Project Title:  
The Unresolved Relationship between Street Trees and Road Safety

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Research Needs
Streets – especially in urban areas – serve as far more than simple conduits of vehicular traffic. They are a place for pedestrians and bicyclists; they are a place for children to play and learn; and they are part of the community as a livable and healthy environment. Trees can play a significant role in these functions. In his research on livable streets, Donald Appleyard discusses how trees “provide relief from the hardness and grayness of the city” and help “provide shade in the summer and remind people of the natural environment, which is often far away; they signal the seasons, and symbolize, through growth, flowering and decay, the cycles of life itself” (Appleyard 1980). The research points to street trees being associated with a better pedestrian environment, reduced urban head island effects, less drainage infrastructure as well as a host of other social, environmental, and even economic benefits (Burden 2006, Ewing and Dumbaugh 2009). Dan Burden points out that planting a tree, including three years of maintenance, costs between $250 and $600, but that the economic return of a single street tree seems to far exceed the initial costs (Burden 2006). By estimating the value of air conditioning savings, erosion control, wildlife habitat, and air pollution reduction over the life of an average tree, the American Forestry Institute estimated this benefit as $57,151 in 1992 (or $96,196 in 2014 dollars) (Moll and Young 1992). This estimate does not even account for the research that suggests that street trees add value to adjacent homes, businesses, and the tax base (Das 1979, Burden 2006).

Considering the extensive list of benefits, it is no wonder that street trees have long been a staple of good urban design and shaping more livable spaces. In fact, they seem to be beneficial in most every way except one: road safety. The national safety data suggests that car/tree collisions account for more than 4,000 fatalities and 100,000 injuries in the U.S. each year (FHWA 2006). So
while traffic engineers acknowledge that trees can be an asset, they also point out that trees are the “single most commonly struck objects in serious roadside crashes” (FHWA 2006). To remedy this issue, traffic engineers prefer that trees and other “fixed-object hazards” be located a safe distance from the roadside. This area where fixed-object hazards are minimized is called the clear zone, which has been standard design practice since the 1967 AASHO\(^1\) publication of Highway Design and Operational Practices Related to Highway Safety, which cited the need for a 6-meter (19.7') clear zone without any trees larger than 4” caliper (AASHO 1967). Soon thereafter, the recommended lateral clearance increased to 9-meters (29.7') and explicitly included both rural and urban locations (AASHTO 1970).

While today’s traffic engineers acknowledge that trees on low-speed residential streets “do not usually present the same problems as trees near high-speed roads and highways” and recognize that urban right-of-ways are often extremely restricted, the 2011 AASHTO Roadside Design Guide continues to encourage clear zone application wherever practical (AASHTO 2011, FHWA 2006).

Despite standard design practice, the research remains conflicted over the true association between street trees and road safety (Zeigler 1986, Turner and Mansfield 1989, Dumbaugh 2005, Gattis 2005, Ivan et al. 1999, Naderi, Kweon, and Maghelal 2008, Ossenbruggen, Pendharkar, and Ivan 2001, Wolf and Bratton 2006). This proposed research seeks to better understand this issue by: i) developing a methodology for deriving tree canopy data via remotely sensed data; ii) collecting an extensive database of road crashes, traffic counts, and other relevant crash factors; and iii) conducting a statistical analysis of roadside trees and road safety. The goal is to shed light on the true relationship between street trees and road safety outcomes.

**Background**

The clear zone concept was partly an outcome of the Congressional road safety hearings held in 1966 to combat the sharp rise in fatalities and injuries on the roadways in the U.S. The hearings took place over the course of more than a year and were highlighted by two key figures: Ralph Nader, who had just published Unsafe at Any Speed the year before; and Kenneth Stonex, a General Motors engineer (Weingroff 2003). Nader’s testimony focused on the need for a new safety paradigm based on the idea that while crashes are inevitable, injuries are not. The previous ten years had focused on public safety campaigns; Nader’s point was that engineering measures – thorough better vehicle and road design - were far easier to influence than the behavior of millions of drivers (Nader 1965). Stonex worked at the GM Proving Grounds, a 65-mile test track in Milford, Michigan. His research suggested three keys to better road safety: access management; one-way traffic; and fewer roadside obstacles (Weingroff 2003). Focusing in on the last point, Stonex reported that removing all fixed objects from within 100 feet of the road, such as at the Proving Grounds, would make it “pretty hard to commit suicide on” (Weingroff 2003). Stonex goes on to say:

“This is the real transportation problem that remains to be approached. What we must do is to operate the 90% or more of our surface streets just as we do our freeways… [converting] the surface highway and street network to freeway and Proving Ground road and roadside conditions” (Weingroff 2003, Dumbaugh 2005).

This quote represents the thinking that has guided much of our roadside design over the last fifty years. The latest edition of the AASHTO Roadside Design Guide includes a little more wiggle room based on contextual factors but still recommends application of the clear zone concept whenever possible (AASHTO 2011).

In terms of early academic research on the topic of trees and road safety, two of the more well-known studies include: a statewide study of Michigan by Zeigler; and a study of Huntsville,

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\(^{1}\) AASHO, or the American Association of State Highway Officials, was the original name of present-day AASHTO, also known as the American Association of State Highway and Transportation Officials.
Alabama by Turner and Mansfield (Zeigler 1986, Turner and Mansfield 1989). One issue is that such early research investigating the relationship between trees and road safety tended to focus on descriptive statistics. For instance, Zeigler found that car/tree crashes represent 2.8% of all crashes but 9% of fatalities (with most fatal crashes occurring with trees larger than 20-inch caliper) (Zeigler 1986). He went on to show that 85% of car/tree collisions occurred within 30-feet of the roadway, a number that supported the original clear zone recommendation, and cited this as an issue in both rural and urban settings (Zeigler 1986). Turner and Mansfield intended to focus more on the issue of urban car/tree crashes and found that 80% of car/tree crashes occurred within 20-feet of the roadway and most of those were with trees of 12-inch caliper or more (Turner and Mansfield 1989). These facts, however, merely describe where car/tree collisions tend to occur and/or how big the offending trees tend to be; they do not tell us anything about whether the presence of the trees themselves are associated with better or worse safety outcomes. Moreover, these studies do not consider whether we would expect fewer crashes in the first place – or perhaps even fewer severe injury or fatal crashes – with more street trees. Nevertheless in the case of Turner and Mansfield, the authors identify a 4% reduction in crashes for every extra foot of clear zone and proceed to romanticize about how nice it would be if every road could conform to clear zone policy (Turner and Mansfield 1989).

More recent research is beginning to tell another story. Based on five arterials in Toronto, Jody Naderi found that mid-block crashes dropped between 5 and 20% with trees or concrete planters located street side (Naderi 2003). Eric Dumbaugh’s well-regarded 2005 paper Safe Streets, Livable Streets focused on two stretches of the same corridor in Orlando, FL. Accounting for traffic exposure, he found that the more livable section – with trees and other fixed-object hazards placed well within the clear zone – experienced fewer crashes across all severity levels (Dumbaugh 2005). In a before-and-after Texas study of ten urban arterials, Mok et al. found that the increased presence of landscaping and street trees was significantly associated with a decreased crash rate (Mok, Landphair, and Naderi 2006). Wolf and Bratton dug into the issue of car/tree collisions at a national level and concluded that urban car/tree crashes are not well understood (Wolf and Bratton 2006).

Despite this growing body of evidence, tree removal policies – typically reserved for highways and rural locations – have become commonplace in many urban settings (West 2000). For instance, the Kentucky Transportation Cabinet is planning to remove seventeen newly planted trees along an urban street in Louisville and is even charging the city $17,000 for the expense, saying these trees should not have been planted in the first place (Bruggers 2014). The district engineer states: “we are not anti-tree at the Transportation Cabinet; we are pro-safety” and goes on to cite the need to preserve the clear zone (Bruggers 2014). Interestingly, they Kentucky Transportation Cabinet also says that removing utility poles from the clear zone is not on their agenda due to impracticality.

Now why might trees actually help improve road safety? In the popular book Traffic, Tom Vanderbilt highlights the 1908 story of Colonel Willoughby Verner who had written a letter to his local newspaper about recently cutting back his hedges from the intersection near his home (Vanderbilt 2008). At the request of the Motor Union, Verner trimmed his hedges back nearly 30 yards and to a height of 4 feet. Much to his surprise, Verner found that vehicle speeds dramatically increased after the hedges had been cut back. When Verner discussed the issue with the police, they told him that people were now driving faster because they could see around the corner and felt safe at the higher speeds. In response, Verner allowed the hedges fill back in, and cars began to slow down (Vanderbilt 2008). Figure 1 is an excerpt from a FHWA document titled Vegetation Control for Safety that depicts “satisfactory” and “hazardous” conditions at an intersection (Eck and McGee
If traffic speeds remain constant, then it stands to reason that the condition deemed “satisfactory” is safer; however if fewer trees results in different driver behaviors and higher vehicle speeds, then the question of safety is much more complicated.

This concept of risk compensation is at the heart of the argument for why street trees might lead to better safety outcomes (Adams 1995, Vanderbilt 2008). The idea is that making a street feel narrower – and perhaps even feel more dangerous as well – could entice people to behave differently and perhaps more safely. Related to this theory, Dumbaugh helps shed light on his results by discussing the concept of a self-enforcing or self-explaining street that, in essence, provides the driver guidance on an appropriate driving speed (Dumbaugh 2005). The goal of a self-enforcing street is to use design elements rather than signage or police enforcement to manage vehicle speeds. In the case of street trees, the increased visual complexity and more pronounced street edge have been shown to be associated with reduced driving speeds (Godley et al. 1999, Naderi, Kweon, and Maghelal 2008, Burden 2006). Speed reduction can, in turn, impact road safety outcomes, particularly with respect to fatal and severe injury crashes. These concepts represent some the issues we are studying with this proposed project in our attempt to better understand the relationship between trees and road safety outcomes.

**Research Objectives**

This study will:

1. Collect and geocode a crash database for the Denver metropolitan area;
2. Collect relevant socio-demographic and socioeconomic data, land use data, built environment data, and traffic exposure data;
3. Create a tree canopy GIS layer using remotely-sensed data;
4. Statistically investigate the relationship between trees and overall road safety;
5. Characterize the influence of the other variables on road safety and the interaction of these variables on the tree/safety association;
6. Advance knowledge by carrying out analyses to answer our research questions;
7. Advance policy and practice with respect to building safer cities;
8. Advance education through the training of students; and
9. Build an evidence base by disseminating findings through publications and presentations.

**Research Methods**

To answer the research questions above, we will carry out road safety study that includes the following steps: i) data collection; ii) built environment measurement; iii) development of tree canopy layer from remotely-sensed data; iv) statistical data analysis; and v) dissemination.

*Data Collection*

We will initially collect a minimum of five years of crash data from various sources and geocode this data using the ESRI ArcGIS geocoding capabilities. Data points that fail to geocode correctly will
be located using the Google Maps API. The crash data will include all severity levels and be separated by road user type (i.e. vehicle, pedestrian, bicycle).

U.S. Census data will be collected at the Census Block Group level of analysis. This data will include population and demography data, including socioeconomic and socio-demographic factors such as income, race/ethnicity, and education. It will also include travel behavior data such as commute mode share and travel time to work.

Land use data will be collected from the Denver Regional Council of Governments (DRCOG) and/or form the National Land Cover Database (NLCD) in order to help quantify the relative level of urbanity.

We will assemble additional built environment data to help identify street characteristics such as the number of travel lanes, presence of sidewalks or medians, shoulder width, and speed limits. Street network data will be used to calculate street network connectivity and street network density indices, which have also been associated with differences in road safety outcomes (Marshall and Garrick 2010, 2011). Street segments will be separated on a basis of cross-sectional consistency, and these variables controlled for in the statistical model.

Traffic count data – to be used to control for exposure – will be collected from the Colorado Department of Transportation, DRCOG, as well as from local municipalities.

Tree Canopy Methodology
In order to develop a tree canopy GIS layer, we will acquire the following data:

- Optical Remotely sensed imagery (via DigitalGlobe)
  - Multi-spectral (tree differentiation)
  - Panchromatic (crisp edges)
- LiDAR imagery (via USGS)
  - Tree canopy detection, above-ground tree heights

The initial plan is to utilize the LAS dataset feature tools within ArcGIS to initially generate an above-ground canopy height. We will then assess tree-type via the multi-spectral data and fuse the two together to create a canopy layer (Chen, Chiang, and Teo 2005).

If necessary, we will adjust our approach to draw upon other automated feature extraction tools (e.g. eCognition or ENVI 5.2). Given pre-existing data, other issues that we may need to contend with include seasonality differences and cloud cover.

One the tree canopy GIS layer has been created, we will calculate the percentage of tree canopy coverage over the street. The width of the street (i.e. number of lanes) will be used to facilitate this calculation.

Statistical Data Analysis
The fundamental question we are trying to answer with this research is the following: how are roadside trees associated with road safety outcomes across all severity levels? The dependent response variable used to address this question in our statistical analysis is a count of the number of crashes. A conventional linear regression model may not be appropriate for this analysis because of the requirement that the dependent response variable be normally distributed (Long 1997). To resolve this issue, researchers often rely upon a generalized linear model (GLM) for analyzing count-based crash data. A GLM can be used to account for a non-normal distribution using a link function that relates the linear portion of the model to the mean of the dependent response variable. Link functions can take various forms – such as log, logit, inverse, or inverse squared – but the
purpose is to allow the response variable to relate to the explanatory variables in a nonlinear way (Long 1997).

The literature suggests that our crash results will be overdispersed and not normally distributed (Long 1997). As a result, the negative binomial model is likely to be appropriate, as it is a generalized version of the Poisson model and accounts for this overdispersion by introducing a random stochastic component to the log-linear Poisson mean function relationship (Long 1997, Noland and Quddus 2004). The following is the negative binomial generalized linear regression model:

\[
\ln \mu_i = X_i\beta + \epsilon_i
\]

where:
- \(\mu_i\) = Randomized version of conditional mean of expected crash count of area \(i\)
- \(X_i\) = Independent predictor variables
- \(\beta\) = Estimated vector of coefficients representing effects of the covariates
- \(\epsilon_i\) = Stochastic component representing random error used to account for overdispersion

Over the last decade, the negative binomial model has become accepted practice for traffic safety researchers conducting statistical testing of crash counts where overdispersion is an issue (Zhou, Ivan, and Sadek 2009). The negative binomial probability distribution is determined by (Long 1997):

\[
P(y_i|x_i) = \frac{\Gamma(y_i + \nu_i)}{y_i!\Gamma(\nu_i)} \left( \frac{\nu_i}{\nu_i + \mu_i} \right)^{y_i} \left( \frac{\mu_i}{\nu_i + \mu_i} \right)^{\nu_i}
\]

where:
- \(\Gamma\) = Gamma distribution function
- \(\nu_i\) = Gamma distribution parameter that affects the shape of the distribution
- \(y_i\) = Crash count of Census Block Group \(i\)

The variance of the negative binomial distribution is (Long 1997):

\[
\text{Var}(y_i|x_i) = \mu_i \left(1 + \frac{\mu_i}{\nu_i}\right)
\]

If \(\alpha\), the dispersion parameter, begins to approach zero, then a Poisson becomes the appropriate model. The dispersion parameter is related to the gamma distribution parameter as follows (Long 1997):

\[\nu_i = \alpha - 1 \text{ for } \alpha > 0\]

Using negative binomial generalized linear regression, we will build expected crash models by crash severity type. For the fatal crash model, however, we may have to slightly modify this approach because fatal crash datasets tend to contain a much larger number of zeros as outcomes than other outcome variables. This limits the effectiveness of the standard negative binomial regression model (Long 1997). One methodology frequently used to account for a large number of zero counts in a dataset is to treat that database as if it was made out of two separate datasets. This zero-inflated negative binomial model separately models the large numbers of zeros while still allowing for overdispersion (Lord, Washington, and Ivan 2005). Since the first dataset contains only zeros, they are dealt with and predicted with a single independent variable using a Bernoulli probability function (Erdman, Jackson, and Sinko 2008, Lord, Washington, and Ivan 2005). Thus, we will attempt to use another relevant variable to attempt to predict areas with zero fatalities; in the fatal crash model, the nonzero portion of the dataset that experienced more than zero fatal crashes...
will be modeled and analyzed as a standard negative binomial regression model (Erdman, Jackson, and Sinko 2008, Lord, Washington, and Ivan 2005).

**Dissemination**
Dissemination of results from this project will target both academic and practitioner audiences. To reach academic audiences, we will produce conference presentations and peer-reviewed journal papers to share findings of this project. Yet, even the best transportation research is of little value until that knowledge is effectively shared with a broader audience. Accordingly, we will work that the results are adapted for practitioner audiences, particularly via popular press articles.

**Expected Outcomes**
The expected outcomes of this work include:
1. Findings with respect to the testable hypotheses and research questions;
2. A set of explanatory and dependent variables and constructs where we can disaggregate the factors influencing better road safety with respect to roadside trees;
3. Manuscripts for presentation/publication at TRB and other peer-reviewed journals;
4. Presentations to academic and policy audiences; and
5. A module about roadside trees and road safety for a graduate-level transportation course at the University of Colorado Denver.

**Relevance to Strategic Goals**
The work primarily falls under the heading of safety, but it also highly relates to the strategic goals of livable communities and environmental sustainability.

**Educational Benefits**
Students involved in this project will be trained in conventional engineering practice and conduct research to the verity of those conventions. These students will gain valuable research experience and have the opportunity to author publications and presentations emanating from this work.

This study will be integrated into Dr. Marshall’s “Sustainable Transportation Systems” graduate courses through a case study approach that will present research materials to the students and be incorporated into student term projects. This transportation courses is based in the Civil Engineering Department and cross-listed in Department of Planning and Design as well as the School of Public Affairs.

The data collected for this project will also be made available to students for use in term projects and/or master’s reports. As a result, this project will influence students from a variety of disciplines that comprise our future transportation professionals.

**Work Plan**
The proposed scope of work is scheduled for a one-year timeframe, beginning with notice to proceed from the Mountain Plains Consortium. Major project steps include the following:

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<th>Task</th>
<th>Timeline</th>
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<tbody>
<tr>
<td>Collect and geocode safety data</td>
<td>Months 1-2</td>
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<td>Collect demography data</td>
<td>Months 3-4</td>
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<tr>
<td>Collect built environment data</td>
<td>Months 3-4</td>
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<tr>
<td>Develop tree canopy methodology</td>
<td>Months 5-7</td>
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<tr>
<td>Create tree canopy GIS layer</td>
<td>Months 7-8</td>
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Analyze Data
Months 9-10

Incorporate lessons into transportation classes
Months 5-10

Draft manuscripts and presentation materials
Months 11-12

Project Cost
Total Project Cost: $270,746
MPC Funds Requested: $135,373
Matching Funds: $135,373
Source of Matching Funds: University of Colorado Denver

TRB Keywords
Road safety, roadside, street trees, clear zones, tree canopy

References


