SOME INSIGHTS ON ROADWAY INFRASTRUCTURE DESIGN FOR SAFE ELDERLY PEDESTRIAN TRAVEL

Venkataraman N. SHANKAR
Associate Professor
Department of Civil and Environmental Engineering
Pennsylvania State University
PA, USA

Sittipan SITTIKARIYA
Department of Civil and Environmental Engineering
Pennsylvania State University
PA, USA

Ming-Bang SHYU
Department of Civil and Environmental Engineering
Pennsylvania State University
PA, USA

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This paper presents insights into the relationship between road infrastructure and elderly pedestrian involvement in traffic accidents. We combine insights from empirical studies involving the probability of a pedestrian accident with insights from studies involving the probability of injuries to elderly pedestrians who are involved in vehicle-pedestrian accidents. The combined insights provide some direction to the methodology for identifying non-motorized improvements for supporting safe elderly travel.

The results of the study indicate that after controlling for vehicle volumes, road infrastructure variables posing the greatest risk of pedestrian accidents in urban corridors include the presence of center turning lanes, traffic signal spacing exceeding 0.5 miles and roadway illumination. Center turning lanes indicate the presence of long corridors which may induce elderly pedestrians especially to attempt to cross roadways mid-block using center turning lane sections as refuges. Presence of traffic signals provides reduced pedestrian accident risk if the spacing is less than 0.5 miles. Especially for elderly pedestrians, the availability of protected crossings at signalized intersections is important considering the fact they cannot travel long block lengths in order to use signalized crossings. Presence of continuous roadway lighting decreases elderly pedestrian accident risk.

The results also show the greatest impacts on injury severity probabilities are from the occurrence of elderly pedestrian accidents in non-intersection locations. Specifically, if elderly pedestrians are involved in marked crosswalk accidents, the probability of lower severity injury is higher; in contrast, if they are involved in unmarked, non-intersection locations such as mid-blocks, the probability of high severity injury is higher.

We obtained these results through the use of Bayesian analysis. Bayesian analysis allows us to use subjective prior information on the distribution of parameters in combination with information from the observed data. The advantage of Bayesian analysis in the assessment of key road variables on safe elderly travel is that we can examine the robustness of results.

Key Words: Pedestrians, Bayesian, Frequency, Severity, Logit

1. INTRODUCTION

While programming roadway projects to accommodate non-motorized safety, the Washington State Department of Transportation (WSDOT) intends to use a pro-active, accident-potential approach rather than solely relying on observed counts. Prior research[1] developed an accident frequency model of crashes involving pedestrians and motorized traffic which accommodates excess zero counts, a typical problem in accident frequency analysis. The issue of excess zero counts relates to the problem of zero-valued observations occurring in excess of what is expected of a lifetime count process. Other documented studies regarding this issue in the roadway safety area have confined their attention to vehicular accidents[2]. While previous accident-frequency research[3,4] has provided insight into the factors determining accident frequencies, it is important to realize that such traditional applications of Poisson and the negative binomial distributions do not address the possibility that more than one underlying process may be affecting accident frequency likelihoods.

In the context of non-motorized safety, this limitation may have important implications, i.e., misidentification of what is truly a hazardous location, when one factors in higher-variability in non-motorized demand. To address such limitations, one may view non-motorized accident frequencies as belonging to two states[1]. One state is when the roadway section from which accident data is being gathered is inherently safe, i.e., follows a zero-accident lifetime regime. In theory, accidents will never occur when the roadway section is in this zero-accident state. The second state is an accident state where accident frequencies follow some known distribution, e.g., the Poisson or negative binomial distribution. The pedestrian accident frequency models specified by previous research[1] take these two-stages into account by using zero-inflated Poisson and zero-inflated negative binomial models.

In addition, little research has been conducted to comprehensively examine the contributing factors affecting the severity of non-motorized accidents. Thus the topic of this paper is to formulate a cogent basis for non-motorized safety evaluation, by adding to the framework, models of injury severity and in this way build on the accident frequency work of Shankar et al.[1] to form a comprehensive picture, based on both accident frequency and severity. Work on elderly pedestrian severity[5-7] has been conducted in a variety of forums especially in the medical sciences and transportation engineering fields.

The empirical basis consists of pedestrian accident data. Note that non-motorized (in this paper) implies the presence of at least one non-motorized mode such as walking, bicycling or other human-powered vehicles. Pedestrian accident data includes accidents involving pedestrians with bicycles and powered vehicular traffic.

To gain comprehensive insight, multivariate assessments of non-motorized safety at both the unconditional (whether or not a non-motorized accident will occur) and conditional levels (given that a non-motorized accident occurred) are required. The unconditional level is also referred to as the frequency level, where the focus is on the number of accidents expected to occur in a section in a given period of time. The attribute set, potentially affecting accident propensities at the frequency level, encompasses all roadway sections. At the conditional level, also referred to as the individual accident severity level, the attribute set consists of accident-specific characteristics because of the conditioning of the physical consequence of the accident on the accident having happened under a given set of circumstances. This research develops an injury severity model at the conditional level.

2. METHODOLOGY AND RATIONALE

The analysis of individual accident severity involves the conditional assessment of the impact of a non-motorized accident in terms of pedestrian injury. The frequency and severity datasets are mutually exclusive and of different aggregation levels. A conditional model of accident severity (i.e., conditioned on the fact that an accident has occurred) is proposed. Generically, severity of an accident is specified to be one of five discrete categories: 1) property damage only, 2) possible injury, 3) non-disabling injury, 4) disabling injury, and 5) fatality. The determination of this severity is made by the officer at the scene of the accident and reported on the Washington State accident report forms. In the context of pedestrian accidents, one is likely to observe only four distinct manifestations, i.e., the property damage consequence is non-existent. In our case, we are interested in the probability of high or low injury severity of elderly involved in accidents with motorized vehicles. In our study, low injury severity is defined as severity that is either a possible injury or a non-disabling injury suffered by the elderly pedestrian. High severity is defined as an injury that is either disabling or fatal. As a result, we focus on the binary logit model of elderly pedestrian severity. Prior work[8,9] on severity in traffic accident contexts includes dealing with severity as multinomial discrete outcomes.

In order to go about estimating a Bayesian binary logit model of elderly pedestrian severity, we briefly describe the Bayesian principle first. We are interested in the distribution of parameters “ ” conditional on the observed data “*y*” such that:

$$p(\theta|y) = \frac{p(y|\theta)\,p(\theta)}{p(y)} \quad \text{..(1)}$$

In equation 1, *p*( ) is the prior distribution of the parameters, representing accumulated knowledge about the density of “ ” prior to the data being observed. Alternatively, one can characterize *p*( ) as a measure of our uncertainty about the parameter space. This is precisely what we are interested in exploring in this paper in terms of its impact on the “sign” of roadway variables on elderly pedestrian safety. The first term in the right hand side of equation 1 is the likelihood density which is used in classical frequentist estimation. The likelihood method in and of itself in the elderly pedestrian safety case can provide no information on the uncertainty of “ .” *The uncertainty issue in elderly pedestrian travel and safety is critical in our understanding of factors that affect elderly mobility. If the findings on roadway variables indicate that certain variables are of the same sign regardless of assumptions of the prior that provides more direction to research those variables further.* The purpose of this study is hence to provide such direction. In this light, several commonly available roadway variables such as presence of marked crosswalks, availability of shoulders, roadway lighting, availability of traffic signals, length of block between traffic signals or marked crosswalks, availability of sidewalks and presence of center turn lanes were available in our study to examine their impact on elderly pedestrian accident frequency and severity. Some are hypothesized to be associated with frequency, and some are likely to be associated in terms of severity of injury. Our prior studies have shown that signal spacing, presence of center turn lanes and presence of roadway lighting are statistically significant indicators of pedestrian accident frequencies. Specifically we found in an earlier study[1] that as signal spacing increases, the probability of pedestrian accidents increases, supporting the view that shorter uncontrolled block lengths are safer for pedestrian travel. In addition, it was also found that presence of center turn lanes was associated with higher pedestrian accident occurrences, supporting the view that center turn lanes provide a mid-roadway refuge point for pedestrians inducing them to take greater risks in crossing at unmarked locations. Presence of roadway lighting was associated with decreased probability of pedestrian accident frequency, supporting the view that continuous lighting in pedestrian travel corridors is essential for their safety. Given our conclusions on pedestrian frequency associations, we now examine the variables that are associated with pedestrian severity. In order to conduct this assessment, we formulate a Bayesian structure where

$$\lambda(\theta; y, z) \propto \prod_{i=1}^{n} F(z_i\theta)^{y_i}\left[1 - F(z_i\theta)^{1-y_i}\right] \quad (2)$$

$$\log\left(\frac{p_i}{1-p_i}\right) = z_i\theta \quad (3)$$

$$\begin{matrix}\theta \sim N(0, \tau) \\ \tau \sim \Gamma(0.05, 0.05)\end{matrix} \quad (4)$$

Equation 2 represents the likelihood density for the binary severity outcome with y_i representing the severity outcome with value one if observed severity is low and zero if observed severity is high, z_i representing the vector of roadway variables and representing a vector of estimable parameters. Equation 3 represents the logit link function that relates the odds-ratio of low injury severity to high injury severity with roadway variables given in the right hand side of the equation. Equation 4 represents the prior density of the parameter vector . The vector is defined as a normal prior with mean zero and with varying precision . The hierarchy of the structure is captured by allowing the precision parameter to follow a gamma distribution. This is a reasonable way of assigning priors to the elderly pedestrian context so that precisions are allowed to be different for different roadway variables. By so doing, we can examine the impact of priors on the uncertainty of key parameters related to roadway design. Estimation of the Bayesian model is conducted using Markov Chain Monte Carlo (MCMC) available in the Winbugs program.

An alternative way of assigning priors is to simplify the above structure to have the same precisions for all parameters. In order to do this, we change equation 4 for the parameter prior as follows:

$$\theta \sim N(0, 0.001) \quad (5)$$

Per equation 5, we have effectively uniform priors on the parameter vector.

3. EMPIRICAL SETTING

To facilitate the merging of results on frequency and severity analyses, the dataset used for the research in Shankar et al.[1] was used. From this dataset, non-motorized accident frequencies involving the elderly were sampled for the same time-period (1991–1994) as used in the 2003 study. Comprehensive and consistent geometric, driver, pedestrian and vehicular data was available for 153 of those accidents. Table 1 shows summary statistics of key variables used in the injury severity model.

To be sure that the unique interaction between automobile and pedestrian in a collision is addressed, only collisions involving single automobiles and pedestrians are examined.

Table 1 Summary statistics of key attributes

Pedestrian Injury			
Variable	Count		Percent
Possible injury	27		17.65
No disabling injury	73		47.71
Disabling injury	31		20.26
Fatal injury	22		14.38
Exogenous Attributes			
Variable	Minimum	Maximum	Mean
Male pedestrian	0	1	0.53
Age	65	92	74.67
Night-time accidents indicator	0	1	0.20
Dry roadway surface indicator	0	1	0.76
Wet roadway surface indicator	0	1	0.21
Clear weather indicator	0	1	0.84
Raining indicator	0	1	0.15
Rural area indicator	0	1	0.20

4. FINDINGS

Table 2 presents estimation results for the Bayesian logit model of elderly pedestrian accident injury severity in automobile-pedestrian collisions. Classical likelihood estimates are provided in the table for comparison. As noted in the table, the non-hierarchical prior with the same precision for all parameters compares closely with the Bayesian estimates. As noted in the table, several variables are associated with elderly pedestrian severity. The marked crosswalk and shoulder location variable alone is associated with low severity while variables such as non-intersection location indicator, rural location indicator, lighting indicator (dark with lighting on), and vehicle movement indicators at signalized intersections are associated with high severity. Vehicle movement indicators at signalized intersections are associated with high severity of elderly injury for several reasons. The elderly may expect vehicles to stop in response to their presence on the roadway even when they are at fault while crossing on a non-walk signal. Intersections are also more demanding of pedestrian cognition – the elderly in particular have to process information on potential conflicts from several vehicle movements. Coupled with poor reactions in the case of inadvertent presence on the traveled way, such situations predispose the elderly to higher severities even at signalized intersections. It may be useful to consider pedestrian only signal phases where elderly activity is significant, and provided with sufficient clarity for them to obey signal crossings. Rural locations are likely to involve high severity elderly accidents for several reasons – rural locations are usually not built to full design standards, and second, the availability of emergency medical care is not timely. Given the physiological characteristics of the elderly, a minor injury can potentially progress into a major injury without timely medical intervention.

Uncertainty in parameters

As shown in Table 2, we are able to note the trend in parameter signs and magnitudes as their credibility levels increase from 50 percent to 97.5 percent. The mean value is the value of the parameter typically reported in most studies, including classical frequentist studies. By examining other credibility levels, we can note with less uncertainty the behavior of parameters. This finding allows us to identify variables for further research in the

Table 2 Comparison of classical maximum likelihood and non-hierarchical Bayesian estimates of elderly pedestrian severity risk factors

Variable[††]	Classic Approach		Non-Hierarchical Bayesian Approach			
	Mean (S.E.)*	t-statistic	Mean (S.E.)*	t-statistic	Credibility Percentile of Coefficient	
					50%	97.5%
Constant	1.804 (0.437)	4.126	1.897 (0.453)	4.190	1.876	2.843
Pedestrian location indicator (1 if pedestrian was at marked crosswalk and shoulder; 0 otherwise)	0.754 (0.557)	1.354	0.808 (0.584)	1.385	0.797	1.990
Vehicle movement indicator 1 (1 if vehicle was going through signalized intersection at the time of accident; 0 otherwise)	-0.939 (0.646)	-1.453	-0.967 (0.679)	-1.424	0.960	0.387
Vehicle movement indicator 2 (1 if vehicle was making a turn at the signalized intersection at the time of accident; 0 otherwise)	-1.277 (0.663)	-1.925	-1.361 (0.692)	-1.966	-1.344	-0.047
Rural area indicator (1 if accident occurred in the rural area; 0 otherwise)	-0.752 (0.471)	-1.598	-0.777 (0.486)	-1.599	-0.777	0.191
Location indicator (1 if location of accident was not intersection; 0 otherwise)	-1.679 (0.527)	-3.187	-1.775 (0.546)	-3.250	-1.764	-0.725
Surface condition indicator (1 if roadway surface was wet at the time of accident; 0 otherwise)	-0.886 (0.454)	-1.952	-0.936 (0.466)	-2.008	-0.936	-0.024
Light indicator (1 if accident occurred in the lighted section at night; 0 otherwise)	-0.818 (0.561)	-1.457	-0.872 (0.578)	-1.508	-0.864	0.242

[††] All variables specific to low severity
* S.E. means Standard Error

context of elderly pedestrian safety.

Out of the seven variables that were found to be statistically significant, two variables maintained their "sign" as they related to injury severity. The marked crosswalk or shoulder location variable was consistently associated with low elderly pedestrian severity regardless of the precision of the prior. The non-intersection location variable that captures elderly pedestrian accidents in the traveled way (not on shoulder) is also consistent in its "sign" by being associated with high severity. All other variables change signs as the credibility level increases. Table 3 shows the comparison of hierarchical and non-hierarchical Bayes estimates of roadway parameters. As can be noted from this table, significant variations in parameter estimates occur. With precisions allowed to vary across parameters, mean parameter magnitudes shrink under the hierarchical prior. This finding illustrates the need for examining a variety of priors including non-informative ones in order to ensure our inferences on roadway variable effects are consistent.

Table 4 summarizes the conclusions from the frequency and severity analyses and identifies variables with high certainty of consistent association with elderly pedestrian accident involvement.

5. CONCLUSIONS

This paper presents insights into the relationship between road infrastructure and elderly pedestrian involvement in traffic accidents. We combine insights from empirical studies involving the probability of a pedestrian accident with insights from studies involving the probability of injuries to elderly pedestrians who are involved in vehicle-pedestrian accidents. The combined insights provide some direction to the methodology for identifying non-motorized improvements for supporting safe elderly travel.

The results of the study indicate that after controlling for vehicle volumes, road infrastructure variables posing the greatest risk of pedestrian accidents in urban

Table 3 Comparison of hierarchical and non-hierarchical Bayesian estimates of elderly pedestrian severity risk factors

Variable††	Hierarchical Bayesian Approach				Non-Hierarchical Bayesian Approach			
	Mean (S.E.)*	t-statistic	Credibility Percentile of Coefficient		Mean (S.E.)*	t-statistic	Credibility Percentile of Coefficient	
			50%	97.5%			50%	97.5%
Constant	1.422 (0.400)	3.554	1.405	2.254	1.897 (0.453)	4.190	1.876	2.843
Pedestrian location indicator (1 if pedestrian was at marked crosswalk and shoulder; 0 otherwise)	0.440 (0.472)	0.933	0.388	1.489	0.808 (0.584)	1.385	0.797	1.990
Vehicle movement indicator 1 (1 if vehicle was going through signalized intersection at the time of accident; 0 otherwise)	-0.409 (0.536)	-0.764	-0.337	0.500	-0.967 (0.679)	-1.424	-0.960	0.387
Vehicle movement indicator 2 (1 if vehicle was making a turn at the signalized intersection at the time of accident; 0 otherwise)	-0.571 (0.559)	-1.021	-0.499	0.335	-1.361 (0.692)	-1.966	-1.344	-0.047
Rural area indicator (1 if accident occurred in the rural area; 0 otherwise)	-0.475 (0.427)	-1.112	-0.445	0.276	-0.777 (0.486)	-1.599	-0.777	0.191
Location indicator (1 if location of accident was not intersection; 0 otherwise)	-1.381 (0.523)	-2.643	-1.375	-0.378	-1.775 (0.546)	-3.250	-1.764	-0.725
Surface condition indicator (1 if roadway surface was wet at the time of accident; 0 otherwise)	-0.676 (0.450)	-1.503	-0.659	0.117	-0.936 (0.466)	-2.008	-0.936	-0.024
Light indicator (1 if accident occurred in the lighted section at night; 0 otherwise)	-0.600 (0.531)	-1.130	-0.547	0.290	-0.872 (0.578)	-1.508	-0.864	0.242

†† All variables specific to low severity
* S.E. means Standard Error

Table 4 Statistically significant roadway variables associated with elderly pedestrian accident frequency and severity

Roadway Variables Associated with Elderly Pedestrian-Vehicle Accident Frequency	Roadway Variables Associated with Elderly Injury Severity in Pedestrian-Vehicle Accidents
Presence of center turn lanes increases elderly pedestrian risk of involvement in accidents with vehicles	Elderly pedestrians involved in accidents in marked crosswalks and shoulders are less likely to be severely injured compared to other locations
Traffic signal spacing less than 0.5 miles decreases elderly pedestrian involvement in accidents with vehicles	Elderly pedestrians involved in non-intersection locations are more likely to be severely injured compared to signalized intersections
Presence of roadway lighting decreases elderly pedestrian risk of involvement in accidents with vehicles	Elderly pedestrians involved in night-time accidents at locations with roadway lighting are more likely to be highly injured than during the day
	Elderly pedestrians are more likely to be severely injured in accidents with vehicles on wet pavements
	Elderly pedestrians are more likely to be severely injured in rural locations

corridors include the presence of center turning lanes, traffic signal spacing exceeding 0.5 miles and roadway illumination. Center turning lanes indicate the presence of long corridors which may induce elderly pedestrians especially to attempt to cross roadways mid-block using center turning lane sections as refuges. Presence of traffic signals provides reduced pedestrian accident risk if the spacing is less than 0.5 miles. Especially for elderly pedestrians, the availability of protected crossings at signalized intersections is important considering the fact they cannot travel long block lengths in order to use signalized crossings.

The results also show the greatest impacts on injury severity probabilities are from the occurrence of elderly pedestrian accidents in non-intersection locations. Specifically, if elderly pedestrians are involved in marked crosswalk accidents or accidents on the shoulder, the probability of lower severity injury is higher; in contrast, if they are involved in unmarked, non-intersection locations such as mid-blocks, the probability of high severity injury is higher.

We attain these results through the use of Bayesian analysis. Bayesian analysis allows us to use subjective prior information on the distribution of parameters in combination with information from the observed data. The advantage of Bayesian analysis in the assessment of key road variables on safe elderly travel is that we can examine the sensitivity of parameters to prior information. This provides for treatment of uncertainty in inferences on parameters.

From a design standpoint, two important findings emerge – the importance of marked crosswalks and short block lengths where elderly pedestrian activity is significant.

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