Frequency and Severity of Tree and Other Fixed Object Crashes in Florida, 2006-2013

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Abstract:

Roadside trees provide benefits to drivers such as traffic calming, roadway definition, and driver stress reduction. However, trees are also one of several roadway infrastructure elements commonly involved in single-vehicle crashes. In this study, Florida Highway Saftey and Motor Vehicle records were analyzed to: (1) evaluate the relative frequency of tree-related crashes compared to other fixed-object crashes; (2) assess the impact of roadway-, vehicle-, and driver-related factors on tree crash frequency; and (3) compare the severity of tree crashes relative to other single vehicle crashes. In accessing 3,033,041 crash records from 2006-2013 (all complete years), we identified 565,303 single-vehicle accidents (10.5%) and 47,341 tree-related accidents (1.6%). Trees were the fourth most common fixed object hit in urban single-vehicle accidents and the second most common fixed object hit in rural single-vehicle accidents. Driver gender, vehicle type, light conditions, weather conditions, and land use all were correlated with the frequency. Additionally, the injuries associated with tree crashes were more severe than all other single-vehicle crash types except vehicle rollovers.

Key Words: Tree Hazards; single-vehicle collisions; urban forestry; transportation; risk

Introduction:

Risk is a combination of the (1) probability of an event occurring and (2) the consequence of the event should it occur (Frank & Bernanke, 2004). When urban foresters and other professionals assess tree risk, they typically focus on the probability that a tree (or part of a tree) will fail and strike a target such as a person or property. Smiley et al. (2011) describes a tree as hazardous if it has both a structural defect that predisposes the tree to failure, and a target that would be struck if it were to fall. Smiley et al. (2011) goes on to say that healthy trees may be hazardous if they obstruct motorist's vision, raise sidewalks, interfere with utilities or are particularly attractant to lighting. To the extent trees are evaluated as roadside hazards, research in arboriculture and urban forestry has been limited to the risk posed by a tree or branch should falling on, or immediately in front of, a passing vehicle (Ellison, 2005; Rooney et al., 2005; Laefer & Pradhan, 2006; Klein et al., 2016). In contrast, research from transportation and planning has largely focused on trees their potential involvement in fixed-objects vehicle crashes (Zeigler, 1986; Turner and Mansfield, 1990; Lee and Mannering, 1999; Naderi, 2003; Dumbaugh, 2005; Holdridge et al., 2005; Dumbaugh, 2006; Mok et al., 2006; Wolf and Bratton, 2006; Abdin et al, 2009; and Park and Abdel-Aty, 2015).

Roadside vegetation is a significant component of roadway planning. Between 2008 and 2013, the Florida (United States) Department of Transportation spent $209 million on highway landscaping (Khachatryan et al., 2014). This roadside beautification led to $46 million in annual output impacts (total state expenditure) and $28 million in annual value added impacts (wages, increased property income, proprietor income, indirect business taxes, and capital consumption) (Khachatryan et al., 2014). While harder to quantify than the economic benefits noted above, tree-lined roadsides increase the aesthetic appeal of streetscape vegetation, reduce driver stress, and facilitate a more pleasant driving experience when compared to more barren streetscapes (Wolf, 2003). These benefits may be especially important for drivers who become frustrated with traffic congestion and long commutes (Cackowski and Nasar, 2003). The psychological health benefits of roadside vegetation are an important consideration for landscape planning.

At the same time, streetscape trees are fixed objects that can be struck during run-off-road (ROR) accidents (Turner & Mansfield, 1990; Wolf & Bratton, 2006). The relative risk of tree crashes is dependent on a number of variables, including roadway design, roadway conditions, vehicle weight, and roadway geometry (Wolf & Bratton, 2006; Abdin, et al., 2009). However, there is some disagreement among researchers as to the effect of fixed objects (such as trees) on crash frequency. Some researchers such as Ewing & Dumbaugh (2009) argue that roadside trees promote safety by enhancing roadway definition, whereas other researchers posit that roadside trees are hazardous (Hall et al.; 1976; Zeigler, 1986; Turner & Mansfield, 1990).

In addition to crash frequency, it is important to identify crash-related factors associated with severe injuries or death. Holdridge et al. (2005), modeled injury severity in fixed object crashes and found that trees, utility poles and the leading ends of guardrails increase the probability of fatal injuries in ROR crashes. Harvey and Aultman-Hall

(2015) conducted a logistic regression study of 244,684 crashes in New York City between 2011-2013 and found that smaller, more enclosed streetscapes were characterized by less severe crashes. The authors suggested that a more constrained streetscape makes drivers more aware of potential hazards and causes them to engage in less risky driving behavior (Harvey and Aultman-Hall, 2015). While these works offer key insights, other factors related to the driver, vehicle, site, and fixed object struck during an ROR collision may impact crash severity.

Quantifying the relative frequency and severity of tree-related, single-vehicle ROR crashes is an important step in assessing past roadside vegetation management efforts and developing future management plans. In assessing the frequency and severity of tree-related crashes, we posed the following research questions: (1) What is the impact of land use (urban/rural), vehicle type, light conditions, and weather conditions on tree and non-tree crash frequency? and (2) How does the severity of tree-relating accidents compared to other single-vehicle accidents? Our results highlight the potential costs of roadside trees with regard to injury and death. In identifying these potential costs, those managing trees along roadways to can begin to assess whether the benefits of roadside trees outweigh the potential risks.

Materials and Methods:

Archival vehicle accident data collected by the Florida Department of Highway Safety and Motor Vehicles (FL DHSMV) from 2006-2014 were analyzed between December 2016 and February 2017. These data was collected from reports (HSMV Long Report

Form 90005) filled out by police officers responding to crash events. The DHSMV data included 3,033,048 crashes in total. Of these, only single-vehicle crashes were included in our analysis of crash severity. Within the single-vehicle crash data, motorcycle crashes and commercial vehicle crashes were excluded – leaving a final dataset containing 323,581 unique events. Data were standardized as needed to account for revisions made to the long report form in 2011. For example, before 2011, there were multiple ways to record seatbelt use (e.g., lap belt only, shoulder harness only, both lap belt and shoulder harness). With the revised form, this was a simple yes or no response. In cases there were differences in data resolution were noted, choices were aggregated (if possible) to make direct comparisons. In some cases, the 2011 revisions made it impossible to match variables across the entire data set. These variables were ultimately dropped from the analysis.

Chi-square tests were used to assess the impact of various driver-, site-, and vehicle-related factors influenced crash frequency. These tests were completed using the prop.test() function in, R (R Development Core Team, 2017). Specifically, we assessed whether or not the number of tree-related collisions varied by driver gender, suspected alcohol/drug use (i.e., yes vs no), vehicle type, land use (i.e., rural vs. urban), light conditions (i.e., daylight, dark with lighting, dark, dusk/dawn), and weather conditions (i.e., clear, cloudy, low visibility, precipitation, severe winds).

In modeling crash severity, we utilized the variable “First Harmful Event” to determine what type of single vehicle collision occurred (e.g., striking one of several fixed objects, rollover, or simply going off the road). The DHSMV (2008) defines "First Harmful Event" as the "injury or damage producing event which characterizes *the* crash type and identifies the nature of the first harmful event." "First Harmful Event" (hereafter, "Crash Type") levels were standardized as one of the following: tree, barrier, ditch, fence, no fixed object (and no rollover), pole, sign, structure, water, and rollover. Additional predictors beyond first harmful event are listed in Table 1:

Table 1. Predictor variables and the associated levels/baselines used when modeling injury severity for single-vehicle accidents in Florida (United States) from 2006 – 2013.

Predictor	Levels of Predictor	Base Level for Model
Gender	Female Male	Female
Age	*Continuous Variable*	*None*
Seatbelt Use	Yes No	No
Airbag Deployed	Yes No	No
Occupant Ejected	Yes No Partially	No
Drug/Alcohol Use	Yes No	No
Estimated Speed	*Continuous Variable*	*None*
Land Use	Rural Urban	Rural

Road Type	County/State Forest Interstate/Tollway Local	County/State
Shoulder Type	Curb Paved Unpaved	Curb
Road Surface Conditions	Dry Loose Slippery Standing Water	Dry
Light Conditions	Daylight Dark Dark w/ Lighting Dawn/Dusk	Daylight
Weather Conditions	Clear Cloudy Low Visibility Precipitation Severe Winds	Clear
Crash Type	Barrier Ditch Fence No Fixed Object Other Pole Rollover Sign Structure Tree Water	Tree

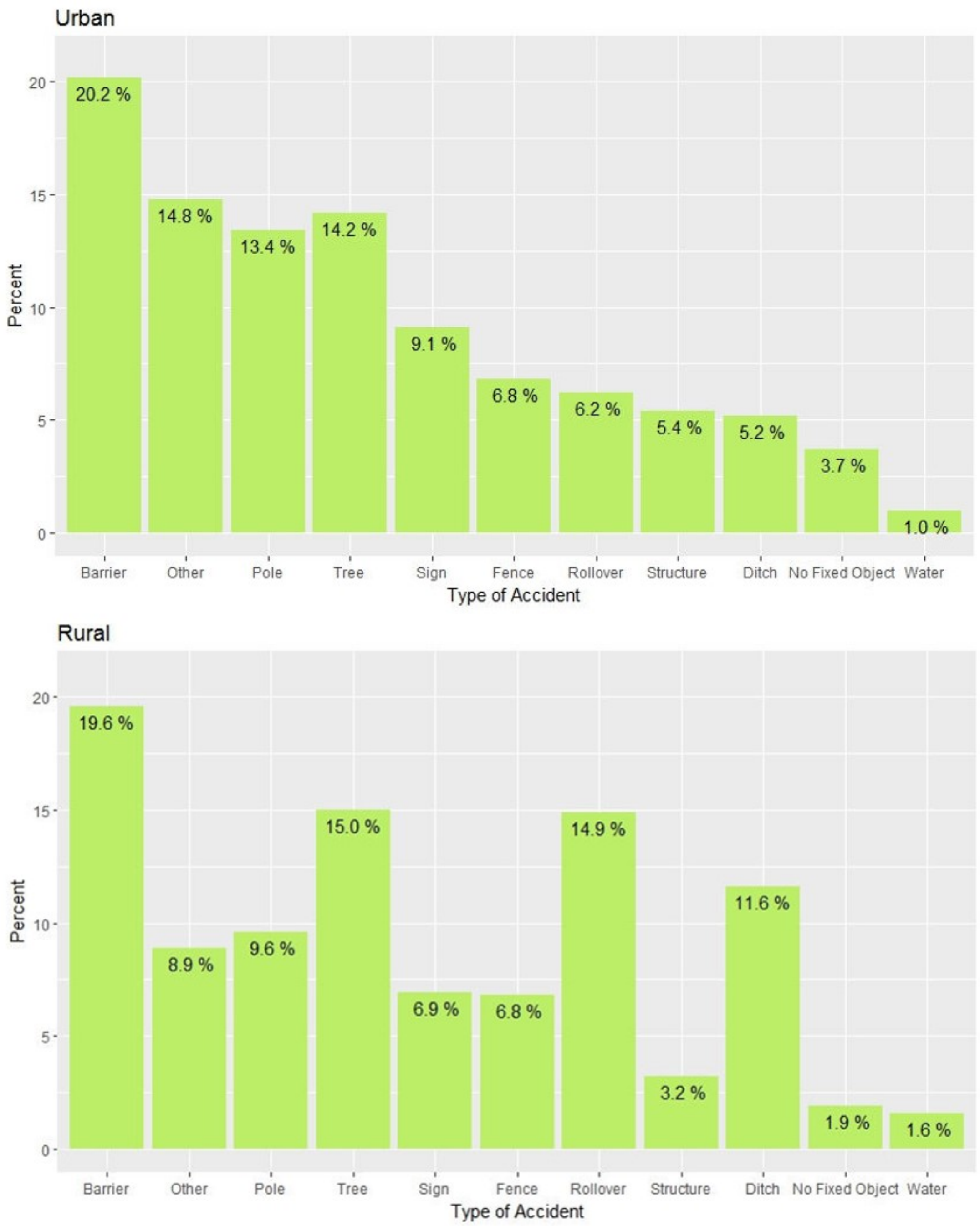
The outcome variable “severity” was recorded as on of four levels: none, minor, severe, and fatal. “None” corresponded to no injury. “Minor” injuries were defined as injuries that were non-incapacitating and non-disabling (DHSMV, 2008). Examples of minor injuries included lacerations, scrapes, or bruises. “Major” injuries were defined as injuries that were incapacitating or disabling (DHSMV, 2008). Examples of major injuries included broken bones and severed limbs. “Fatal” injuries were defined as injuries resulting in death within 30 days of the crash (DHSMV, 2008).

Crash severity was modeled via ordered logistic regression using the polr() function from the MASS package in R (Venables and Ripley, 2002). Odds ratios and their associated 95% confidence intervals were calculated for greater ease in interpretation. A *P*-value of 0.05 was chosen as the threshold for statistical significance for all of the above-mention tests.

Results and Discussion:

RELATIVE FREQUENCY OF TREE RELATED CRASHES. Of the 323,581 single-vehicle crashes analyzed, 47,341 (14.6%) involved a collision with a tree. In urban areas, tree collisions were the fourth most common crash type observed (Fig. 1). In rural areas, tree related crash types were the second most common crash type. That said, the percentage of tree-related crashes was quite similar for urban (14.2%) and rural (15.0%) settings (Fig. 1). Given the large sample size, this small difference was still statistically significant (*P*-value<0.0001)

Figure 1. Comparison of single-vehicle (excluding commercial vehicles and motorcycles) crash types for urban and rural settings. The figure represents 323,581 crash events that occurred in Florida (United States) from 2006-2013.



Parked car crashes not shown as less than 1% (0.6% for urban and 0.0% for rural).

Beyond land use, the relative proportion of tree-related crashes differed given light condition (*P*-value<0.0001). Nearly a quarter (23.1%) of single vehicle crashes occurring at night under lighted conditions involved a tree. In contrast, trees were only involved in

10.0% of crashes occurring during the day, 9.8% of crashes occurring at dusk or dawn, and 8.2% of crashes occurring at night without supplemental lighting. The difference in proportions between “dark with lighting” and the other three lighting scenarios (especially dark without lighting) suggests street lighting may be ineffective in preventing tree collisions. The presence or absence of lighting at night may impact driving behavior (perhaps drivers traveling along unlit roads are more cautious). It may also highlight a relationship between illuminated roadways, tree crashes, and some unmeasured predictor variable.

Given the data available, we were not able to normalize for vehicle-miles travelled/road use intensity. Therefore, it is possible that differences in crash frequency could be attributed to greater road use, rather than the variable in question (e.g., lit roadways are traveled more often than unlit roadways which is reflected in the elevated accident rates).

Of course, the inability of the authors to normalize road use intensity limits any definitive extrapolations. In addition, trees and lights may co-occur, leading to greater crash frequency in a “dark with lighting” scenario. In order to fully understand the effect of lighting on trees, it would be necessary to normalize road use intensity and the presence of trees in varying scenarios.

The proportion of single vehicle crashes involving trees also varied by weather conditions (P-value <0.0001). The order of tree crash frequency for weather conditions (most frequent to least frequent) is (1) severe crosswinds (14.29%), (2) low visibility (9.48%),

(3) clear weather (6.8%), (4) precipitation (4.48%), (5) cloudy weather (3.72%). An equality of proportions test for drug/alcohol use showed no significant difference in tree crash frequency for drug/alcohol use as compared to no drug/alcohol use (proportion of tree crashes for drug/alcohol use 10.83%, proportion of tree crashes for no drug/alcohol use 11%, *p*=0.2521). It should be noted that this does not imply that drivers under the influence of drugs/alcohol are as safe as sober drivers (we do not have the data to address this question).

IMPACT OF CRASH TYPE AND OTHER FACTORS ON INJURY SEVERITY.

Of the 47,341 tree-related crashes, 22,061 (46.6%) were without injury (Figure 2). The second most common injury level for tree-related crashes was “minor.” There were 19,315 tree-related accidents (40.8%) where minor injuries were recorded. Severe injuries and death were the two least common consequences of a tree-related car accident, making up 10.8% and 1.7% of crashes recorded (Fig. 2).

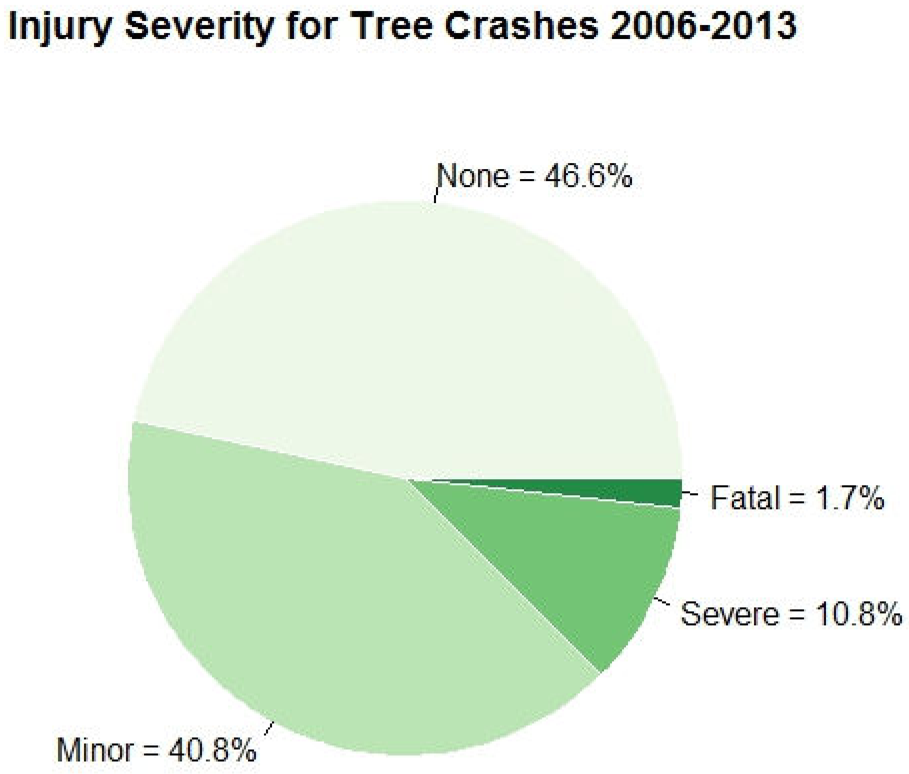


Figure 2. The proportion of tree-related crashes that resulted in no, minor, severe, and fatal injuries. The figure depicts the relative severity of 47,341 tree-related car crashes recorded in Florida (United States) from 2006 to 2013.

The results of the regression model show that tree crashes were more severe than all other single vehicle crash types except rollovers (*P*-value <0.0001; Table 2). In Table 2, the crash type "Tree" serves as the base level for the crash type factor. The odds ratios correspond to the odds of crash type "tree" being one severity level higher (e.g., minor as opposed to none, severe as opposed to minor, and fatal as opposed to severe) than each of the listed crash types. When compared to all non-rollover crash types, tree-related crashes were 1.2 to 2.5 times more likely to have an increased the severity (all other factors held constant, Table 2) than crashes with other fixed objects. Crashes with signs and structures tended to be among the least severe as compared to tree related crashes.

In contrast, rollover crashes were 1.5 times more likely to have an increased severity level than tree crashes (all other factors held constant, Table 2). In fact, rollovers were more severe than all other single vehicle crash types. Rollovers were nearly twice as prevalent (proportionally) in rural areas compared to urban areas (proportion of rollovers in urban areas 6.1%, proportion of rollovers in rural areas 14.72%, *P*-value <0.0001).

Tab1e 2. Factors influencing crash severity (i.e. none vs. minor vs. severe vs. fatal) for single vehicle crashes. Model derived from 323,581 single-vehicle crash events (not including commercial vehicles and motorcycles) that occurred in Florida (United States) from 2006-2013.

Predictor Variable	**Coefficient**	**Standard Error**	***P*-value**	**Odds Ratio**	**Lower 95% CI**	**Upper 95% CI**
Gender – Male	-0.4506	0.0115	<0.0001	0.6373	0.6231	0.6518
Age	0.0119	0.0004	<0.0001	1.0120	1.0113	1.0127
Drug/Alcohol Use – Yes	-0.1010	0.0165	<0.0001	0.9039	0.8752	0.9336
Vehicle – Truck	0.0692	0.0127	<0.0001	1.0716	1.0454	1.0986
Vehicle – Van	0.0585	0.0273	0.0320	1.0602	1.0050	1.0986
Land Use – Urban	-0.0481	0.0128	0.0002	0.9530	0.9294	0.9772
Road – Local	-0.1819	0.0156	<0.0001	0.8337	0.8087	0.8596
Road – Interstate	-0.3631	0.0168	<0.0001	0.6955	0.6721	0.7188
Road Surface – Loose	-0.4175	0.0916	<0.0001	0.6587	0.5505	0.7882
Road Surface – Water	-0.2329	0.0219	<0.0001	0.7923	0.7590	0.8270
Shoulder – Paved	-0.0536	0.0196	0.0062	0.9478	0.9121	0.9849
Shoulder – Unpaved	0.0655	0.0176	0.0002	1.0677	1.0315	1.1051
Light Conditions – Dark w/ Lights	-0.1988	0.0149	<0.0001	0.8198	0.7961	0.8441
Light Conditions – Dark	-0.0791	0.0156	<0.0001	0.9240	0.8961	0.9527
Light Conditions – Dawn/Dusk	-0.0761	0.0266	0.0043	0.9267	0.8796	0.9764
Weather – Cloudy	0.1246	0.0164	<0.0001	1.1326	1.0969	1.1695
Weather – Low Visibility	0.1445	0.0548	0.0084	1.1555	1.0378	1.2865
Seatbelt – Yes	-1.2963	0.0226	<0.0001	0.2735	0.2617	0.2859
Airbag – Not Deployed	-1.1149	0.0122	<0.0001	0.3279	0.3202	0.3359
Ejected – Partially	2.5154	0.1134	<0.0001	12.3720	9.9054	15.4525
Ejected – Yes	1.8757	0.0538	<0.0001	6.5254	5.8723	7.2512
Crash Type – Barrier	-0.6619	0.0191	<0.0001	0.5159	0.4969	0.5355
Crash Type – Ditch	-0.1412	0.0223	<0.0001	0.8683	0.8312	0.9070
Crash Type – Fence	-0.5793	0.0307	<0.0001	0.5603	0.5276	0.5950

Crash Type – No Fixed Object	-0.4855	0.0561	<0.0001	0.6154	0.5514	0.6869
Crash Type – Other	-0.5622	0.0278	<0.0001	0.5700	0.5397	0.6019
Crash Type – Parked Car	-0.9448	0.2771	0.0006	0.3888	0.2258	0.6692
Crash Type – Pole	-0.4089	0.0216	<0.0001	0.6644	0.6369	0.6931
Crash Type – Rollover	0.4120	0.0212	<0.0001	1.5099	1.4483	1.5740
Crash Type – Sign	-0.8497	0.0262	<0.0001	0.4276	0.4061	0.4501
Crash Type – Structure	-0.9076	0.0361	<0.0001	0.4035	0.3759	0.4331
Crash Type – Water	-0.4574	0.0479	<0.0001	0.6329	0.5762	0.6952

Study Limitations

Comparison to Other Literature on Tree Crashes

The relatively higher tree crash frequency in rural areas compared to urban areas in the present study is consistent with existing literature on tree crashes (although the difference was very small in our study). Wolf and Bratton (2006) found that tree crashes were more frequent and more severe in rural areas when compared to urban areas. The authors argued that higher speeds in rural areas contributed to this difference. Dumbaugh (2005) suggests that fixed objects in an urban roadside promote safety by reducing speed and enhancing driver caution. Dumbaugh (2005) compared two similar urban roadways and found that the roadway with larger lane widths and clear zones had more crashes narrower lanes and clear zones. In other words, if a more “forgiving” roadway with larger clear zones and lane widths induces drivers to increase speed, this explains why rural areas with the attributes above have more severe and more frequent tree crashes compared to urban areas. Also, Harvey and Aultman-Hall (2015) found that smaller, more enclosed streetscapes were characterized by less severe crashes and suggested that a more constrained streetscape makes drivers more aware of potential hazards and causes them to engage in less risky driving behavior. Harvey and Aultman-Hall (2015) argue that in-fill development and roadside trees may create smaller, more enclosed streetscape along urban arterials, which may improve traffic safety by encouraging safer driver behavior.

Naderi (2003) found that inclusion of features such as trees and concrete planters along the roadside resulted in statistically significant reductions in the number of mid-block crashes along the sampled roadways, with the number of crashes decreasing between five to 20 percent. Lee and Mannering (1999) also found that in urban areas, the presence of trees was associated with a decrease in the probability that a run-off-roadway crash would occur in urban areas and the opposite effect was found in rural areas. Park and Abdel-Aty (2015) found that safety measures such as wide shoulders and reduced speed limits had less effect on promoting safety as driveway density and pole density increased. It appears there is a body of research suggesting that a defined roadside boundary, as enhanced by roadside trees and other fixed objects, has a traffic-calming effect that enhances safety in some circumstances.

The present study found that rural tree crashes were more frequent and more severe as compared to urban tree crashes, which may support the assertions of Dumbaugh (2005) and Harvey and Aultman-Hall (2015). The present study also found that tree crashes are most frequent at nighttime with lighting and least frequent at nighttime without lighting. Low visibility is similar to fixed objects in that they are both obvious hazards, which may induce drivers to reduce speed, thus lowering accident severity and frequency. Of course, the unique characteristics of the roadway and surrounding land use will impact driver perception of hazards. Ultimately, urban driving patterns differ from rural driving patterns, and this impacts both the frequency and severity of tree- and other run-off-road collisions.

Holdridge et al. (2005), modeled injury severity in fixed object crashes and found that trees, utility poles and the leading ends of guardrails and bridge rails increase the probability of fatal injuries in run-off-road crashes. Other variables that contributed to fixed-object crash severity include speed, intoxication, and falling asleep at the wheel/inattention. By contrast, the present study did not find a significant impact of intoxication on tree crash frequency.

Implications for Planning

In looking at all traffic accidents (i.e., not just single-vehicle), tree-related crashes accounted for 1.5% of all crash events recorded (n=3,033,048) during the eight-year study period. While somewhat disproportionate given crash frequency, tree-related traffic crash fatalities accounted for just 3.5% of the total road fatalities recorded from 2006-2013 (FDOT Office of Planning, 2017). On average, 94 people died each year in tree related car crashes. During the same time frame, there was an average of 15,464,241 licensed Florida drivers (FDOT Office of Planning, 2017). Ignoring unlicensed or visiting motorists, this equates to an average annual risk of harm (based on fatalities) of 1:164,513 for tree-related, single vehicle crashes. This calculated risk of harm assumes the driver is the only occupant. By comparison, the annual risk of harm for car occupants in general in the United States is 1:50,822 (National Safety Council, 2017). The annual risk of harm for falling down steps in the United States is similar, but still more likely at 1:139,544 (National Safety Council, 2017). Interestingly, the annual risk of harm associated with working in the finance and insurance industry in the United States is double (1:82,350) the risk of harm posed by Florida's roadside trees (National Safety Council, 2017).

While risk assessment if the United States is largely qualitative (Smiley et al., 2011), arborists and urban foresters in the United Kingdom assess and manage tree risk by estimating risk of harm (Ellison, 2005). Drawing on the Tolerability of Risk (ToR) framework (Health and Safety Executive, 2001), the Quantitative Tree Risk Assessment method defines situations with an annual risk of harm 1:1,000,000 or less as being broadly acceptable (Ellison, 2017). Situations, such as tree-related car crashes in Florida where the calculated annual risk of harm falls between 1:10,000 and 1:1,000,000, are deemed tolerable to the public if the risk has been mitigated to be as low as reasonably possible (ALARP) given the costs and benefits of risk reductions efforts (Ellison, 2017). Future research to quantify the costs of current roadside clear zones and relative changes in safety and management costs (and loss of tree benefits) for more or less aggressive management scenarios could help determine if risks are currently ALARP.

While potential risks such as second-hand smoke inhalation offer no benefit to those subjected to it, roadside trees differ in that they can do both harm and good. In fact, excessive tree removal has its risks. In a study on the effects of drastic urban tree removal following infestations of the highly destructive emerald ash borer, researchers found that areas that lost tree canopy over a 17-year period experienced an additional 6,113 deaths related to respiratory illness and an additional 15,080 deaths linked to cardiovascular-related deaths (Donovan et al., 2013). Even the act of removing trees itself increases the likelihood of death, as forestry is consistently ranked one of the most dangerous occupations (National Safety Council, 2017). As such, roadside tree removal or retention decisions are a balance of risk versus benefit. Removal efforts should focus on high risk and low-value trees, leaving trees with lower risks and higher benefits. Ultimately, risk is situation-specific, and the character of the road and land use must be considered in evaluating trees as crash hazards.

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