Trees and Roadside Safety in U.S. Urban Settings

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Abstract

Historically, transportation planning has focused on design objectives that achieve the highest levels of safety and capacity for roads at the lowest cost. This has frequently resulted in a roadside environment that ignores inherent characteristics such as community values and environmental amenities. The recent movement to incorporate context sensitive solutions into roadway and roadside designs has led to improved functionality of roads while maintaining high levels of safety. This study analyzes national traffic accident data to address questions relating to roadside attributes that are associated with accident incidence and severity, urban and rural spatial differences in accidents, the association between trees and roadside accident severity, and the implications for roadside planning, design, and management. The analysis involved the application of descriptive, comparative, and predictive modeling statistical methods to answer the research questions. The findings show that collisions with trees are more harmful than other types of accidents, accidents in rural areas are more harmful than accidents in urban areas, collisions with fixed objects are more frequent in rural areas than in urban areas, and that the statistical models predict accident outcomes with reasonable accuracy. From these findings, several conclusions may be drawn relating to context sensitive solutions. The clear zone philosophy, while arguably effective at improving safety, fails to incorporate community values and environmental amenities into design. A more comprehensive solution is proposed, including the implementation of collaborative design processes and the exploration of the idea of trees as technology to be incorporated into safe roadside designs.

INTRODUCTION

Historically, transportation planning has focused on design objectives that achieve the highest levels of safety and capacity for a road at the lowest cost. These goals have been accomplished by building wider lanes and shoulders, along with straighter and flatter alignments. Engineering economics, a historical mainstay of engineering schools, focuses on solving problems at the lowest cost with little emphasis on cultural or other impacts.

Citizens and communities began to perceive such design motives as being external decisions that had high local impact, but did not acknowledge diverse community values. Citizens have challenged construction of wide, 1950s-style highways through open space, neighborhoods and community centers. Recently, transportation planners have implemented practices of flexible highway design and context sensitive solutions (CSS) in an effort to balance issues of concrete and community.

CSS include participatory processes that ensure that transportation projects “fit” within the landscape, are sensitive to the interests of the local community, and do not unnecessarily impact important environmental, historic, and scenic values. Friendlier highway design must not compromise safety and mobility. Some of the greatest challenges facing CSS involve reconciling community input with the values of human life and property.

Trees within the driving environment have both community value and roadside safety consequences. Trees are imbued with historical, cultural and environmental value in communities, and are often a source of disagreement in CSS. More knowledge about the role of trees in accident incidence can better inform CSS programs throughout the U.S. Additional data are needed to better understand the causes and implications of the roadside urban forest for drivers who leave the road

A study was conducted, using national traffic accident data, to address the following questions:

1. What are the roadside attributes, with regard to roadside accidents, associated with incidence and severity?
2. Are such patterns of association different between urban and rural settings?
3. What are the associations between trees and roadside accident severity?
4. What are the implications for roadside urban forest planning, design, and management?

Literature Review

Two general approaches to improving roadside safety have emerged: deterrence and mitigation. Some safety planning emphasizes the importance of keeping cars on the roadway; other approaches emphasize reducing the severity of the consequences for not doing so. Largely absent from design policy, however, is the recognition of local community values, including urban forest issues. Environmental, aesthetic, and cultural considerations deserve greater attention in future roadside design research.

In 1981, the National Transportation Safety Board released a special study about safety issues specifically involving trees, and in 1988 AASHTO released a revised roadside design guide. The latter publication promoted the concept of designing “forgiving roadsides,” yet neglected to discuss the role of trees in the new guidelines. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 brought changes. This act introduced environmental and aesthetic provisions as well as addressing safety in design, historically represented by organizations such as AASHTO and the Federal Highway Administration (FHWA) (1).

Updated in 2001, AASHTO's "Green Book" is the most current design guide and has been adopted by the FHWA as a national set of guidelines. Uniform application of these guidelines would provide national consistency for safety, but limitations persist with regard to environmental concerns (1). The 1997 FHWA Flexibility in Highway Design report provided ideas, options, and examples of ways to design more environmentally friendly highways without compromising safety and mobility. The guide stresses the importance of early public participation, identifying community interests, and fostering creative thinking as an essential component of achieving community highway design (2).

Solutions to Roadside Traffic Safety Problems

The AASHTO approach to roadside safety of removing, relocating, altering, and shielding hazards embodies a philosophy of mitigation. Clear zone policy emerged in a 1967 AASHTO report (the "Yellow Book") in response to a series of rapidly changing national standards of road safety design. Turner, et al. (3) reported that earlier there was no national consensus on what clear zones should be, that there was a diversity of clear zone development among states, and an inconsistent adoption of policies. The 1967 AASHTO report standardized clear zone definitions and guidelines.

More recently, Mak et al. (4) discussed clear zone requirements for suburban highways. Cost-benefit analysis was used to propose guidelines for clear zones that took into account conditions specific to each site. This direct cost approach is limited by the difficulties of quantifying public values for the more intangible properties of roadside features.

Community Values

Community values have been historically underrepresented in the discussion of transportation planning and safety. Roads are often treated as discrete land use entities, separate from the spaces surrounding them. In debate on the 1991 ISTEA and the National Highway Systems Act of 1995 Congress challenged the FHWA to consider environmental and cultural values, along with the traditional values of safety and mobility in the transportation decision-making process (1).

Passonneau (5) identifies two problems with the planning process: community concerns about highway proposals have been viewed as obstacles to be swept aside rather than as problems to be solved, and highway building has neglected the aesthetics of roads. Increased communication among state highway agencies, increased recognition and understanding of community and environmental interests, and a realization of opportunities for context sensitive design will be important future steps for designers (1).

Trees Benefits and Safety

Roadside trees are often considered expendable and are readily sacrificed in the face of safety concerns. Yet the urban forest provides extensive benefits and functions. Citizen based community values for trees are supported by empirical evidence. A program of studies at the

Center for Urban Forest Research confirms that trees in cities reduce storm water quantity and improve surface water quality, reduce urban heat island effects, reduce levels of pollution particulates in the air, and reduce building energy costs (6). Other investigators have found that trees affect urban economics by increasing desk worker productivity (7), residential property values (8), commercial rental rates (9), and shoppers' willingness to pay for goods in business districts (10). In the transportation context, drivers highly prefer views of trees in the roadside (11), and a view of nature while driving contributes to reduced physiological stress response in drivers (12).

Despite these extensive benefits, less research has been done on safety and trees in urban settings. Much urban policy is derived from rural precedents. An Australian study (13) is a rare example of urban policy based on research. The study intention was to address the increased number of accidents along busy roads and in areas with accident-prone geometry. The physical characteristics of different tree species were evaluated with respect to accident outcomes. A recent investigation in Palo Alto California (14) regarding accident rates associated with trees in urban highway medians found that California State policy overstated fatality and injury risk. The state-wide research resulted in a transportation agency variance that permits planting of larger trees within smaller setbacks adjacent to traffic lanes.

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Methods

Using archival national transportation accident data, a progression of statistical analyses was carried out to better understand the relationships of trees and safety in urban transportation corridors. Analysis started with a reconnaissance of available data variables, and descriptive evaluations to understand the scope of the data set. Subsequent analyses involved greater complexity and predictive capacity, and revealed some limitations associated with the data set with respect to the research questions. Year 2002 data from the National Automotive Sampling System (NASS) General Estimates System (GES) database were used for this study. These data are collected by the National Center for Statistics and Analysis, a division of the NHTSA in order to identify traffic safety problems and conduct analysis of traffic related programs (15).

Analysis Variables

A subset of the 91 GES variables was used for analysis. Selection was based on which factors other researchers had found to be salient in prior studies, as well as original hypotheses on such relationships. The dataset included:

- Vehicle mass
- Alcohol consumption
- Driver gender

- Driver age
- Speed
- Restraint use
- Weather/light conditions
- Roadway geometry (gradient and curves)
- Traffic way flow
- Number of travel lanes

Additions to this list are:

- Urban/rural spatial component
- Nonlinear speed relationship
- Accident category
- Accident type
- Injury severity

Variable Transformation and Coding

Some variables needed for analysis were not present in the data set in a useful form. Certain variables were transformed to make them meaningful and useful. Other variables were absent and values had to be inferred from the values of other variables. Transformations were performed for the following variables:

- Vehicle mass
- Weather/light conditions
- Urban/rural spatial component
- Accident category

The transformations primarily involved creating dummy variables for the categorical values of the constructed variables. Vehicle mass was inferred from recorded vehicle body type to be light, medium, or heavy weight according to Environmental Protection Agency fuel economy classifications. Weather and light were transformed from specific meteorological conditions to adverse or non-adverse driving conditions. The location of the accident was defined as being either in an urban or a rural area. No explicit measurement existed for this spatial component in the data set, so index variables were created as proxies using these attributes:

Case Attributes	**Urban Designation**	**Rural Designation**
Population of accident area	>50,000	<50,000
Road width	4 lanes or fewer	any number of lanes
Speed limit	<45MPH	> 45 MPH
Road divided?	No & with 1 or 2 way traffic	No and two way traffic
Interstate highway condition	No	Yes or no, if met population

The accident category variable was collapsed into three dummy variables: collision with non-fixed object, collision with fixed object, and non-collision accident.

Comparative Analysis

Comparative analysis examined whether a difference exists between two groups across some measure. The hypotheses tested by comparative analysis relate to the research question "Are the patterns of association involving trees and roadside accident outcomes different between urban and rural areas?" Hypotheses were structured for two-tailed tests, using chi-squared analysis of categorical variables:
Is there a significant difference between:

- General accident category and injury severity?
- Specific accident type and injury severity?
- Accident location (urban vs. rural) and injury severity?

Examining accident location, is there a difference between urban/rural sites in terms of:

- Accident category?
- Incidence of striking fixed objects?
- Incidence of striking trees?

Predictive Analysis

Predictive analysis was used for the research question, "What are the implications for roadside urban forest planning, design, and management?" More specifically for the analysis methods, the question could be phrased "What factors influence the injury outcome of accidents, by how much, and which ones really matter?" Regression analysis was performed using binomial logit and ordinal probit models.

Model Choice

The binomial logit regression is the appropriate functional form for a dependent variable having two values. As the dummy dependent variable measured whether or not an accident resulted in an injury, the model coefficients predict the likelihood that an accident will result in an injury given a set of values for the explanatory variables.

The ordinal probit regression is appropriate when the dependent variable takes several discrete values in some inherent order. In the case of the second model, the dependent variable took five values along a continuum of injury severity ranging from no injury to fatality. An advantage is that the finer resolution of the dependent variable allows for a smoother gradient in the calculation of the coefficients. For example, variables whose explanatory powers were dampened in the "all or nothing" form of the binomial logit may emerge as better predictors in the underlying scale of the ordinal probit form.

The justification for including two separate but related models in the analysis is twofold. The ordinal probit model is a refinement of the binomial logit, and shows how a different measurement of the dependent variable reveals hypothesized relationships that were suggested at the level of comparative analysis. Secondly, a comparison of the two regressions shows that, with minor exception, the theoretical model is robust to changes in specification.

Variable Transformation

The following variables were constructed or transformed for use in the models. For the binomial logit model, the dummy dependent "Injury" variable was coded as a "1" = some injury was sustained in the accident, and "0" = no injury was sustained. The choice of options for a dependent variable measuring some component of traffic safety was limited. One constraint of the GES data set, or any traffic safety data set, is that the only driving observations included are those that include an accident. There are no data recording non-accident occurrences. For the ordinal probit model, the dependent variable was coded as a scaled continuum of injury severity taking five discrete values. These were "no injury," "possible injury," "non-incapacitating injury," "incapacitating injury," and "fatality." The structures of the explanatory variables are identical for both models (Table 1).

Results and Outcomes

The findings of the analysis are presented in three sections of increasing complexity: descriptive, comparative, and predictive analysis. The general conclusions drawn may be summarized as

1. Collisions with trees are more harmful than other types of accidents
2. Accidents in rural areas are more frequent and more harmful than accidents in urban areas
3. Collisions with fixed objects are more frequent in rural areas than in urban areas
4. The binomial logit and ordinal probit models predict injury outcomes reasonably accurately, but with variation in relationship strength.

Descriptive Analysis

The GES dataset defines three general accident categories. These include

- collisions with non-fixed objects
- non-collision accidents
- collisions with fixed objects

The most frequently occurring of these accident categories is that of collisions with non-fixed objects (85.2%), followed by collisions with fixed objects (10.1%) and non-collision accidents (4.7%). The data set enumerates more specific accident types (36 total). The four most common of these overall are car vs. car collisions (78.6%), rollovers (4%), collisions with poles or signs (2.1%) and collisions with trees (1.9%). Of all accidents involving only collisions with fixed objects, the top two objects struck are poles and signs (21%) and trees (19%), followed by guardrails (11%), ditches (11%), and traffic barriers (10%).

The average speed at which accidents occurred was 34 miles per hour. The speed, if not known at the time of the accident, was either estimated or reconstructed. Of all accidents, almost twice as many occurred in rural areas (63%) than urban areas (37%).

For all crashes, the majority (61%) of accidents resulted in no injury. Furthermore, 14% resulted in possible injury, 12% resulted in a non-incapacitating injury, 12% resulted in an incapacitating injury, and 1% resulted in fatality.

Trees as a Hazard

Based on the research questions, the rate, and characteristics, of collisions of cars and trees was examined. In the GES data set, there were 1,830 recorded instances of cars striking trees. Of all these collisions, 11.8% occurred on Federal interstate highways, the remainder occurred on non-interstate roads.

One notable difference in accident characteristics between tree collisions and all accidents is that of speed. The average speed at which drivers stuck trees was 48 miles per hour. If not known, collision speeds were either estimated or reconstructed. This difference in mean accident speed (34 mph versus 48 mph) is significant ($t = 23.94$, $p < .01$), and the distributions are shown in Figure 1.

The proportion of accidents occurring in urban and rural areas was nearly identical for tree collisions as for all accidents. 39% of tree collisions occurred in urban areas while 61% occurred in rural areas. Collisions with trees were often harmful, as 61% of collisions with trees resulted in some sort of definite injury while in only 29% were the vehicle occupants unharmed.

The plurality of these accidents occurred on undivided roadways (48.8%), most commonly only with two lanes (40.3%), where the average speed limit was 52 miles per hour. This is consistent with the conclusion that a higher probability of collisions with trees exists in rural areas. Population attributes at crash sites are also consistent. Of all roadside accidents involving cars striking trees, 50.5% occurred in areas with populations less than 50,000 people. Exactly 40% occurred in areas with populations above 100,000.

Comparative Analysis

The research question, "Are there significant differences in roadside accident characteristics between urban and rural areas?" guided comparisons involving injury severity and accident location. Analysis addressed whether there are significant differences between these accident traits and injury severity:

- accident category (3 general categories)
- accident type (36 specific types)
- accident location (urban vs. rural)

Other tests examined accident location, and whether there a difference between urban/rural sites and:

- accident category?
- incidence of striking trees?
- incidence of striking fixed objects?

Accident Categories and Injury Severity

Certain accident categories do result in more serious injuries than others. Non-collision accidents are the most injurious, followed closely by collisions with fixed objects. Collisions with non-fixed objects are by far the most common accidents, but they are also the least injurious. Frequencies of injuries among the different accident categories are not independent (chi square = 7384, $p < .01$).

Accident Type and Injury Severity

Also, some accident types result in more serious injuries than others. In a comparison of the four most frequent accident types, car vs. car is not only the most common but also the least injurious. Over 63% of all accidents of this type result in no injury, while only 11% result in serious injury or fatality. By contrast, rollovers are less frequent but result in injuries or fatalities at a much higher rate. In terms of the two fixed object collision types, striking a pole or post is generally less injurious than striking a tree. While collisions with trees happen at the lowest frequency of these four accident types, the injury rates are higher than for all other accident types (Figure 3).

Accident Location and Injury Severity

Accidents in rural areas are likely to be more injurious relative to accidents in urban areas. There is a significant difference between urban and rural areas in terms of accident severity (chi square = 15, $p < .01$). All injury outcomes are more frequent in rural areas than urban areas. More accidents occur in rural areas as a percentage of all accidents, but the trends in accident severity appear similar for both rural and urban settings (Figure 4).

Accident Location and Tree Collision Incidence

There is no significant difference between urban and rural areas in relative collision incidence of cars striking trees (1.1% vs. 0.7%).

Accident Location and Accident Category

There is a significant difference between urban and rural areas in terms of collisions with fixed objects (chi square = 4.57, $p = .032$**).** Of all accidents in rural areas, 6.1% are collisions with fixed objects, whereas that type constitutes only 3.8% of urban accidents.

Predictive Modeling Results

The outcome variable for binomial logit model had no/yes values. Regressing a combination of explanatory factors against this measurement determined likely influences on the injury outcome and their relative magnitudes. The outcome variable for the ordinal probit model had five indicators of increasing injury severity. The model is mathematically similar to the logit function, but provides greater precision in estimating the coefficients in terms of the scaled dependent variable.

Model Interpretations

Due to the non-linear mathematical nature of the binomial logit model, it is difficult to evaluate its predictive power using the same measurements as for linear models. The reported Nagelkerke pseudo-R^2 value for this model is .117 and the goodness of fit chi-squared statistic is significant at the .01 level. The reported R^2_p is .642, meaning that this model correctly predicts the injury outcome about 64% of the time. The model correctly predicted that no injury would result 84% of the time, while predicting that some injury would result 37% of the time. This discrepancy reflects the fact that injuries occur in only a small percentage of all accidents and thus the distribution of accident outcomes is not normal.

The ordinal probit model results are similar to those of the binomial logit. The reported Nagelkerke pseudo-R^2 is .107 and the goodness of fit chi-squared statistic is significant at the .01 level. A comparison of the two models shows that their estimates are generally consistent across functional forms. Table 2 compares the coefficients and associated p-values of all explanatory variables across both models. Since interpretations of the coefficients are relative, they have all been normalized to the speed coefficient so they may be compared on the same scale.
For both models, the explanatory variables speed, vehicle weight, driver gender, road geometry, and accident category were significant at the 95% level or higher. For the binomial logit model, the non-linear speed variable was also significant, while for the ordinal probit model the urban/rural spatial variable was significant.

The structure of the dependent variable is a drawback of the logit model. The coding of the variable is binary; thus there is no distinction between degrees of injury severity, so a broken bone is treated the same as a fatality. The variable was structured in this way to explore whether or not there were relationships between the explanatory factors and any injury outcomes, as opposed to specific injury outcomes.

To a certain extent the vagaries of the logit model are improved upon by the ordinal probit model. This model provides the finest resolution permitted by the data set. A small number of coefficients differ between the two models but the results across both are generally consistent. Furthermore, differences that were significant in the comparative analysis, specifically the urban/rural spatial component, are also shown to be significant predictors of accident outcome in the ordinal probit model. Taken together, the two models show that the explanatory factors are robust to changes in specification.

Discussion

The research outcomes discussion will incorporate the broader ecology of accidents, roadside environments, and trees. Findings of this study have planning and policy implications for both deterrence and mitigation strategies, and future research efforts on roadside safety.

Findings Summary

Comparative analysis addressed research questions about patterns of association between urban and rural settings. Accident frequency in general is higher and injury outcome is more severe in rural areas than in urban areas. With regard to trees, the majority of tree collisions occurred on undivided, two-lane roads for which the average speed limit was 52 miles per hour. Collisions with trees are more injurious than all accidents in general. While there is no significant difference in tree collision rates between urban and rural areas, there is a significant difference between urban and rural areas for collisions with all fixed objects. The predictive models describe the associations between trees and roadside accident severity. Both models show that trees, as fixed objects, increase the likelihood of injury in accidents. Nonetheless, trees are involved in a small percentage of all accidents and collisions.

The predictive models also demonstrate that the significant explanatory factors external to the driver influencing injury outcome are road geometry, urban/rural setting, accident category, and vehicle weight. From the solution approach of deterrence, these findings would suggest that, in order to reduce the likelihood of injury in accidents, the installation of safety devices such as rumble strips, warning signs, and guardrails should be increased on rural roads. These physical deterrents would improve safety by helping to reduce the likelihood of cars leaving the roadway. Deterring consumers from buying certain types of cars is an impractical solution, but the current propensity for heavier vehicles in the United States means that drivers of those vehicles will be somewhat safer in certain types of accidents while injury risk increases for drivers of lighter vehicles.

Traditional Safety Design

From the mitigation perspective, the findings suggest that roadside objects pose a major hazard and should be removed, relocated, or shielded. The universal adoption of clear zone policies would probably reduce the likelihood of accidents resulting in injuries. Taken at face value, this would imply large-scale removal of trees from the roadside.

One superficial implication of the findings is that they provide further support for planners to pursue the mitigation approach to roadside traffic safety. This interpretation, however, is simplistic. Mitigation, while a popular design philosophy in safety engineering, is not necessarily the most comprehensive approach to reducing roadside traffic accidents. Mitigation may also be more expensive than deterrence. The attitude that improved safety should be achieved primarily through physical alteration of the landscape is specious, and limits the potential of incorporating diverse, effective, and sustainable ameliorations into the roadside environment.

Use of clear zone and forgiving roadside mitigations provide ostensibly efficient solutions. They reflect an engineering perspective focused on mechanical attributes of fixtures and assumptions about driver fallibility- people will continue to drive off the road, so the fewer and friendlier objects they can hit, the better. The majority of the research exploring roadside safety improvements has dealt with either landscape transformations or technological developments to reduce hazards to drivers. Very little attention has been paid to the role of trees.

Trees as Technology Research

Other than acknowledging their dangers as fixed objects, transportation planners have done little to develop a deeper understanding of how trees can be integrated into a safe roadside environment. Trees are regarded as fixed objects that cannot be redesigned like signposts, and since they possess no inherent technological benefit, it is often thought best to simply remove them. While outright removal may lead to a reduction in injurious roadside accidents, it does so without taking into account the benefits trees provide or their value to communities. The current engineering solutions are constrained by a narrow understanding of trees' potential contributions to the safety of the roadside environment and their role in its design.

The issue should not be simply framed as one of safety versus aesthetics and environment, but rather one of how trees can be effectively incorporated into a safe roadside design that integrates engineering, community values, and environmental amenities. Extensive research effort has been directed to developing roadside object technologies, such as breakaway poles and energy absorbing guard rails. Meanwhile, trees have been largely neglected as an engineering problem. Trees are another roadside technology. Research about the physical properties of various trees in collisions would enable roadside design that integrates plant life as a safety feature.

This concept has been applied in a limited way in Australian urban roadsides (13). The Traffic Authority of New South Wales addressed an increasing number of accidents along busy roads and in areas with accident-prone geometry by developing a tree planting policy. Minimum distances from the roadway were specified for certain types of trees, and the Authority differentiated between the physical characteristics of different tree species, namely how their physical properties related to accident outcomes. Emphasis was placed on improving driver visibility and selecting frangible (breakable) trees for stretches of road that were more prone to run-off-road accidents.

Communities and Planning

Mitigation approaches must also acknowledge community values. Policy makers may appreciate the need for community values to be reflected in roadway design, but the difficulty lies in implementation. Community values have not been systematically incorporated into the transportation engineering process or resulted in physical transformations of the roadside on a broad scale. How should planners go about taking ideas from a community and manifest them in the roadside environment? This problem begins to move away from engineering and into the realm of public affairs and social science.

A collaborative design process that brings together engineers, natural scientists, local officials, and community leaders would be a good first step in acknowledging that community and environmental values can be integrated with traffic safety. As roadway designers become increasingly aware of the diversity of interests in planning that go beyond transportation efficiency, the role of community stakeholders in the design process will gain importance. Governments will continue to build and upgrade roads, and this will invariably create conflict within communities. The contribution of public opinion to the planning process may lead to broader acceptance of public works than a unilateral declaration of the design made by a closed group of designers and officials. To this end, designers should address the need for creating roadways and roadside environments that are influenced by the desires of the communities in which they are built.

The design features of the parkway, as described by Passonneau (5), appear to effectively address many issues of traffic safety, community values, environmental benefits, and aesthetics. Parkways are a successful integration of the pavement with surroundings, as well as having safety records comparable to expressways. If drivers are introduced to a roadway setting which is scenic and has perceptible environmental amenities, which has lower traffic speeds but handles traffic volumes efficiently, and in which they feel like they had some input in developing, they are more likely to view the roadway as a part of their community and less as a mundane transportation corridor.

Additional research is needed to effectively address the interconnected issues of traffic safety, community values, environmental benefits, and aesthetics. Urban trees and forests are not only aesthetic roadside elements, but have been scientifically confirmed to provide extensive human health and welfare benefits. There are several research needs. First, greater clarity is needed in accident data collection and interpretation, so that the distinct accident circumstances of urban, suburban and rural areas can be distinguished. A limited amount of research has been done on urban trees and transportation impacts; most studies have been done locally or regionally and should be expanded in scope to address national scale issues. Additional research is needed to better understand the “technology of trees” and associated built structures. Finally, empirical investigations generally yield insights that suggest refinements if follow-on studies are undertaken (14); a commitment to tree-based research is needed in order to generate a “critical mass” of knowledge that can be translated into policy and guidelines. Better understanding of trees and urban roads will contribute to transportation systems that are more safe, handle traffic volumes efficiently and are perceived as community assets.

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List of Tables and Figures

TABLE 1 Descriptions of Variable Structures as Used in the Models

Independent Variable	Variable Structure
Vehicle Weight	3 dummy variables (heavy, midweight, lightweight), lightweight vehicles were omitted from the model as the reference case
Alcohol	Dummy variable, 1=alcohol involved, 0=not involved
Atmospheric Conditions	Dummy variable, 1=inclement weather, 0=moderate weather
Driver Gender	Dummy variable, 1=male, 0=female
Driver Age	Continuous variable, actual driver age in years
Speed	Continuous variable, actual or estimated speed in miles per hour
Speed Squared	Continuous variable, quadratic speed term
Roadway Geometry	Dummy variable, 1=curve in roadway, 0=straight roadway
Restraint Use	Dummy variable, 1=restraint used, 0=no restraint used
Accident Category	3 dummy variables (non-collision, fixed object, non-fixed object), non-fixed object category omitted from model as reference case

TABLE 2 Predictive Model Results, Coefficients Normalized to Speed

Variable	Binomial model Coefficient (P-value)	Ordinal model Coefficient (P-value)
Speed	1 (<.01)	1 (<.01)
Speed squared	.000 (<.01)	$3.24 * 10^{-4}$ (.928)
Heavyweight	-39.10 (<.01)	-54.87 (<.01)
Midweight	-8.62 (<.01)	-11.37 (.015)
Male	-6.52 (<.01)	-7.38 (.029)
Curve	-7.29 (.033)	-11.75 (.018)
Non-collision	69.52 (<.01)	100.38 (<.01)
Hit fixed object	36.10 (<.01)	53.25 (<.01)
Urban locale	-3.95 (.09)	-9.13 (<.01)
Alcohol	-1.71 (.665)	-0.75 (.897)
Adverse conditions	-4.05 (.219)	-7.35 (.123)
Age	-.048 (.653)	-0.125 (.322)
Hill	0.95 (.736)	2.0 (.630)
Restraint use	4.33 (.188)	2.88 (.554)

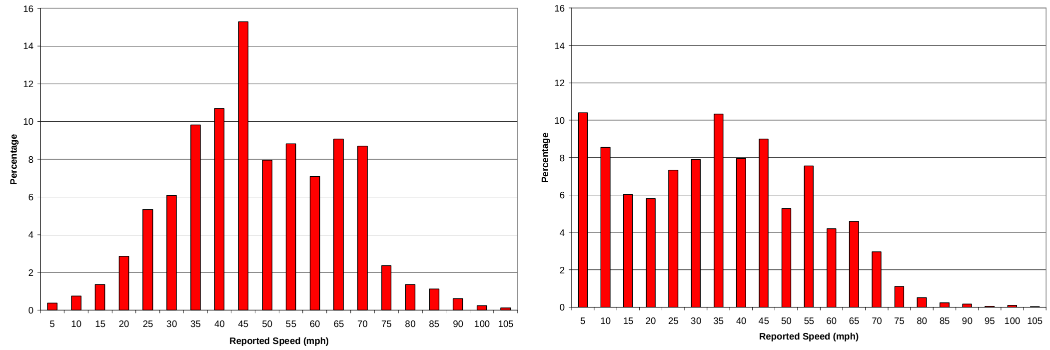

FIGURE 1 Comparison of accident speeds between tree collisions and all accidents (%).

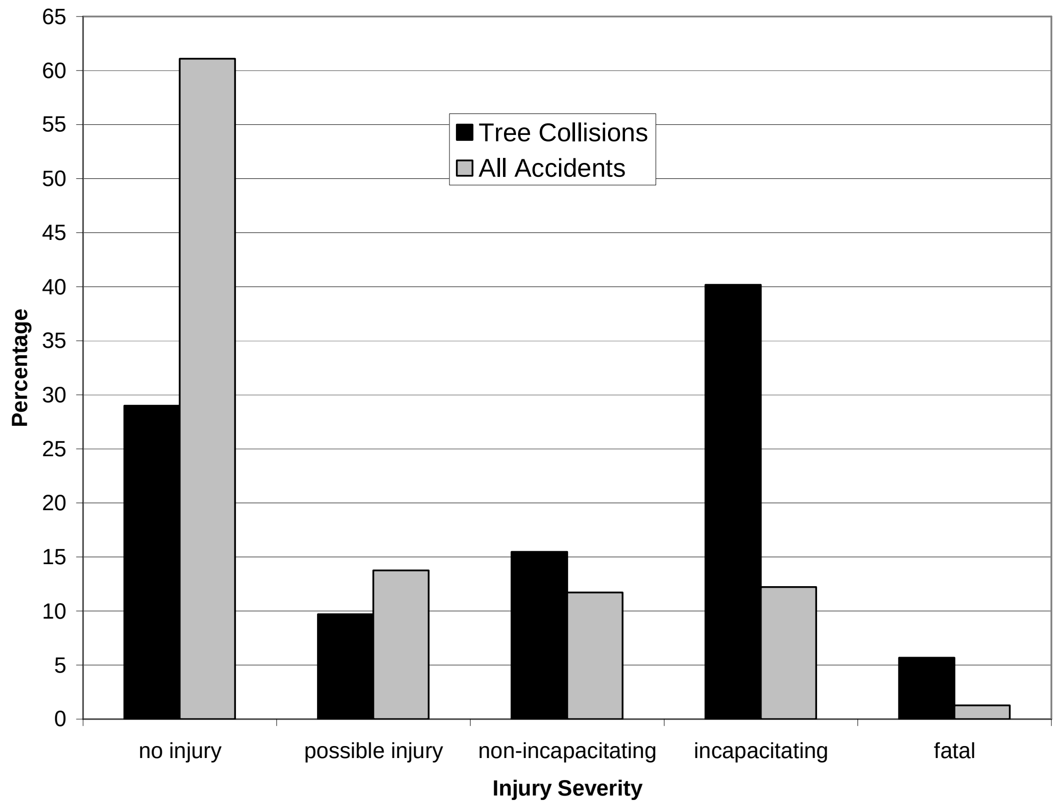

FIGURE 2 Relative frequency of injury severity for tree collisions and all accidents (%).

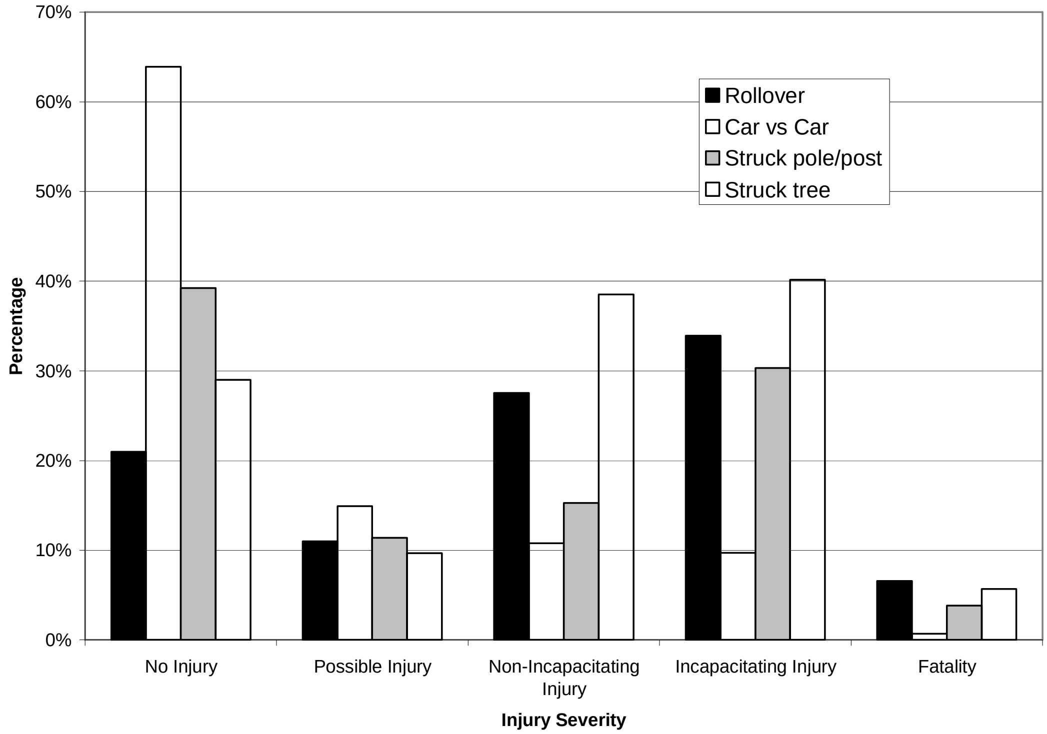

FIGURE 3 Relative frequency of injury severity by accident type.

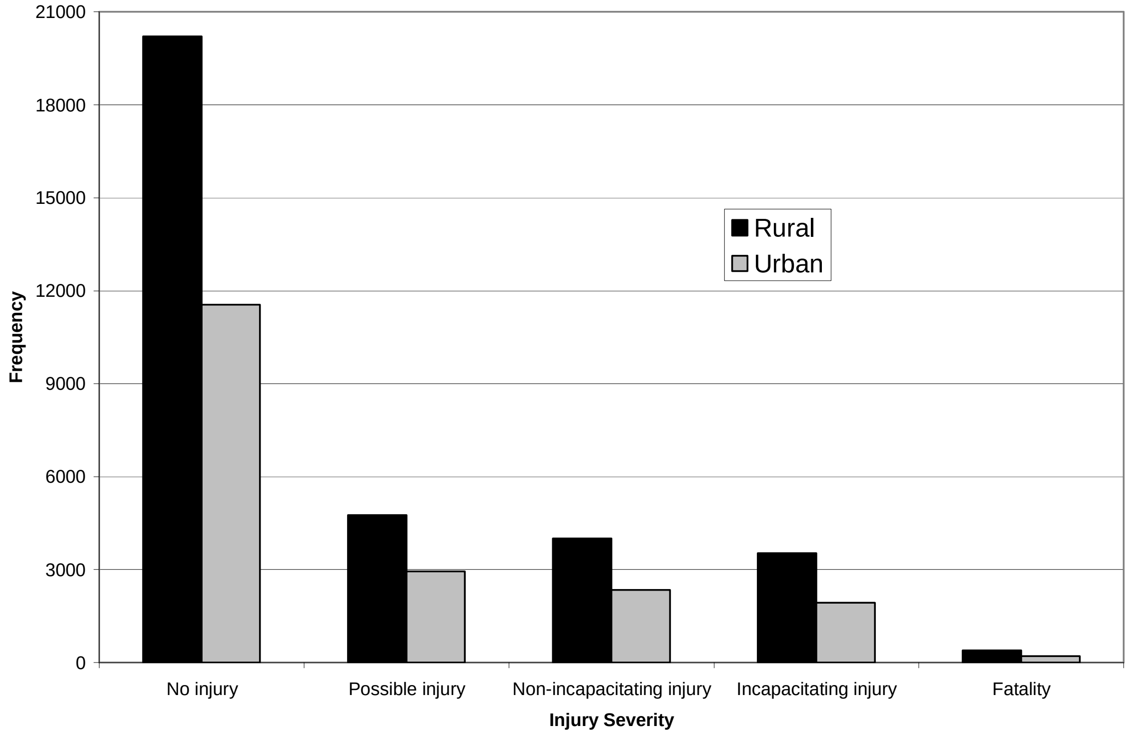

FIGURE 4 Distribution of injury severity by urban and rural areas.