II-2. Both population density and total population increase somewhat linearly until about 1,000 people per square mile and 25,000 people. Using our familiarity with the character of specific Connecticut towns helped us to select these as maximum rural thresholds for population density and total population.

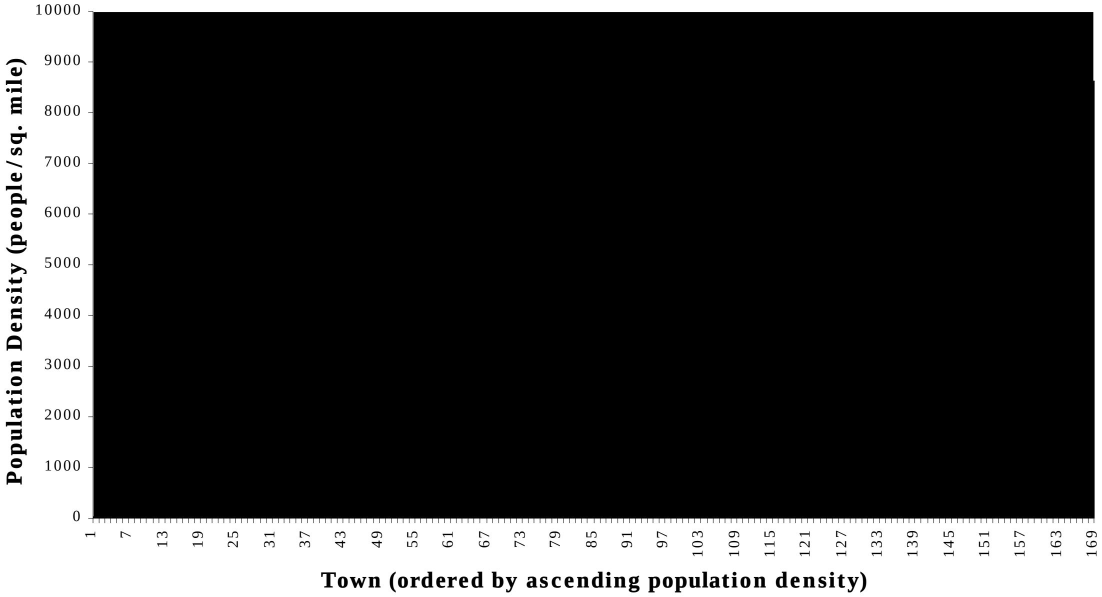

Figure II-1. Connecticut Town Population Densities

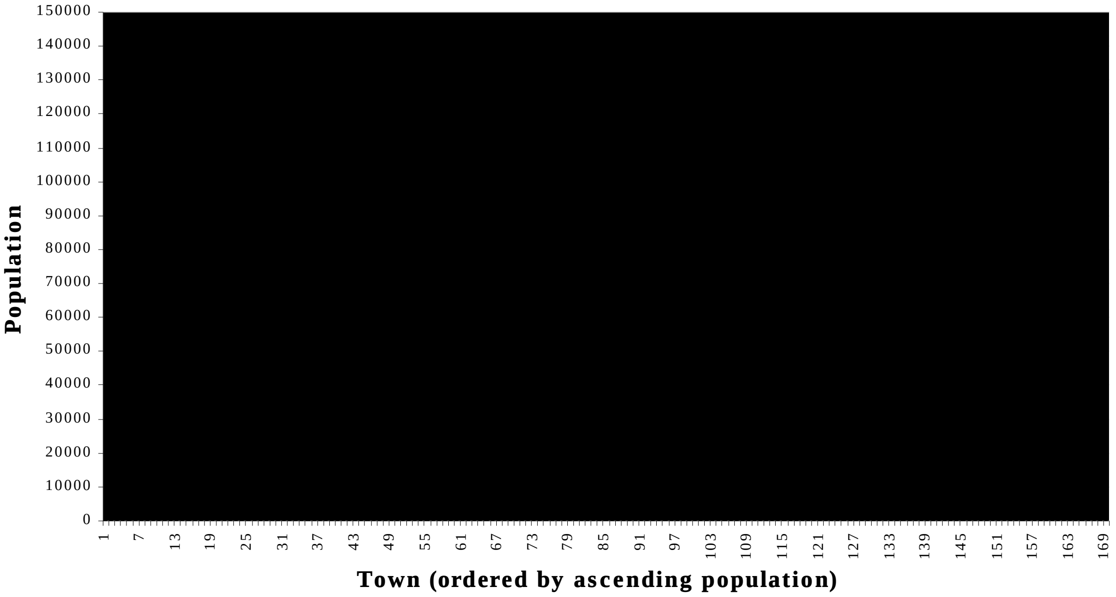

Figure II-2. Connecticut Town Populations

Variables such as pedestrian age, pedestrian alcohol involvement, driver alcohol involvement, vehicle type, light condition, weather, and road surface condition were available from the crash summaries obtained from the Connecticut Department of Transportation (ConnDOT) [10]. Annual Average Daily Traffic (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 mi.).

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 [8,11,12]. 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 [13,14]. 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 ordered probit model is a multivariate model, which means that many variables contributing to pedestrian injury severity may be included in one model.
The general form of the ordered probit model is:

$$y^* = b'x + e \tag{1}$$

where y^* is an unobserved variable measuring the risk of injury, x is a vector of non-random explanatory variables, *b¢* is a row vector of unknown parameters, and e is the random error term. The error term is assumed to have a mean equal to 0.0, variance equal to 1.0, 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:

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

where the *m*'s are unknown parameters that are determined along with *b* in estimating the model. The model is estimated using maximum likelihood estimation [13]. Models for this research were estimated using the LIMDEP software package [4].

MODEL ESTIMATION

The continuous variables such as AADT, speed limit, and clear roadway width were scaled to have means between 0.0 and 1.0 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 [4].

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:

$$LRS = -2\left[L\left(b_k\right) - L\left(b_k + b_{k+1}\right)\right] \tag{4a}$$

$$H_O : b_{k+1} = 0 \tag{4b}$$

$$H_A : b_{k+1} \neq 1 \tag{4c}$$

$$\text{Reject } H_O \text{ if } LRS > c^2_{(\text{degrees of freedom}, a)} \tag{4d}$$

where α is the selected significance level, $L(\beta_k)$ is the likelihood for the restricted model, $L(\beta_{k+1})$ is the likelihood for the unrestricted model, and there is one degree of freedom. H_O is the null hypothesis and states that the additional parameter in the unrestricted model does not significantly increase the likelihood [15].

The 90 percent 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 II-1 through II-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 0.0), 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. We are more concerned with 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 [16]. For example, if we are testing a variable for significance at the 90 percent 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 percent because $0.045 < 0.10$. In fact, the variable is significant at the 95 percent 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.

Table II-1. Results From Control Variable and Roadway Variable Models

	Model	Variable	Coefficient	p-value
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 II-2. Results From Base Model Estimation

Variable	**I** Base Model 1		**II** Alt. Base Model		**III** Base Model 2	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
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	N/A	N/A	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	N/A	N/A	N/A	N/A	1.8137	0.07677
Log Likelihood (null model)	-358.3511		-358.3511		-358.3511	
No. 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	
No. 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					

Table II-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 II-4. Results From Area Type Model Estimation

Variable	Base Model 2		Base Model 2 Stratified by AREA7		Base Model 2 Stratified by AREA4		Base Model 2 Stratified by AREA2	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
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	
No. 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	
No. 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							
$\chi^2_{(6,0.90)}$ (comparison of **V** and **VI**)	10.64							
LRS (comparison of **III** and **VI**)	10.28							
$\chi^2_{(3,0.90)}$ (comparison of **III** and **VI**)	6.25							

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

BASE MODEL

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 II-1. The first round of estimation indicated that VEHTYPE, OPER_ALC, PED65, and PED_ALC all significantly explain injury severity level at a 95 percent 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 II-1, indicate that the confidence in these four variables increased slightly with the addition of the six cases.

Table II-5. Thresholds by Area Type

Model	Area Type	μ_1	μ_2	μ_3
Base Model 2	N/A	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 Commericial	1.5205	2.7345	7.1770*
	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

All thresholds significant at 90 percent confidence interval except *

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 percent confidence level whereas the other three independent variables were significant at the 95 percent confidence level. An alternative base model was tested in which OPER_ALC was not included. The results of both models are given in Table II-2. The LRS for comparing alternative base model to Base Model 1 is greater than the χ^2 value for one degree of freedom at the 90 percent 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 base model. More specifically, OPER_ALC does significantly increase the log-likelihood. Therefore, we accept the unrestricted model, Base Model 1.

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 implies that drivers tend not to observe lower speed limits in rural areas.

MODELS INCLUDING ROADWAY VARIABLES

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 II-1. None of the variables tested by themselves were significant at the 90 percent confidence level. The best results came from the model including only WIDTH, which was significant at a level close to 90 percent. 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 II-2. VEHTYPE, PED65, and PED_ALC involvement were significant at the 95 percent confidence level, while OPER_ALC and WIDTH were significant at the 90 percent 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.

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 percent 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 percent. When compared to Base Model 1, Base Model 2 better predicted pedestrian injury severity at a confidence level of 90 percent.

AREA TYPE MODELS

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 II-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 II-4 and the threshold values are shown in Table II-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 II-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.

Note that the μ thresholds shown in Table II-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, and
- 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 II-4 and the threshold values are presented in Table II-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 II-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 and
- 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 II-4, and the thresholds are shown in Table II-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 II-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.

Discussion

The models stratified by AREA4 and AREA2 both explained pedestrian injury severity significantly better than Base Model 2 at the 90 percent 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. An explanation for low- and medium-density commercial areas experiencing lower pedestrian injury severity than village and downtown fringe areas may be that drivers travel 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.

A possibly important observation is that at least one-third of the low-density residential crashes occurred at locations at which a driveway and mailbox were on opposite sides of the road. Though we did not study causes of pedestrian crashes, it is possible that a significant fraction of the crashes in low-density residential areas may have occurred when residents were crossing the road to get their mail. If indeed some of these crashes occurred because a resident was getting his/her mail, the practice of placing mailboxes on only one side of the highway should be reconsidered on higher-speed road sections in low-density residential areas.

In addition to mailbox placement, 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 [17]. Narrower 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.

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 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 narrowing 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-hour period. The time at which a crash occurred is available in the crash summary from ConnDOT [10]. 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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Pedestrian Safety in Maine

ABSTRACT

The aim of the project this paper is based on is to analyze pedestrian crashes in the state of Maine and propose ways of improving it. Pedestrian and vehicle volumes were counted and crash numbers predicted and compared to outcomes in varying environments. It was found that high speeds and wide roads lead to more crashes and that the focus of improvement should be on arterials and major collectors.

INTRODUCTION

The primary objective of this paper is to quantify pedestrian safety and to assess how pedestrian safety in the state of Maine can be improved. The paper focuses on pedestrian traffic safety. Pedestrian security, i.e., how a layout may influence the risk of assault, rape, or other violent crimes, is also an important issue. The attractiveness of facilities is also important for promoting walking as a mode of transportation. We know that people want direct, aesthetically pleasing and safe facilities. Making the facilities attractive can by itself promote safety. If drivers see many pedestrians along a street, they are more likely to slow down and yield to crossing pedestrians.

There are clear benefits from having people walk more, not least for their health. Carre’ [1] estimates that a person gains one hour of expected life for every hour he/she is engaged in moderate exercise, for example walking. Walking is probably the form of exercise that has the fewest negative side effects in the form of injuries—as long as injuries caused by collisions with motor vehicles are avoided [2]. If we extrapolate these findings, a person would live forever if he kept on walking. Obviously, that is not true. But the results do mean that “no time is wasted” when going by foot to and from activities. People can incorporate walking into their everyday activities, even if they live far away from work and service centers, by walking, for example, from shop to shop. But safe, secure, unrestricted, and aesthetically attractive facilities are needed to persuade people to do that rather than to drive.

The pedestrian safety situation in the United States is worse than in many other ‘civilized’ countries. The annual number of pedestrian fatalities per hundred thousand people in the U.S. is according to FARS [3] around 2.04. Every northern and central European country has a lower crash rate based on data from a report by the European Transport Safety Council [4]. The safest countries are the Netherlands (with a rate of 0.70), Sweden (0.84), and Denmark (1.29).

The fatality-rate comparison is certainly not flattering for the U.S. considering the fact that people probably walk less in the U.S. than in most other countries. Surprisingly, the situation in Maine is noticeably better than in the average state. Maine had 77 pedestrians fatally injured in the 5-year period 1994-98 [3]. That gives a rate of 1.25 fatalities per 100,000 people. (For 1991 to 1993, there were 45 fatal pedestrian crashes giving an almost identical rate [5]. However, this may again not be indicative of good planning or safe behavior, but purely reflect the fact that people do not walk as much in Maine as in some other states. Still, pedestrian safety is less of a public health issue in Maine than in some states.

CRASH DATA, MAINE

Maine Department of Transportation provided me with pedestrian crash data, covering the years 1994-98, a total of 1589 reported pedestrian crashes.

Crashes are fairly evenly distributed over the week, with Tuesdays through Fridays being ‘average,’ Saturdays (with 285 crashes) being the worst whereas Sundays and Mondays have the fewest crashes. These numbers may express correlation to factors such as exposure, alcohol, etc. The likelihood we would observe 285 or more if 227 (=1589/7) are expected is about 0.03% assuming a Poisson distribution. In other word, Saturdays have statistically significant more crashes than the average day.

Analysis of the time of day when crashes occur shows that there are about 75 crashes an hour in the morning and early afternoon, but about 150 crashes an hour between 4 PM and 7 PM. Then there is a linear reduction in numbers from 7 PM to 4 AM when there is hardly any. Pedestrian and vehicle exposure is not that much higher in the afternoon than in the morning, and the exposure in the morning is higher than in the late evening. Obviously other factors are needed to explain this time distribution. Such factors can include alcohol consumption, tiredness, daylight conditions, etc.

The weather reported at the time of the crash shows that 68% of all crashes happened in clear weather, 17% in cloudy, 8% in rainy, and 4% in snowy conditions.

The analysis shows that 75% of the crashes occurred on dry roads and 14% on wet roads. Only about one in ten crashes happen on ‘wintry’ roads in spite of Maine often having these roadway conditions.

Also, 61% happened in daylight, 24% during darkness with streetlights on, and 7% on dark streets lacking lit streetlights. Finally, 3% and 4% respectively happened in dawn and dusk

The vast majority (71%) of pedestrian crashes happened on level, straight roads where sight distances should be adequate. Only 4% were reported on curves whereas 19% happened on straight roads with a grade.

Most crashes happened away from intersections, but a surprisingly high percentage happened at 3-leg intersections (19%). Another 17% occurred at 4-leg intersections and 5% at driveways.

Most of the crashes (1025 crashes) happened at locations without any traffic control device or signage. Others happened in no-passing zones or at locations with curve warning signs or at locations with other unspecified signs. Yet others happened at locations with some type of control. Most commonly that control is traffic signals—stop and go (186 cases), stop sign—other (156), flagger/officer/school patrol (36), traffic signal—flashing (24), all-way stop (11) and yield (8). Without knowing exposure, it is difficult to comment on risk, but it seems as if, for example, all-way stop is a ‘safe’ regulation. It is much harder to speculate on the safety of yield versus stop since yield control is rare in Maine.

The speed limit at the location is presented and discussed below.

In Maine, for all other types of crashes, roughly 3% lead to incapacitating injuries. For pedestrian crashes, that portion is 19% (300 crashes). Another 40% (642) had non-incapacitating injuries, whereas 34% (546) lead to possible injuries. There were 81 fatalities, i.e. 5% of all crashes.

Fatal Crash Data

All 1994-98 fatal pedestrian crashes in the State were analyzed by studying copies of the original police reports. This was done for the reason that it is certainly not only chance that determines whether a crash will be fatal or not, and economic analysis shows that the total societal disutility of fatal crashes is roughly as great as that for all other crashes combined

Of the fatally injured pedestrians, 37% (30) were female and 63% (51) were male. The median age was 49. Ten percent of the fatally injured pedestrians were below the age of 18. Another ten percent were between 18 and 28. Forty-two percent were 65 or older, and 20% were eighty or older. In other words, serious pedestrian crashes are certainly more a problem for the elderly than for the young people in Maine.

Twenty-one of the drivers were women (27%) and 57 (73%) were men. The genders of the remaining two drivers are unknown (hit and run crashes). The data indicate that women are 'safer' drivers than men since women are behind the wheel at roughly 36% of all miles driven in Maine. (Observations by the author and students from the University of Maine showed that in 1995, on average, 64% of drivers in Central Maine were male and 36% were female.) The median age of the crash-involved drivers was 35. Just over a quarter (26%) were 25 or younger, 13% were 65 or older and 6% were older than 75. It can be assumed that elderly drivers will be increasingly involved in these crashes since this group is rapidly growing in numbers. Still, younger drivers will most likely remain the primary safety concern for a foreseeable future.

At least fourteen (17%) of the fatally injured pedestrians were under the influence of alcohol. At least eight (10%) of the drivers were operating under the influence. Both pedestrian and driver had consumed alcohol in one case. In one case, the crash involved a person who had stopped to help a driver with a disabled vehicle, where that driver was under the influence of alcohol. The two hit-and-run crashes may obviously also involve alcohol.

There were 41 regular sedans and station wagons involved in the crashes. (One was a police car.) There were 19 pickup trucks, five vans, one jeep, one MC, and eleven full-sized trucks involved. Two of the vehicles are unknown, since these were hit-and-run crashes. Trucks and vans make up 46% of the vehicles involved in fatal crashes. In non-fatal crashes, they make up a lower percentage, around 36%. In traffic, these vehicles made up less than a third of all vehicles during the period of analysis. However, trucks and sport utility vehicles are becoming increasingly common. This may mean that the pedestrian crash severity will become higher in the future.

The distribution of fatal crashes by month shows that there is a concentration of fatal crashes to fall and winter in spite of the fact that there is more pedestrian activity in the summer. December had the highest number, 13. No month from April through September had more than six fatalities. No month from October through March had less than six.

Analyzing the distribution by weekday shows that Friday is the only ‘deviant’ day, with clearly more fatal crashes (20) than other days (p=0.016). The other weekdays had on average 10.0 crashes each.

Fatal crashes are concentrated to the evening hours. No one-hour period between midnight and 5 PM had more than five crashes, whereas there were at least four crashes within each hour between 5 PM and 11 PM, with a maximum of eleven between 5 and 6 PM.

Seventeen of the eighty fatal crashes (21%) occurred on local streets, eighteen (23%) on collectors and 45 (56%) on arterials. Only three of the collector crashes happened on minor collectors, meaning that 75% of all fatal crashes took place on arterials or major collectors.

The median Average Annual Daily Traffic (AADT) was just below 6,000 vehicles a day, or roughly ten vehicles per minute during the busier times of day. The 10-percentile was around 350 vehicles per day and 20% of crashes occurred at roadways with less than 1,000 vehicles a day. At the other end of the spectrum, the 80-percentile was 13,585 vehicles a day, and the 90-percentile just over 18,000 vehicles a day. The busiest road carried about 38,000 vehicles a day.

The roadway is often wide were serious pedestrian crashes occur. The pedestrian was walking along the roadway in 28 cases, and the width of the road is then of little relevance. For the remaining crashes, the traveled way had 2-lanes and less than 38 feet of combined travel-lane width in 22 cases, whereas the traveled way was wider than 38 feet in 26 cases.

Thirty of the eighty fatal crashes (37.5%) occurred in areas designated urban by federal and state authorities. Another 14 crashes (17.5%) occurred in areas designated urban by the state but rural by the federal government. The remaining 36 crashes (45%) occurred in rural areas. However, some of these also occurred in built-up areas, but with building density or total populations not triggering urban designation.

Speed and Violation Records

The speed limit was 25 mph (40 km/h) or lower in 21 of the fatal crashes. It was 30 mph (48 km/h) in 7 cases, 35 mph (56 km/h) in 21, 40 mph (64 km/h) in 3, 45 mph (72 km/h) in 16, 50 mph (80 km/h) in 6, and 55 mph (88 km/h) in 6 cases. These numbers as well as the speed limits of all crashes (fatal and non-fatal) were compared; giving the likelihood a crash will result in a fatality. These results, with 95%-confidence intervals, are presented in Figure I-1.

The actual speed at the time of collision, or prior to an evasive maneuver, may not coincide with the speed limit. Drivers involved in these crashes may be typical drivers, meaning that they like ‘most’ drivers in Maine exceed the speed limit by at least 5 or 10 mph (8-16 km/h) when they are driving on non-congested roads. It is also a fair assumption that some of the drivers involved in crashes, on average, may be driving faster than typical drivers do. Many of the drivers involved in the fatal pedestrian crashes have received speeding tickets during the last couple of years indicating that they exceed speed limits more than 10 to 15 mph at least sometimes. Some of the drivers also have multiple crash involvement in the years leading up to the fatal crash. One driver had three crashes within the month of the fatal crash. But, there are also many drivers with no accident or violation records. Some of the crashes these drivers have involve pedestrians with extensive violation records as habitual offenders and abusers of alcohol. Finally, there are a fair number of crashes where none

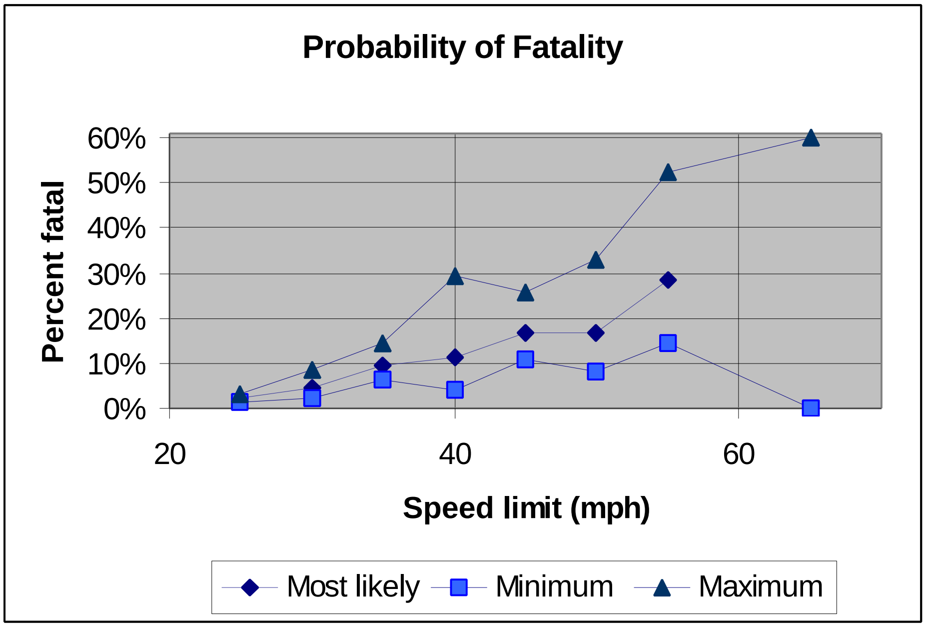

Figure I-1. Speed limit and probability of fatality with 95% level of confidence.

of the involved parties have any demerit points or crash involvement prior to this event. In summary, some groups of people seem more prone to being involved in fatal pedestrian crashes, but no one is completely immune against this risk.

Behavior

The traffic safety of a pedestrian who is crossing a street is influenced by many factors. If the pedestrian crosses when there are no vehicles close by, he/she will obviously be safe. If the pedestrian wishes to cross a street when there are vehicles going by, he/she can either wait for a ‘safe’ gap to occur, for a vehicle to slow down or stop for him/her, or just walk out into traffic hoping for the best. This third option is primarily chosen by intoxicated people and possibly by people in great stress or with mental handicaps—or by mistake by, e.g., a visually impaired person. And children may do it because they do not realize the dangers. Measures to provide safety for people walking straight out into traffic may be different than measures aiming at providing safety for people choosing either of the other two strategies. Also, it should be taken into account that introducing measures providing safety for the group “walking straight out into traffic,” such as reducing speed or legislating pedestrian priority may increase the frequency of that behavior.

Studies from around the state indicate that the higher the driving speed, the lower the percentage of drivers who stop and yield to pedestrians in crosswalks. This relationship can be illustrated with observations from 1998 showing that at crosswalks where the average speed is less than 11 mph, almost 100% of drivers yield. Where the average speed is 11-15 mph (18-24 km/h), 28% do; if 16-20 mph (26-32 km/h), 23% do; and 21-30 mph (34-48 km/h), 17% yield.

OBSERVED NUMBER OF PEDESTRIAN CRASHES VERSUS EXPECTED NUMBERS

Besides a thorough investigation of the fatal crashes, all pedestrian crashes were analyzed in detail for a small number of Maine towns representative of different types of communities in the state. These are Bangor, Paris, Norway, Camden, Rockport, Hallowell, and Brunswick.

In these communities, pedestrian and vehicle volumes were recorded along randomly chosen streets, prior to any knowledge of the crash data from those streets. Pedestrian counts, typically a minimum of two hours at each location, were expanded to approximate annual average daily volumes. Motor vehicle traffic counts were taken from Maine DOT's website

(http://www.state.me.us/mdot/traffic/1999book.pdf).

One would expect that sites with heavy use, especially a combination of high vehicle flows simultaneously with high pedestrian flows, have more pedestrian crashes than other sites. However, locations with high speeds, wide roadways, etc, may also have more crashes than other sites.

If we predict the number of crashes based on volumes alone, then locations with (statistically significant) more crashes than expected would have designs (or road-user behavior) that are less desirable than those having fewer observed crashes.

One assumption could be that locations with identical geometric designs, identical speed profiles, and identical surroundings, etc would have crash numbers proportional to traffic volumes. That would mean that if we have two identical locations in every aspect including amount of motor vehicles passing through them, except that the number of pedestrians is double at one site compared to the other, the busier location would be expected to have the double number of pedestrian crashes. However, research [6,7] has clearly shown that that assumption is not a good one. Drivers will be more alert, looking for pedestrians, at locations where there are many pedestrians. The same goes for varying vehicle volumes. At locations with high vehicle volumes, pedestrians will be more likely to look carefully before crossing. Rather than 'guess' on relationships between volume and expected number of crashes one should look for empirically 'proven' relationships. The data material here is too small for developing such relationships. Thus, I have searched the literature for already existing empirically based models. The results of these literature searches showed that there does not seem to be any validated American models for predicting the number of pedestrian crashes based on volumes. I have therefore chosen to base my estimates on a Swedish model developed by VTI and an English model.

The Swedish model [8] states:

$$\text{Number of Pedestrian Crashes per Year} = (0.00000734) \times (\text{Vehs})^{0.50} \times (\text{Peds})^{0.72}$$

where

Vehs = no. of incoming vehicles a day, and Peds = no. of passing pedestrians a day

This model applies to 'typical' traditional design. A better than average design should have fewer pedestrian crashes than this. The model has not been calibrated to account for Maine conditions. What is a typical crash rate in Maine, per pedestrian and vehicle interaction, may be higher (or lower) than in Sweden.

The English model was developed by TRL [9] and has a similar algorithm as the VTI model. It states that

$$\text{Number of Pedestrian Crashes per Year} = (0.028) \times (\text{Vehs} \times \text{Peds})^{0.53}$$

where

Vehs = thousands of incoming vehicles a day, Peds = thousands of passing pedestrians a day

The model is based on the crash experience at roundabouts in the U.K. in 1974 to 1979. The study included 25 small roundabouts, 11 conventional and 14 at dual-carriageways, all in a 30 to 40 mph environment. The dual-carriageway roundabouts all have at least double entry lanes along the major road. Several of them have three or four entry lanes. Since multi-lane roundabouts are part of this mix, the safety at these sites can be assumed to be fairly close to other types of control. Single-lane roundabouts typically have lower pedestrian crash rates than stop or signal controlled junctions [10].

City of Bangor

The analysis of the different towns can be exemplified by some of the low-speed sites in Bangor.

In Bangor, there are high pedestrian volumes across Harlow Street in front of the post office since the parking lot and the building are on opposite sides of the street. The VTI model predicts 1.26 crashes in a five-year period and the TRL model predicts 0.96 crashes. The actual number of crashes is zero. That is not a statistically surprising outcome, but the low-speed, congested environment may also be the reason that this site has remained accident free for pedestrians.

The crosswalk across State Street in downtown Bangor (on top of Kenduskeag Stream) has roughly half a crash expected per five years. None were observed.

Just north of Kenduskeag Stream is a signalized intersection with Harlow Street with marked crosswalks where right-turn-on-red is not allowed. However, right-turn-on-red is still practiced to some extent, and quite a lot of jay walking takes place partly because the walk phase does not come in as quickly as many pedestrians desire. These two crosswalks across State Street are expected to have around 0.4 pedestrian crashes per 5-year period according to the two models. The actual number of reported crashes was one.

The top part of Table I-1 shows the predicted and the observed crash numbers for 12 low-speed locations in Bangor.

A similar analysis was done for 28 median and higher speed locations in Bangor, see further down in Table I-1. The detailed results can be found in the full report [2].

In conclusion, the low-speed parts of downtown Bangor have a better than average pedestrian safety. The studied semi-central arterials have about three times as many crashes as typical according to the European models. The total number of crashes is also higher in the higher-speed environment than downtown. This means that pedestrian safety projects should be focused on these higher-speed arterials rather than the areas where most pedestrian activity occurs.

Table I-1 Predicted and observed pedestrian crash numbers, Bangor CBD—low-speed and overall

Town	Route	Crosswalk at	Type[1]	Pedestrian volume	AADT	Predicted number VTI model	Predicted number TRL model	Observed number
Bangor	Harlow Street	Post office	MB2+1	2500	15000	1.26	0.96	0
Bangor	Main Street, downtown	Hammond Street	MS2+1	117	13850	0.13	0.18	0
Bangor	Main Street, downtown	Broad Street	MS2+2	616	13850	0.44	0.44	0
Bangor	Main Street, downtown	between Broad and Cross	UU1+1*	645	13850	0.46	0.45	0
Bangor	Main Street, downtown	Cross Street	MU1+1*	293	13850	0.26	0.29	0
Bangor	Main Street, downtown	between Cross and Water	UU1+1*	30	13850	0.05	0.09	0
Bangor	Main Street, downtown	Water/Middle Street	MS2+2	235	13850	0.22	0.26	1
Bangor	Main Street, downtown	between (the Tavern)	UU1+1*	352	13850	0.29	0.32	0
Bangor	Main Street, downtown	Union, northeast side	MS2+1*	323	13850	0.28	0.31	1
Bangor	US-2/State Street	Kenduskeag Stream	MU2+0	733	15000	0.52	0.50	0
Bangor	US-2/State Street	Harlow Street, SW	MS4	120	15000	0.14	0.19	1
Bangor	US-2/State Street	Harlow Street, NE	MS4	210	13000	0.20	0.24	0
SUM	Bangor—low speed					4.24	4.23	3
		Bangor, CBD				4.24	4.23	3
		Bangor, outside CBD				2.12	3.27	7
		University of Maine				3.36	3.52	2
		Rest of Penobscot County				1.09	1.23	1
		Hallowell				1.57	1.70	1
		Camden				2.68	2.62	1
		Brunswick				2.17	2.59	8
		Oxford Hills				2.15	3.68	16
		SUM Maine				19.38	22.84	39

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[1] MU=marked, uncontrolled, MB = marked, uncontrolled with barrel or similar sign, MS = marked signal, UU = unmarked, uncontrolled. Symbol is followed by number of lanes in each direction. An asterisk (*) following the number of lanes means that a lane on that approach is so wide that it can be used by two vehicles simultaneously, e.g., by a through vehicle passing a turning car that has stopped waiting for a gap.

Other Areas

The results of this section are summarized by Table I-1 and detailed results are given in the full report [2]. Studies were done at six locations in the Greater Bangor area outside the City of Bangor. The locations were expected to have roughly one crash combined according to the European models. They also experienced one crash.

Pedestrian and vehicle counts throughout the University of Maine campus were also taken. Nine crosswalks and three major roadways were covered. Only two pedestrian crashes were reported along these roads. Even two are two too many, but the number is lower than what the typical ‘European’ safety standard would be, as can be seen in Table I-1. On the other hand, one may expect ‘absolute’ safety on a campus.

In Brunswick, ten intersections/sections were covered along Maine Street, which is the main street through the downtown. There are about 2,000 pedestrians crossing Maine Street every day, and pedestrian crashes can obviously be expected. The models applied here indicate that around two to three crashes in five years would mean that the safety standard was about average for European conditions. We should not accept lower standards in this country. However, the actual number of crashes in 1994-98 was more than three times that expected number; that is statistically significantly greater than either of the expected two numbers ($p<0.01$).

For Hallowell, the VTI model predicts a total of 1.56 pedestrian crashes in the five crosswalks along US201/27/Water Street. The TRL model predicts 1.88 crashes. There are also some (about 10%) of pedestrians crossing outside the crosswalks. Adding these gives an expected total of just about two crashes per five years. If we look at the official pedestrian crashes, only one occurred. (However, one multi-vehicle crash occurred where one of the vehicles went across the street and hit a person on the sidewalk. This injury is not included since it did not involve a crossing pedestrian.) That indicates that this environment is about as safe as what typically can be expected, at least in Europe. The low-speed is a positive factor, but the environment may be more complex than desirable.

The pedestrian safety in the towns of Norway and South Paris seems to be lower than in any of the other areas included in these studies. About five times as many crashes were observed as what would be expected for those volumes. One signalized intersection and 13 crosswalks and 12 sections between them were included along Main Street in Norway. In South Paris, all of Main Street was covered. This meant that nine separate areas were analyzed. Both Main Streets are wide State highways with high speeds outside the town centers.

The total number of expected crashes in four crosswalks along Main Street in Camden—one of the most congested tourist towns in Maine—is, according to the VTI model 2.68. There is also an estimated 280 pedestrians a day crossing this section of US Route 1 outside crosswalks between Mountain Street and Oak Street. One would expect these pedestrians to be involved in another 0.25 crashes per 5-year period for a total of 2.93 crashes. The TRL model predicts 2.62 pedestrian crashes in crosswalks in Camden, an almost identical number compared to the 2.68 predicted by the VTI model. The observed number of pedestrian crashes was only one. In other words, the environment (and design) in Camden seems to be somewhat safer than the typical environment. The numbers are small, and there is a 20% statistical chance that zero or one crash would occur when

2.93 are expected. Still, the low-speed environment may certainly also explain the low number of actual crashes.

It is clear that the studied locations, on average, have more crashes than ‘typical’ European locations would have. The difference between the total observed number and that predicted by the VTI model is statistically significant (p=0.00005), so is the difference between the observed number and that predicted by the TRL model (p=0.001). The predictions by the two models themselves also deviate somewhat from each other, but this deviation (of approximately 17%) is far from statistically significant. In other words, the models seem to perform well, it is the safety of the locations that is not doing so well. However, the low-speed environments of downtown Bangor, Hallowell and Camden as well as the University of Maine campus have better safety than the models predict.

Explanatory Variables

It is difficult to analyze the effect of different layout variables for as few sites as we have here. There also is a risk that variables covariate with one another. Still, below that is what is attempted.

Crosswalk or Not?

If we compare marked crosswalks at non-signalized locations to unmarked crosswalks, we get, on average, higher safety at marked than unmarked locations. Unmarked locations had 17 observed crashes whereas the two models predicted 4.92 and 6.60 respectively. That means that there were 2.95 times more crashes than predicted. Marked, unsignalized crosswalks without barrels saw 15 crashes; 1.58 times the average of 8.88 and 10.09 predicted. This does not necessarily mean that marking a crosswalk improves the safety. It may also be that ‘safer’ locations—e.g., low-speed locations—are marked. The only ‘normative’ variables considered in the predictive calculations above are pedestrian and vehicle volumes. Still, for the selected sample, marked crosswalks seem to be about 46% safer.

Signal

Marked crosswalks are less safe when signalized than when being uncontrolled according to the data. Signalized crosswalks had 6 crashes which is 1.99 times as many as predicted (2.67 and 3.35). Again, it may be other variables that covariate with signalization. For our sample, signalized locations are 26% more dangerous than unsignalized ones.

Barrel

Comparing marked, unsignalized crosswalks with and without central barrels/cones shows that the locations with the devices are 78% safer than the ones lacking them. (Locations with the barrels had 1 crash whereas 2.67 and 3.35 were predicted by the two models. Again, it is not necessarily the cones/barrels that make these locations safer but a covariance with other variables. Also, numbers are small.

Speed, Number of lanes and Control

The speed limit at more or less every location included here is 25 mph (40 km/h). However, actual speeds vary quite a bit. I measured the daytime speeds at all locations. I have divided the locations into low, medium and high-speed ones. The low-speed locations have average speeds below 20 mph (32 km/h), medium-speed locations have average speeds in the 20 to 25 mph (32-40 km/h) interval, and high-speed locations have average speeds above 25 mph (40 km/h).

Table I-2 shows the results. Statistically significant deviances are found for a few layouts. Clearly more dangerous than expected are the wide, medium-speed, unmarked locations (p=0.0005) and the wide, high-speed, unmarked locations (p=0.000003). Also more dangerous are medium-speed, wide, marked locations (p=0.03) and high-speed, marked, wide locations (p=0.0002)

Not statistically significant deviances were found for several layouts. Somewhat more dangerous than expected (predicted) are medium-speed unmarked narrow streets (p=0.08) and high-speed unmarked narrow streets (p=0.14). The low-speed unmarked locations are safer than expected (p=0.07).

None of the signalized cells deviate from the predicted in a statistically significant way. However, the low-speed signalized locations are somewhat more dangerous than expected whereas the non-signalized low-speed locations summed together are safer than expected (p=0.014). There was not a single pedestrian crash in an unmarked, non-signalized, low-speed location.

Risk

Crash data without exposure doesn't say much about risk. Therefore, crash numbers should be correlated to volumes. That can be done as outlined above or just by calculating crash rates, i.e., number of pedestrian crashes per crossing pedestrian. This latter rate is what is of interest to the pedestrian. For example, an injured pedestrian will be no happier if he/she is hit by a car on a road carrying 10,000 vehicles a day compared to on a road with 10 vehicles a day. In other words, the statistical risk seen from a pedestrian's perspective is not influenced by the vehicle volume; and should be calculated as the expected number of pedestrian crashes divided by the number of pedestrians.

Using the data presented in previous sections of this chapter gives us crash rates per crossing pedestrian. We conclude that the risk varies a lot between the different towns. It is very low (0-0.15 per million pedestrians) for people crossing the [studied] streets of the University of Maine campus and the congested Route 1 through Camden. The risk is reasonably low (0.25 to 0.33 per million crossings) in downtown Bangor and Hallowell as well as at the other locations studied in the Greater Bangor area. The risk is high (2-3 per million pedestrians) on the outer sections of State Street and Main Street in Bangor as well as for pedestrians crossing Maine Street in Brunswick. The risk is very high (above 5 per million pedestrians) on the Main Streets in Norway and South Paris. These streets are non-congested state highways going through the town centers.

SURVEY

A total of 308 students and their parents participated in a survey in the seven communities studied in detail. Results for each town are shown in the main report of this project [2].

Table I-2 Predicted and observed pedestrian crashes by typical speed, street width and control

	Speed	2-lane		>2-lane	
		Average number predicted by the VTI model and the TRL model for five years	Observed number of crashes in five years	Average number predicted by the VTI model and the TRL model for five years	Observed number of crashes in five years
Unmarked location	low	2.63	0	0.00	0
	med	0.08	1	2.21	9
	high	0.65	2	0.21	5
Marked crosswalk, no signal, no barrel	low	5.43	3	0.20	0
	med	0.00	0	2.29	6
	high	1.04	1	0.53	5
Marked crosswalk, no signal, with barrel	low	1.76	1	1.11	0
	med	0.00	0	0.00	0
	high	0.00	0	0.00	0
Marked crosswalk, signal	low	0.00	0	1.52	3
	med	0.25	1	0.93	1
	high	0.22	0	0.11	1

Risks to Children

Parents were asked, “When (if) your child walks/rides a bike to school, do you worry that he/she may be a) involved in a traffic accident; b) assaulted by other child; c) assaulted by an adult. The results from every community shows that traffic is more of a worry than other personal safety issues, as illustrated by Table I-3 for Norway/Paris.

Encouragement and Use of Countermeasures

The parents' responses to the question: "What could the town do to encourage you to walk more on, or along, public streets and roads?" shows that the most popular measure would be to build more sidewalks and pave shoulders. A high number of respondents also want more streetlights and more police enforcement. Roughly half of all parents want to see more marked crosswalks. Almost as high a percentage want barrels or cones placed in the middle of the street. About one in three want more signalized locations and more crossing guards.

Table I-3. Parents' opinion on risks their child is exposed to when walking/bicycling

	Elementary school			High school		
	Traffic	Assault by child	Assault by adult	Traffic	Assault by child	Assault by adult
worries frequently	19%	8%	11%	9%	0%	4%
worries sometimes	18%	10%	18%	17%	13%	0%
worries but only rarely	13%	15%	13%	30%	22%	35%
total worries	50%	33%	42%	56%	35%	39%

OVERALL CONCLUSIONS AND DISCUSSION

It is human to make mistakes, no matter if you are a pedestrian or a driver. The consequences of mistakes can be deadly when we mix vulnerable human beings with cars and trucks. It may even be human to break rules at times, and only in an ideal world could we regulate away all problems. Enforcement of existing rules governing safe behavior has possibilities to improve pedestrian safety—but probably only marginally. That is both because intense enough police enforcement is expensive and because we break rules we typically follow when we need the rules the most, when we are in an extreme hurry, or under the influence of, e.g., alcohol.

To a large degree, the pedestrian safety problem in Maine is focused to our arterials, where highways pass through villages and towns. There are at least three possible ways of dealing with the problem of pedestrians and vehicles sharing the same space. The first approach was practiced about a hundred years ago in many communities. That was to give pedestrians true priority. A man carrying a red flag had to walk ahead of any motor vehicle, and the speed obviously would be modest. The second approach is that drivers have absolute priority, especially on rural roads but also on arterials going through built-up areas. To be safe, pedestrians must stay away from roads, at least when cars are approaching. Crossing a street is a risky business of which the pedestrian must take full responsibility. Reality today, is close to this second approach even if pedestrians formally have the right of way in marked crosswalks and at signalized intersections. To have the practical right of way only sometimes means that a pedestrian always must wait for all nearby cars to come to full stops before it is safe to step into a crosswalk. The third approach is one were drivers and pedestrians are equal partners. The pedestrian is no longer seen as a nuisance or adversary to vehicular traffic and the pedestrian therefore doesn't need to be protected from drivers in the same way. In everyday life, for example in a grocery line, we do not push our way ahead just because we are heavier or more powerful. Why couldn't it be the same way in traffic—in areas were pedestrians and cars have equal rights—as they, in my opinion, should have on Main Street in a village center? And rather than compete for space the two groups ought to voluntarily offer each other space as civilized human beings do. To make this interaction possible—and likely—vehicle speeds must be very low. This study confirms that speed is the most important predictor of pedestrian safety.

It also becomes obvious that long-distance travelers and long-haul freight operators will get frustrated if they frequently have to interact with slow-moving pedestrians. The goal should therefore be that our National Highway System (NHS) should have alternative routes bypassing towns and villages. However, many travelers along the NHS roads will want to access businesses in those towns and villages, and business alternatives should therefore also be easily reached. Junctions should be built so that it is equally easy to head onto the bypass as onto the business alternative. One junction type offering this quality is the modern roundabout.

Pedestrians and bicyclists are sometimes referred to as vulnerable road users. It should be remembered that there are also extra-vulnerable road users, i.e., the very young, the very old, the visually impaired, the mobility impaired, and the mentally challenged who also have a right to get to their destinations as independently as possible.

Pedestrians often share space with motorists. When walking along highways and streets, pedestrians at least sometimes have adequate sidewalks or shoulders, but, especially in the wintertime, the roadway may be the only practically usable area. And, pedestrians often need to cross roadways in order to reach desired destinations. It is important that pedestrians are provided with safe locations for such crossings. And those locations must be along the shortest route for the pedestrian; else we will not get a substantial number to cross at the intended locations. For example, at the roundabout in Little Falls, Gorham marked crosswalks are located approximately 15 to 20 meters (50 to 65 ft) upstream from the respective yield lines. Only 23% of observed pedestrians took the detour to the marked crosswalk. It may be possible to increase that percentage with education and enforcement but, basically, it is very hard to restrict pedestrian movements without putting up physical barriers. And pedestrians have a tendency to get through or around even such barriers.

A high percentage of urban pedestrian accidents occur in marked crosswalks. Marked crosswalks have the advantages of telling pedestrians where it is 'safe' to cross and telling drivers where they can expect pedestrians. Still, the risk of an accident may not be lower in marked crosswalks than away from them. The safest location according to this study is the non-signalized, unmarked, low-speed one. The reason marking crosswalks gives limited benefits is that many motorists do not even notice a crosswalk, and if they do, they do not modify their behavior in a substantial way. Many pedestrians, however, feel secure in the crosswalk and assume that all approaching drivers will yield to them. Some towns put up barrels or cones to notify drivers that they are approaching a crosswalk. Most of these devices are not approved by MUTCD. Also, such devices may cause injuries if they are hit by a vehicle and 'torpedoed' at pedestrians or other traffic. However, they may also improve the safety by making drivers notice the existence of a crosswalk as well as provide a refuge area in the middle of the street. The data here support the latter. Flashing lights and the recently MUTCD-approved fluorescent signs may also make crosswalks noticed by a majority of drivers, but these devices do not provide for a refuge area where pedestrians feel that they 'safely' can wait rather than hurry across in front of vehicles on the second half of the road.

So what can we then do to further improve pedestrian safety in Maine? We have the four E’s to work with. That is education, enforcement, encouragement and engineering. These concepts can be applied individually or in some type of combination.

When it comes to education, my belief used to be very optimistic. But my review of literature within this project [2] has shown that there are very few evaluated programs indicating any clear benefits. I could summarize my present belief with that it is possible to sell ideas and products, e.g., stationary bikes, to people but very hard to make them actually use such equipment consistently. In the same way, we can have people “buy into” good behavior, but they may not follow those recommendations when there is significant resistance to it; when it is easier not to. And especially not when they are in a hurry.

Enforcement has potentials. Unfortunately, high-level enforcement is very expensive and enough of a focus on pedestrian safety to have enforcement make significant improvements is unlikely [2].

Encouragement by rewarding people behaving safely (or legally) has similar problems as enforcement. It may be effective in theory, but in practice would be very hard to implement. Another type of encouragement that has more potential is to provide safe facilities to pedestrians. Then, hopefully, pedestrians will gravitate towards these facilities and away from dangerous locations.

Engineering, sometimes in combination with education and enforcement, is probably the way to clearly improved pedestrian safety. But all engineering measures are not effective. We know, e.g., that rumble strips prior to crosswalks do not seem to be effective [2]. But we also know that there are several measures that are very effective. That includes installation of refuge islands, adding warning signs that are activated only when a pedestrian is present, making the road narrower and reducing the travel speeds of in particular the faster vehicles. Also, barrels and cones in the roadway seem to act as good substitutes for refuge islands where it is impractical to install permanent islands.

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