Countermeasures to Improve Pedestrian Visibility to Tall Vehicles

Final Report

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16. Abstract

With increasing urbanization, interactions between pedestrians and vehicles have become more frequent, raising safety concerns. Now comprising about 40% of the consumer fleet, tall vehicles like trucks and SUVs pose unique risks with their elevated front profiles and large blind zones. This "car bloat" trend, combined with distracted and risky driving behaviors, has contributed to an 80% increase in pedestrian fatalities in the United States since 2009. In this WisDOT policy research project, the University of Wisconsin-Milwaukee's Institute for Physical Infrastructure and Transportation conducted a study to identify effective countermeasures to improve pedestrian visibility to tall vehicles. The research involved a literature review and analysis of 39 years of single-vehicle single-pedestrian crash data from Wisconsin, Tennessee, and Florida, covering over 100,000 crashes from the 2010s. Tall vehicles are defined as those over 66 inches in height using vehicle identification and specifications databases. Findings show that tall vehicles are disproportionately involved in crashes during left turns and backing maneuvers, with higher risks across specific pedestrian locations and lighting conditions, such as crosswalks and dark environments, respectively. Statistical models showed that tall vehicle involvement was significantly associated with specific driver actions, such as left turns, as well as road types, and pedestrian presence in crosswalks. In Wisconsin, tall vehicles increased the odds of severe pedestrian injuries by 36%. Additional risk factors include high speeds, poor lighting, driver impairment, and older pedestrians. Guided by the Safe System approach, the study recommends engineering treatments such as advance yield markings, high-visibility crosswalks, curb extensions, leading pedestrian intervals, refuge islands, and flashing beacons. It also provides WisDOT with actionable strategies for roadway design, integrated planning, data-driven safety analysis, and targeted driver education addressing tall vehicle risks.

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EXECUTIVE SUMMARY

Over the past few decades, tall vehicles have become much more commonplace on American roads. These vehicles pose great risks to pedestrians as they have significantly larger blind zones and higher levels of pedestrian injury severity. Notably, these vehicles have also become taller, resulting in increasing blind zones over time. This phenomenon, often called "car bloat," combined with distractions from electronic devices and risky driving behaviors, has contributed to an 80% rise in pedestrian fatalities in the United States since 2009's record low. A 2023 Insurance Institute for Highway Safety (IIHS) study found that vehicles with hood heights over 40 inches are approximately 45% more likely to cause fatal pedestrian crashes than lower-profile vehicles. Wisconsin's crash trends reflect this national pattern, with tall vehicle-involved crashes now surpassing those involving non-tall vehicles in recent years.

To address this issue, the Wisconsin Department of Transportation (WisDOT) commissioned a study (WisDOT 0092-24-12) led by the University of Wisconsin-Milwaukee. The goal was to identify effective engineering and policy countermeasures that improve pedestrian visibility, especially in interactions with tall vehicles that have large blind zones and elevated front profiles.

The research team conducted a comprehensive review of 83 academic and industry sources and analyzed 39 years of single-vehicle single-pedestrian (SVSP) crash data from Wisconsin, Tennessee, and Florida. The dataset comprised 101,778 crashes that spanned the 2010s, a decade marked by rapid growth of tall vehicles. Vehicle heights were identified by joining crash data with the Canadian Vehicle Specifications (CVS) database through the National Highway Traffic Safety Administration (NHTSA) VIN Decoder, defining tall vehicles as those exceeding 66 inches in height. The finding shows a steady rise in tall vehicle crash involvement, with Wisconsin's tall vehicle crash share increasing by over 30% between 2008 and 2022, surpassing non-tall vehicle involvement.

The crash data analysis revealed notable differences in crash patterns involving tall versus non-tall vehicles across three states. In Wisconsin, SVSP crashes most frequently occurred in speed zones of 20–25 mph and 30–40 mph, while Tennessee and Florida reported most crashes in the 30–40 mph range. When stratified by vehicle type, tall vehicles consistently showed higher crash percentages than non-tall vehicles in critical maneuvers, particularly left turns and backing. Crashes involving tall vehicles were overrepresented in nearly every pedestrian location and crash scenario, regardless of lighting.

To quantify contributing factors, the research team developed statistical models focusing on crash involvement and injury severity. Tall vehicle involvement was significantly associated with certain road and driver characteristics: backing and left-turn maneuvers, failure to yield, and other factors (e.g., driver condition) all increased the likelihood of a tall vehicle crash by over 50%. Similarly, crashes on rural roads, divided highways, and in parking lots showed elevated risk, along with posted speed limits at ≤15 mph, 30–40 mph, and ≥45 mph. Pedestrian presence in the crosswalk or roadway also raised the odds of a crash with a tall vehicle compared to when pedestrians are on the sidewalk. In Wisconsin, tall vehicles were linked to a 36% increase in severe pedestrian injuries, though this trend did not hold in Tennessee or Florida. After including interaction variable between the states and vehicle types based on tallness, tall vehicles were 22% more likely to be associated with more severe outcomes in Wisconsin, likely due to taller average vehicle heights and a higher proportion of 20–25 mph crashes compared to other states. Across all SVSP crashes in all three states, turning and backing maneuvers tended to have lower injury severity, likely due to slower speeds. However, the interaction between vehicle maneuvers and tallness showed elevated injury severity associated with tall vehicles during backing and left turn maneuvers as compared to non-tall vehicles. In other words, the protective effect of these maneuvers is reduced when the vehicle is tall. Additional risk factors for severe outcomes included high speeds, poor lighting, impaired drivers, and older pedestrians, highlighting the need for targeted safety interventions.

Informed by these findings, the team recommended proven countermeasures that improve pedestrian visibility, particularly for drivers of tall vehicles. These include:

- Low-cost, high-impact engineering treatments such as advance yield markings, high-visibility crosswalks, curb extensions with daylighting, leading pedestrian intervals (LPIs), refuge islands, and raised crosswalks.
- Flashing pedestrian beacons like Rectangular Rapid Flashing Beacons (RRFBs) and High-Intensity Activated Crosswalks (HAWKs) to improve driver awareness.
- Intersection and midblock design changes that reduce speeds and improve sightlines.

Guided by the Safe System approach, countermeasure selection should focus on four key aspects: prioritizing crash types and locations with fatal and serious injury outcomes; enhancing safety in high-risk communities (e.g., school zones, senior communities, transit hubs); adjusting speed limits to reflect changing vehicle fleet characteristics, and building redundancy into the safety solutions. Finally, the study made recommendations in four strategic areas:

- **Planning**: Pedestrian safety must be fully integrated into transportation planning, from land use to project prioritization, especially as tall vehicles pose growing visibility risks. Applying the Safe System approach by lowering vehicle speeds, improving pedestrian infrastructure, and designing for human error can reduce crashes and create safer, more inclusive communities.
- **Roadway Design and Traffic Operations**: Roadway design and traffic operations should shift from prioritizing efficiency to emphasizing safety, especially in areas where pedestrians are vulnerable to

tall vehicles. This includes narrowing roads, lowering speeds, enhancing pedestrian visibility, and more routinely applying proven safety measures like PHBs, RRFBs, and updated signal timing. Corresponding design options should be supported by assertive and clear guidance in manuals such as the Facilities Development Manual (FDM) and Manual for Uniform Traffic Control Devices (MUTCD).

- **Safety Analysis and Evaluation**: Agencies should use data-driven analysis including crash modeling, video analytics, and field observations to identify and address pedestrian visibility issues around tall vehicles. Incorporating vehicle height in crash prediction and conducting before-and-after evaluations of safety interventions will help refine strategies and ensure effective implementation of both proven and emerging countermeasures.
- **Driver Education and Outreach**: Risky driver behavior like speeding and failure to yield are major contributors to crashes involving tall vehicles, often worsened by their larger blind zones. Agencies should update driver education materials, conduct targeted outreach campaigns, and partner with local communities to promote awareness of pedestrian visibility challenges, especially for vulnerable groups.

This research provides WisDOT with actionable strategies to address the increasing threat posed by tall vehicles to pedestrian safety. Implementing these engineering and policy recommendations will help prevent severe injuries and fatalities and create a safer transportation environment for all users.

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INTRODUCTION

As American cities undergo increasing urbanization and densification, more pedestrians and vehicles are sharing the same space. Tall vehicles like trucks, buses, and SUVs are more common on roads, heightening the risk of collisions with pedestrians. This pressing safety issue is compounded by the pervasive distraction of electronic devices such as smart phones, affecting both drivers and pedestrians, and the increase in aggressive and risky driving behaviors. Over the past three decades, the dimensions of the average U.S. passenger vehicle have grown substantially, contributing in part to an alarming 80 percent increase in pedestrian fatalities since 2009's record low. A 2023 study by The Insurance Institute for Highway Safety (IIHS) revealed that pickups, SUVs, and vans with hood heights exceeding 40 inches are roughly 45 percent more likely to result in pedestrian fatalities compared to vehicles with lower hood heights and a sloping profile (Tyndall, 2024).

Tall vehicles have significant blind zones, particularly in their immediate front and rear, potentially obscuring pedestrians from view, especially children. Large vehicle design elements like wide a-pillars and large mirrors could obscure pedestrians during turning movements. However, our understanding of effective countermeasures to enhance pedestrian visibility to tall vehicles remains hindered by inadequate high-quality and comprehensive data, complex interactions between pedestrians and tall vehicles, wide disparities in pedestrian facilities and roadway infrastructure, and challenges and opportunities posed by technology and regulation. Addressing these limitations demands a concerted effort involving researchers, engineers, policymakers and industry stakeholders, emphasizing the adoption of a Safe System approach that addresses infrastructure, vehicle design, speed management, behavior, and post-crash response.

We performed a comprehensive data collection from at least eight years in three states – Wisconsin, Tennessee, Florida – to support an in-depth analysis of single-vehicle single-pedestrian (SVSP) crash data, and the identification of safety and policy measures aimed at improving pedestrian safety and visibility. The primary emphasis is on pedestrian interactions with vehicles, particularly those vehicles with limited fields of vision that are known to pose higher risks.

There has been little research regarding the effects of vehicle height and pedestrian visibility, despite the supersizing of vehicles over the past three decades. However, taller vehicles have significantly larger blind zones. If nothing is done to circumvent these issues, the number of crashes will continue to rise, along with the death and injury toll. We aim to investigate the relationship between tall vehicles and pedestrian visibility to provide recommendations. We anticipate these recommendations will reduce the likelihood of SVSP crashes, especially those involving tall vehicles, and reduce the injury severity.

LITERATURE REVIEW

The project team reviewed past pedestrian safety studies and established a foundation for defining tall vehicles, the relationship between visibility issues and vehicle height, pedestrian crash typologies linked to these factors, and related countermeasures suggested in the literature.

Vehicle Type, Height and Visibility

Studies on vehicle design and size generally categorize vehicles into passenger cars, either separate or combined groups of light-truck vehicles, such as SUVs, pickup trucks, minivans, and larger commercial vehicles (Ballesteros, Dischinger, & Langenberg, 2004), (Liu, Hainen, Li, Nie, & Nambisan, 2019). Recent research goes further by dividing SUVs into small and large categories (Tyndall, 2021) (Tyndall, 2024). This categorization accounts for smaller SUVs like crossovers, which have recently driven consumer vehicle sales. According to a report, the market share of crossovers has been steadily increasing since 2004, reaching approximately 40% of consumer vehicles by 2018, as illustrated in Figure 1 (Consumer Reports, 2019). This growth has largely come at the expense of conventional SUVs and passenger car models such as sedans and coupes.

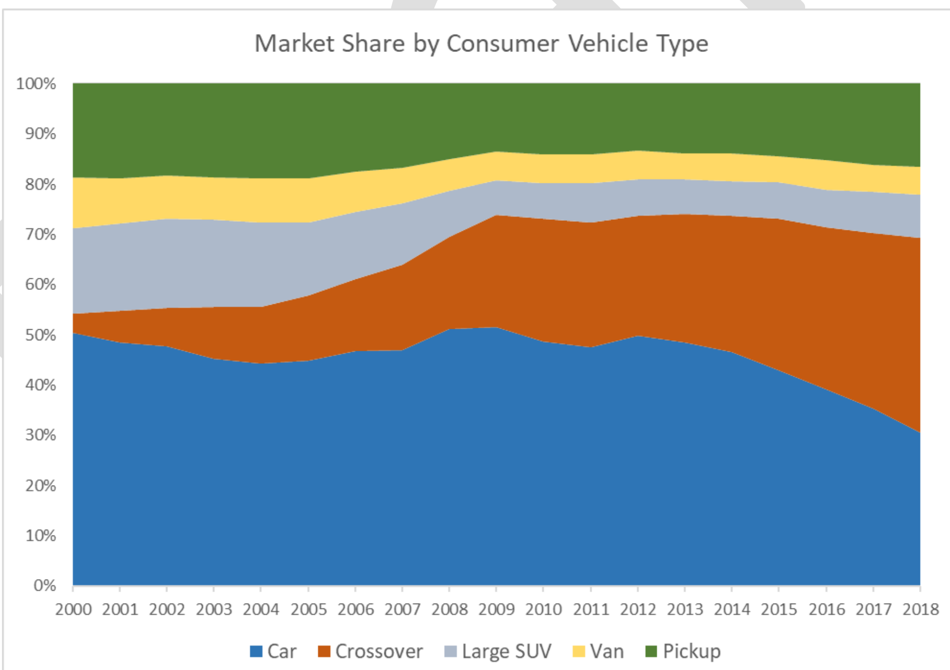

Figure 1. Consumer Vehicle Market Share. Modified from (Consumer Reports, 2019) (Originally Sourced from Wards Intelligence)

Although some studies have started using more detailed vehicle type categories, very few have included these measurements in their analyses (Tyndall, 2024). A common explanation for this omission is that many studies treat vehicle type as a control variable and extend this control to account for vehicle dimensions. Figure 2 presents the distribution of vehicle heights for 23,240 consumer vehicles, with model years spanning 1995 to 2024, from the Canadian Vehicle Specifications (CVS) dataset, a standardized source that includes overall height and other dimensions for North American vehicles categorized by year, make, and model (The Canadian Association of Road Safety Professionals, 2024). Over time, this distribution reveals significant shifts. In the 1995–2004 decade, two primary peaks emerge, one representing consumer vehicles with lower heights (4 to 5 feet), possibly representing passenger cars, and another representing light trucks with higher heights (5 feet and above). In contrast, the most recent decade shows three distinct peaks, likely reflecting crossovers (approximately 5.25 to 6 feet) alongside large SUVs and pickup trucks (6 feet or above). This trend aligns with the growing popularity of crossovers as consumer vehicles (Consumer Reports, 2019). Furthermore, the histograms provide valuable insight into defining tall vehicles and ensuring that the categorization appropriately encompasses vehicles that pose visibility challenges for pedestrians, including crossovers, large SUVs, minivans, and pickup trucks.

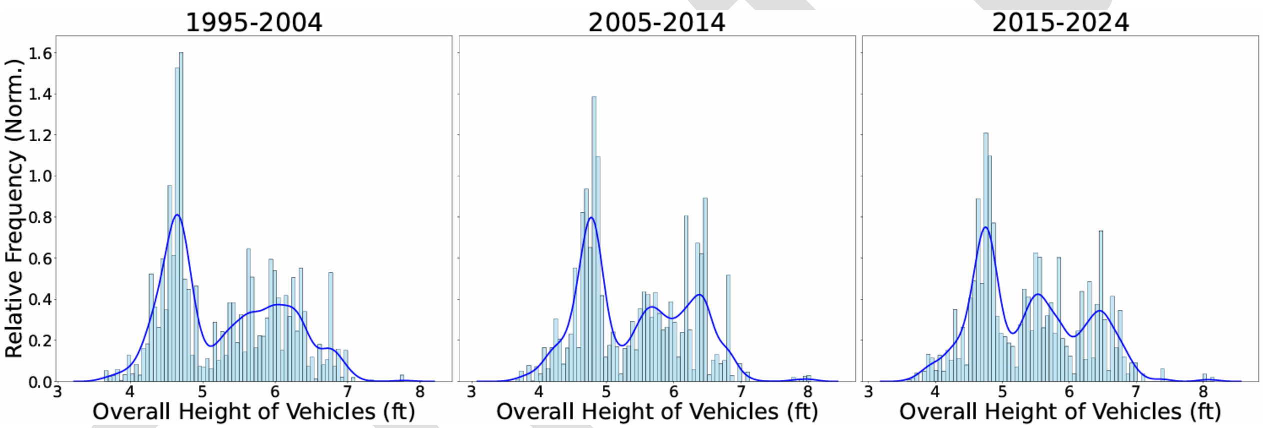

Figure 2. Distribution of Vehicle Height of Models listed in the CVS dataset over 30 years.

Existing studies have linked vehicle-related visibility issues with vehicle body type and design and have found mixed results. For instance, tall vehicles offer better visibility over vertical curves (Zwahlen & Schnell, 1999). Taller vehicles, however, come with larger blind zones, making it harder to detect nearby pedestrians or obstacles (Hu & Chicchino, 2022). For instance, A-pillar blind zones are a common visibility concern in all vehicles. Thicker A-pillars will make the A-pillar blind zone larger in these vehicles. Manufacturers also equip these vehicles with larger mirrors to address the reduced field of view caused by the greater distance between the driver and the mirror (Sivak, Devonshire, Flannagan, & Reed, 2008). The large mirrors and thicker A-pillars further obscure vulnerable road users, such as pedestrians. Further exacerbating visibility is the front hood height of these vehicles, which is generally higher than the height of children, producing a substantial blind zone in the front (Schmitt, 2020). In vehicles without backup cameras, blind zones behind the vehicle range from 9 to 13 feet for sedans and 13 to 24 feet for SUVs and pickup trucks for an average driver (Consumer Reports, 2014). The effect of a thicker A-pillar, larger mirrors, and higher front hood height on blind zones is illustrated in Figure 3. The figure compares the blind zones of a sedan and a full-size SUV using a web-based application called VIEW Blindzone Calculator (Drake, et al., 2023). The figure shows that the ground blind zone and blind zone for a 37-inch-tall elementary school child are considerably larger in the SUV than in the sedan. For a 49-inch-tall pedestrian, the blind zone is nearly nonexistent in the sedan, while it remains substantial in the SUV. On this note, we can also assume that blind zones will be even larger on vehicles with increased heights due to after-market customization.

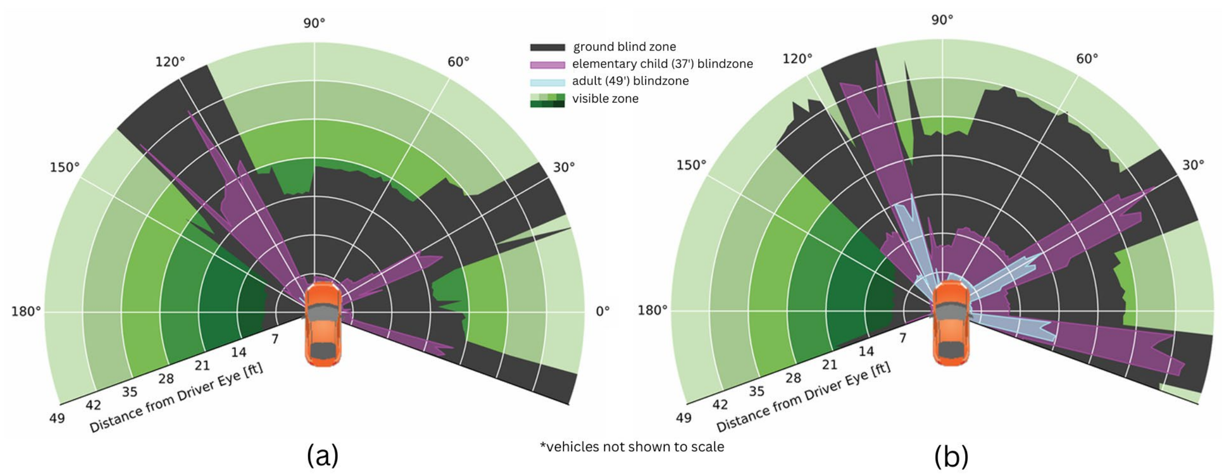

Figure 3. Comparison of Blind Zones for (a) 2024 Nissan Altima and (b) 2025 Honda Pilot (VIEW Blindzone Calculator, n.d.)

As shown above, the blind zones at the front of the tall vehicle extend much farther as compared to that of the non-tall vehicle. Recent studies confirm that taller vehicles have larger blind zones that contribute to reduced visibility. Researchers with the United States Department of Transportation (USDOT) and IIHS found that "outward visibility" decreased in all six vehicle models measured over time, with SUVs having a 58% reduction in visibility within a 10-meter radius. It's important to mention that non-tall vehicles have reductions in outward visibility, but they are much smaller, ranging from 7% to 19%. (Epstein, et al., 2025).

Pedestrian Crashes involving Tall Vehicles

Although there is no direct evidence suggesting tall vehicles are responsible for a higher number of pedestrian crashes, studies unanimously agree that these vehicles are responsible for higher severity rates of pedestrian crashes (Desapriya, et al., 2009), (Edwards & Leonard, 2022), (Liu, Hainen, Li, Nie, & Nambisan, 2019). According to a meta-analysis of 11 studies, the risk of a pedestrian sustaining fatal injuries is 50 percent higher when struck by a light truck vehicle compared to a passenger car (Desapriya, et al., 2009). The crucial variables responsible for causing severe injury outcomes in pedestrian crashes are vehicle impact speed, size/weight, and design. Impact speed and vehicle weight contribute to the transfer of kinetic energy, and vehicle body type and design contribute to injury mechanisms during and just after the crash (Ballesteros, Dischinger, & Langenberg, 2004), (Hu, Monfort, & Chicchino, 2024), (Islam, 2023), (Tyndall, 2021). Existing research has extensively studied the relationship between vehicle impact speed and pedestrian safety risks, and design and policy-related strategies to minimize them (Hussain, Feng, Grzebieta, Brijs, & Oliver, 2019), (Tefft, 2013). On the other hand, the individual effects of vehicle weight and design remain underexplored, as most studies use vehicle body type as a proxy for weight, obfuscating the analysis. That said, Tyndall has shown that vehicle design aspects, indicated by the vehicle type and front hood heights, might be more crucial than weight in determining injury severity in pedestrian crashes (Tyndall, 2024). Very few studies have explored the correlation between vehicle design parameters, such as front hood height, shape, and slope, body types, and material, and pedestrian injuries (Han, Yang, Mizuno, & Matsui, 2012), (Hu, Monfort, & Chicchino, 2024), (Tyndall, 2024). The shape and slope of a vehicle's hood influence the contact area and where a pedestrian is hit during a crash, affecting injury outcomes (Hu, Monfort, & Chicchino, 2024). Design variables such as vehicle width, length, wheelbase, and center of gravity have rarely been included in analyses, likely because their effects are often captured by more intuitive and commonly used parameters in pedestrian crash studies.

In pedestrian-vehicle collisions, injury severity is shaped by the impact force and body region struck, with head and chest impacts often leading to more serious outcomes than those to the limbs. Most research focuses on frontal collisions and blunt trauma, with findings highlighting the importance of vehicle front-end design. Han et al. (2012) found that, beyond impact speed, vehicle shape plays a crucial role: medium-sized sedans and SUVs increased the risk of head and lower extremity injuries, minivans were more likely to cause chest injuries, and both minivans and SUVs were linked to a higher likelihood of pelvis fractures. Minicars, by contrast, had a lower overall injury risk. Similarly, Simms and Wood (2006) reported that SUVs caused more severe lower-body injuries due to their larger, flatter front ends, which limit pedestrian rotation and amplify energy transfer. Hu et al. (2024) analyzed nearly 18,000 crash reports and determined that tall-blunt, tall-sloped, and medium-height-blunt front-end profiles increased pedestrian fatality risk by 43.6%, 45.4%, and 25.6%, respectively. Tyndall (2024) further observed that every 10 cm increase in front-end height raised fatality risk by 22%. Beyond primary impacts, the biomechanics of secondary impacts have also been studied. Halari et al. (2022) found that tall vehicles like pickup trucks disproportionately run over child pedestrians, even at low speeds. Hamacher et al. (2012) noted that SUVs and minivans posed "very critical" secondary impact risks, especially to children, while lower-hood vehicles posed "moderate" to "critical" risks. Simms et al. (2011) concluded that higher front-end vehicles also led to more severe ground-contact injuries in pedestrian crashes.

The literature consistently shows that collisions involving tall vehicles and pedestrians tend to result in more severe injuries, though visibility advantages and disadvantages affect certain crash risks. Dozza et al. (2020) emphasize that pedestrian visibility timing, speed, and path are critical for driver response at intersections. Tools like the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) help classify crash scenarios influenced by visibility limitations, particularly those linked to tall vehicles (Thomas et al., 2022). In parking lots and driveways, although vehicle speeds are low, young children are disproportionately involved in crashes where they are backed over by taller vehicles (Desapriya et al., 2009; Fenton et al., 2005; Muttart et al., 2011; Stanley et al., 2011). Rearview cameras reduce such backing crashes by an estimated 41% (Austin, 2008; Keall et al., 2017), but risks remain for older vehicles without this technology and for hazards in tall vehicle front blind zones (Consumer Reports, 2014; Schmitt, 2020). Elderly pedestrians are also more vulnerable in these scenarios (Kim & Ulfarsson, 2019).

Taller vehicles also pose risks during turning maneuvers, especially at intersections. Left turns are particularly hazardous due to visibility obstructions from the driver-side A-pillar, which create compounded blind zones obscuring pedestrians, especially shorter individuals or those using mobility aids (Reed, 2008; Drake et al., 2023). Cherry et al. (2024) and Ulfarsson et al. (2010) confirm that drivers often fail to notice pedestrians during low-speed turning or merging. While right turns typically involve less severe visibility issues, blind zones on the passenger side may still contribute to crashes, especially when drivers focus on oncoming traffic from the left (Roudsari et al., 2007). Additionally, multiple-threat crashes occur when a pedestrian is struck by a second vehicle whose driver's view is blocked by a stopped vehicle in an adjacent lane—a problem not exclusive to large vehicles but exacerbated by the visual obstruction they pose (Thomas et al., 2022; Fisher & Garay-Vega, 2012).

Most existing design guidelines for vehicle visibility issues, such as driver eye height for determining sight distances, are tailored to the smallest passenger vehicles, like sedans and coupes. Particularly, addressing the issues with these vehicles will accommodate taller vehicles by default. However, existing research has proven that taller vehicles are associated with larger blind zones around the vehicle, posing a significant threat to pedestrians. These blind zones increase the risk of direct collisions with pedestrians and can contribute indirectly to multi-threat scenarios by becoming taller obstacles. The growing popularity of crossovers SUVs on U.S. roads and the increasing average height trends of pickup trucks—often exceeding 20 years in turnover and prone to height-related modifications—amplifies the risks associated with tall vehicles.

DATA COLLECTION AND PROCESSING

Crash Data

We performed a comprehensive data collection from Wisconsin, Tennessee, Florida to support an in-depth analysis of SVSP crash data, and the identification of safety and policy measures aimed at improving pedestrian safety and visibility. The primary emphasis is on pedestrian interactions with vehicles, particularly those vehicles with limited fields of vision that are known to pose higher risks. This task involves sourcing and integrating diverse datasets to create a robust foundation for developing effective engineering enhancements and policy recommendations. Table 1 summarizes the data collection effort in this task, which includes:

- State Crash Data: Information from Wisconsin, Tennessee, and Florida, including Vehicle Identification Numbers (VINs) that will link to specific vehicle geometry (e.g., height) and crash coordinates.
- Vehicle Specifications: Using NHTSA VIN Decoder and the Canadian Vehicle Specifications dataset to obtain details on vehicle mass and dimensions, crucial for categorizing vehicles by height.
- Road Geometry and Traffic Data: roadway geometric characteristics, intersection configuration and traffic control strategies, and post speed limit.

Table 1. Data Collection Summary

Data Type	**Data Source**	**State**	**Year**
Crash Data[1]	WisDOT (MV4000 or DT4000)	WI	2008-2022
	Tennessee Integrated Traffic Analysis Network (TITAN)	TN	2009-2023
	FDOT	FL	2012-2020
Vehicle Specifications	NHTSA VIN Decoder	WI, TN, FL	2008-2023
	Canadian Vehicle Specifications (CVS)	WI, TN, FL	2008-2023
Road Geometry and Traffic Data	WisDOT (MV4000 or DT4000)	WI	2008-2023
	Tennessee Integrated Traffic Analysis Network (TITAN)	TN	2009-2023
	FDOT	FL	2012-2020

The following details the data sources and data fields as well as their values for Wisconsin, Tennessee and Florida, respectively. We collected crash data for the state of Wisconsin using WisTransPortal and Wisconsin Motor Vehicle Crash Data. For most of the data, we used WisTransPortal, which provides two different motor vehicle crash reports: MV4000 and DT4000. While DT4000 has a wider range of data

[1] Crash data may include crash narratives that help to identify stated visibility issues in the crash report

fields, MV4000 was used because DT4000 was not implemented until 2017. WI SVSP crash data from 2008 to 2022 was pulled from MV4000. The study scope is limited to SVSP crashes. We limited crashes to the SVSP scenario to all our research to be focused on the visibility issue occurring, eliminating chain reactions where other vehicles are involved after the initial crash. More complex crashes with more than two units could overcomplicate the data, making it harder to find contributing factors to tall vehicle crashes. When we collected the data on pedestrian crashes involving tall vehicles, some data needed to be removed. The original dataset from 2008-2022 contained crash data for 16,215 SVSP crashes in Wisconsin. Of these crashes queried from WisTransPortal, we needed to remove some from the dataset because they had more than two units according to the crash report, involved buses or semis (for which there is no vehicle height data in CVS), or there was no vehicle information available (hit and run scenario). After this data removal, 11,756 SVSP crashes remained for the 2008 to 2022 data. Of these 11,756 SVSP crashes, 4,766 involved tall vehicles. MV4000 provided us with an extensive list of data fields that can be sorted into general categories. There are three different categories for the data fields: roadway/traffic, person-level (or behavioral), temporal/environmental.

We used the Tennessee Integrated Traffic Analysis Network (TITAN) database for Tennessee pedestrian crash data spanning 15 years from 2009 to 2023. Crash reports in the TITAN dataset adhere to the Model Minimum Uniform Crash Criteria (MMUCC) guidelines established by the Department of Safety and Homeland Security to ensure consistency (NHTSA, 2017). Injury outcomes in TITAN are classified using the same KABCO scale (FHWA). The database is organized into person, vehicle, and crash datasets. Comprehensive crash information is obtained by linking these datasets through a unique master record number assigned to each crash. 27,281 instances of pedestrian crashes from 2009 to 2023 were collected. Over 27,281 crashes, 28,874 pedestrians were involved. After we excluded cases involving multiple vehicles or pedestrians, 23,670 SVSP crashes were analyzed.

The Florida pedestrian crash data spanned 9 years from 2012 to 2020. Similar to the Tennessee data, injury outcomes in the Florida crash data were classified using the KABCO scale. 88,642 instances of pedestrian crashes involving a total of 95,919 pedestrians were collected. After excluding cases involving multiple vehicles or pedestrians, 66,352 SVSP crashes remained.

Vehicle Information

To determine the vehicle year, make, and model information, we used the National Highway Traffic Safety Administration (NHSTA) VIN Decoder and the Canadian Vehicle Specifications (CVS) database to determine a vehicle's overall height based on the year, make, and model. It's important to note that these standardized data sources reflect vehicle specifications at the time of manufacture and do not account for aftermarket modifications, such as driver-added increases in vehicle height.

The National Highway Traffic Safety Administration (NHTSA) maintains a platform that can provide detailed information about a vehicle's make and model based on the VIN. The VIN Decoder is powered by the Product Information Catalog and Vehicle Listing (vPIC) section of NHTSA. The purpose of the VIN decoder is to provide users with consolidated information about a given vehicle, including the plant of manufacture. For this study, we needed the make and model information. We gathered the VINs from the Wisconsin Motor Vehicle Crash Data and input into the VIN Decoder to retrieve said information.

The Canadian Vehicle Specifications (CVS) is owned and maintained by the Collision Investigation and Research Division of Transport Canada. The CVS database details the original dimensions of a vehicle. The primary purpose of CVS is collision investigation and reconstruction. For this study, we needed the overall height (OH) of the vehicle. By inputting the year, make, and model for a given vehicle, we were able to gather the OH information.

We selected a metric for what makes a vehicle tall. After performing a literature review, a clear divide began to emerge around 66 inches (5.5 feet). When analyzing graphics regarding the distribution of vehicle height in feet put out by the CVS from the past three decades, one can observe the emergence of two additional distinct peaks in density from 2005-2024 (refer back to Figure 2 on Page 3). We made the preliminary decision to use 66 inches as the definition for a tall vehicle. A trend analysis of average vehicle age across the model years of vehicles from all three states SVSP crash data further cemented a significant difference between passenger cars and vehicles that are known to be taller such as pick-up trucks, SUVs, and minivans. The data shows the average vehicle height for pick-ups, SUVs, and minivans tends to be above 66 inches in height. Each states data solidified 66 inches as an appropriate definition of a tall vehicle.

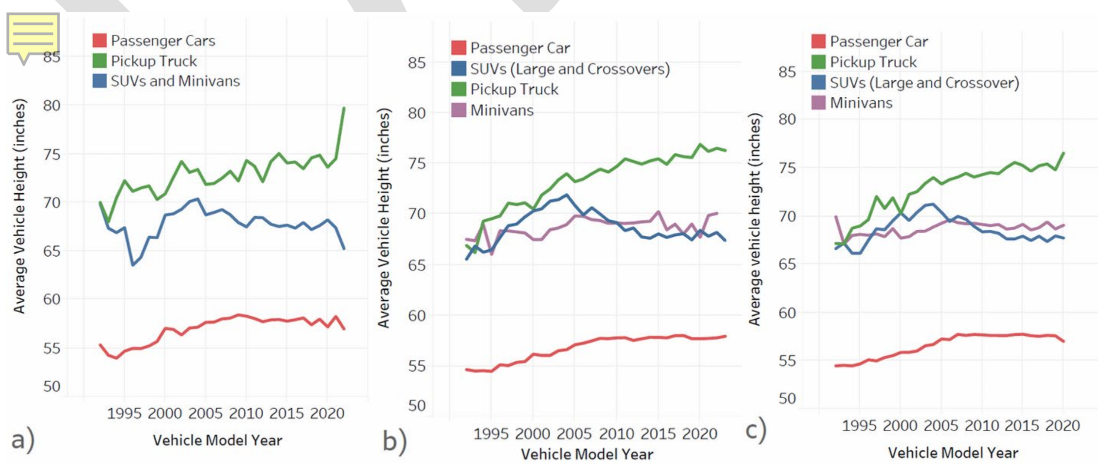

Figure 4. Average Vehicle Height by Model Year for a) Wisconsin[2], b) Tennessee c) Florida

[2] Motorcycle, incomplete vehicle, and buses SVSP crash data were omitted from the chart for simplicity.

To obtain SVSP crashes involving tall vehicles, we developed a methodology to link vehicle height information with crash data, illustrated in Figure 5. The documented crash numbers provided in WisTransPortal were aligned with crash numbers Wisconsin Motor Vehicle Crash Data from which the VIN numbers for the vehicles in each crash were obtained. Then, we input the VIN numbers into the NHTSA VIN Decoder which provided the year, make, and model of the vehicle. We processed the vehicle year, make, and model in the CVS to gather the overall height of the vehicle in inches. Initially, we were hoping to use the vehicle hood height as it aligns more closely with previously published data. However, the CVS does not collect this dimension, so the overall height was used as an alternative.

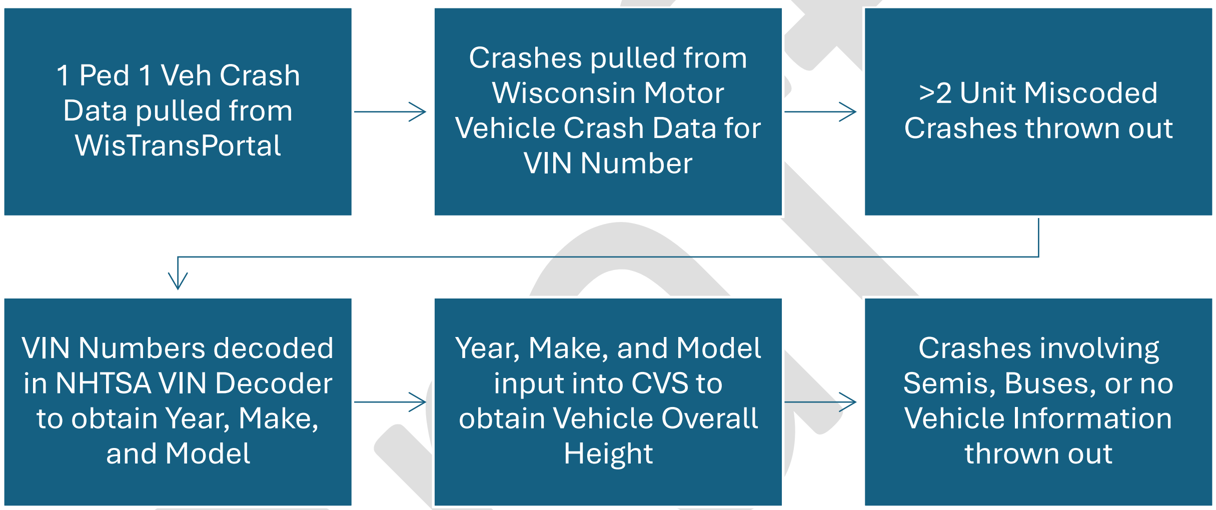

Figure 5. WI Vehicle Height Data Collection Process

Figure 6 illustrates the distribution of vehicle heights involved in SVSP crashes in Wisconsin. The vehicle body types were classified by the NHTSA VIN Decoder. The figure shows that most light truck vehicles, such as multipurpose passenger vehicles and trucks, fall under the tall vehicle classification.

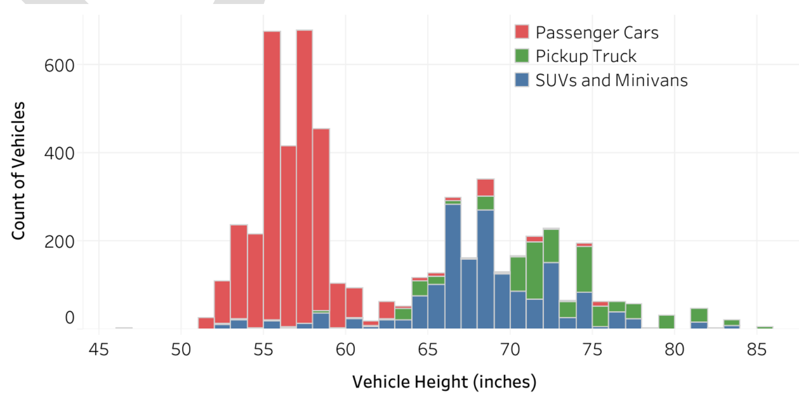

Figure 6. Distribution of Vehicle Height across Vehicle Type in WI SVSP Crashes, 2008-2022[3]

[3] Motorcycle and incomplete vehicle SVSP crash data was omitted from the chart for simplicity.

Figure 7 illustrates the distribution of vehicle heights involved in SVSP crashes by vehicle body types. The figure shows that most light truck vehicles, such as SUVs and pickup trucks, fall under our classification of tall vehicles. In Tennessee, after we ran the data through CVS, 14,893 crashes were retained. Of these crashes, 6,322 involved tall vehicles (an overall height threshold of 66 inches). The remaining 8,571 crashes involved non-tall vehicles. Similarly, in Florida, 45,629 crashes were retained. Of these crashes, 18,033 vehicles were classified as tall, while the remaining 27,589 were categorized as non-tall vehicles. We used an overall height threshold of 66 inches.

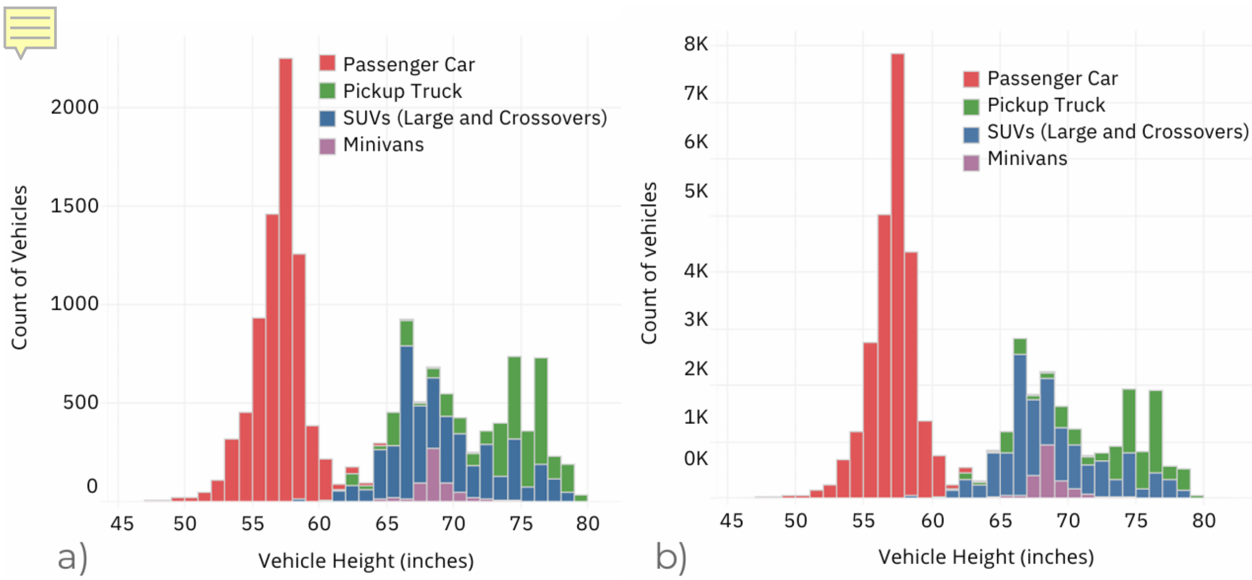

Figure 7. Distribution of Vehicle Height across Vehicle Types in a) TN SVSP b) FL SVSP Crashes

EXPLORATORY DATA ANALYSIS

Descriptive Statistics of Crash Data

The literature has identified crash features mostly linked to visibility issues in pedestrian crashes. These features include low-speed maneuvers like turning, backing, and accelerating maneuvers, lighting conditions, location and actions of pedestrians during the crash, and pedestrian features relating to their heights, such as gender and age found in crash information. This section presents selected exploratory data analysis for data from WI, TN, and FL.

As the preliminary data analysis was performed, we analyzed the number of crashes by year for both non-tall and tall vehicles over time, as shown in Figure 8. In 2008, non-tall vehicles made up over 70% of the SVSP crashes in Wisconsin. As the years progressed, the percentage of non-tall vehicles involved in SVSP crashes decreased, while the percentage of tall vehicles continued to rise from 2008 to 2022. This trend continues as 2022 was the first year where there were more SVSP crashes involving tall vehicles than non-tall vehicles.

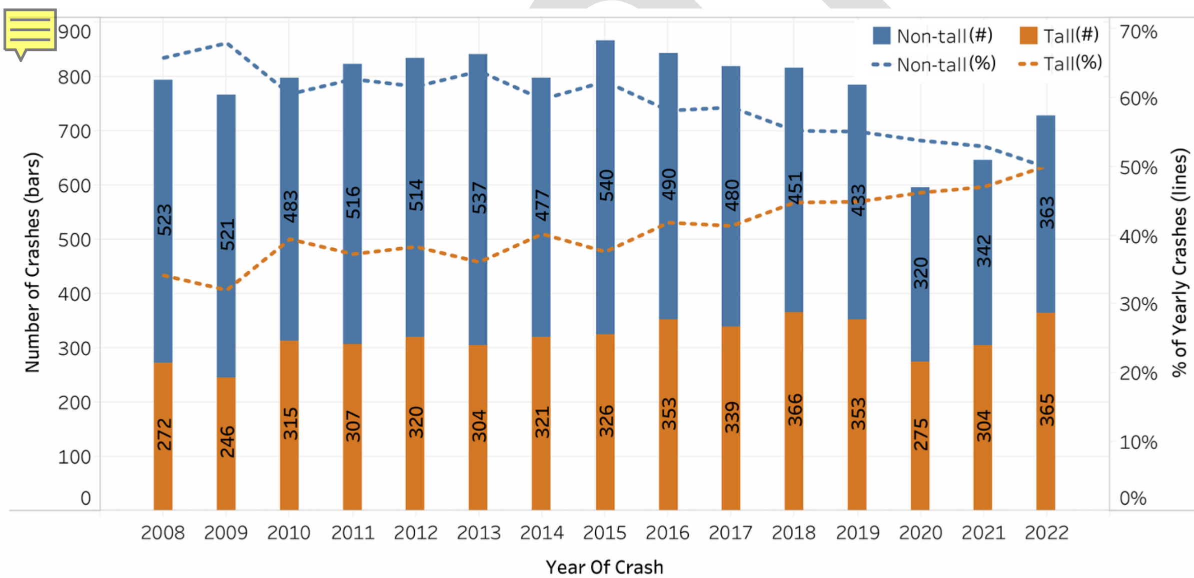

Figure 8. WI SVSP Crashes by Year (2008-2022)

After setting 2008 as the base case, we analyzed the yearly change in crashes from 2008 for both non-tall vehicles and tall vehicles, as shown in Figure 9. Except for 2013 and 2015, non-tall vehicles had a negative percent change compared to 2008, meaning the number of non-tall vehicle SVSP crashes decreased. Conversely, tall vehicles experienced a positive percentage change each year, except in 2009. In 2020, there was a slight difference compared to 2008, but by 2022, the percentage change had returned to the alarming rates observed from 2016 to 2019. Compared to 2008, tall vehicle crashes were up by over 30% in 2022.

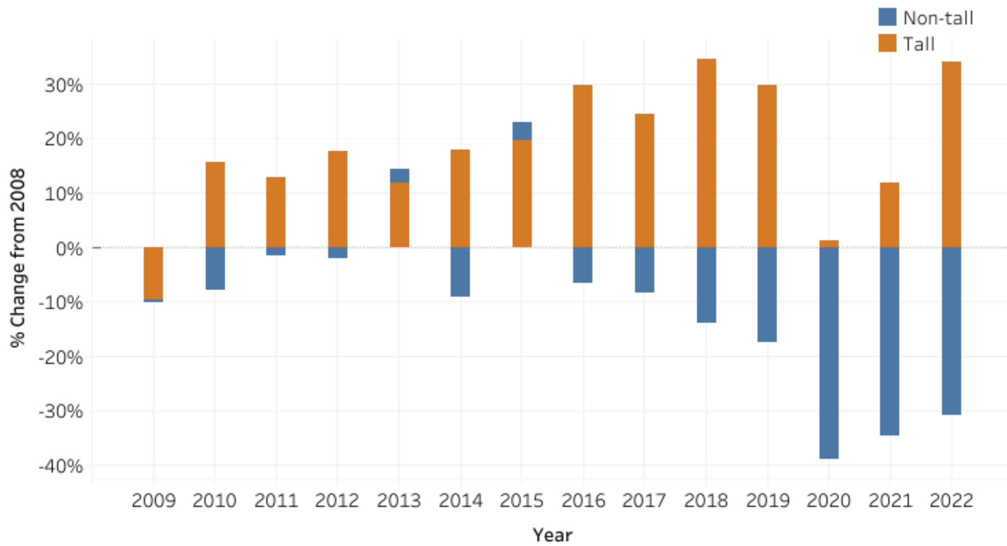

Figure 9. Yearly Change in WI SVSP Crashes from 2008

It is important to gauge the level of injuries occurring when crashes occur. We analyzed crashes by pedestrian injury severity, which reflects the injury level inflicted on the pedestrian. Injury severity is rated on the KABCO scale. For both non-tall and tall vehicles, B is the most common pedestrian injury severity outcome in Wisconsin, followed by C, which represents possible injury.

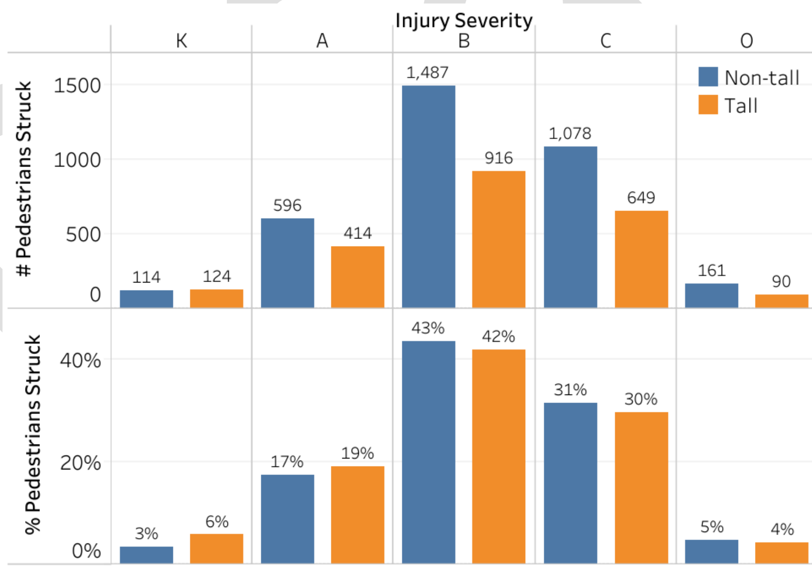

Figure 10. WI SVSP Crashes by Pedestrian Injury Severity, 2008-2022

The percentage shares across tall and non-tall vehicles for non-fatal injuries are uniform for all three states, WI, TN, and FL, as shown in Figures 10 and 11. Notably, however, in Wisconsin, the percentage of tall vehicles involved in fatal outcomes is twice that of non-tall vehicles, unlike in Tennessee and Florida, where the shares are approximately equal across vehicle types.

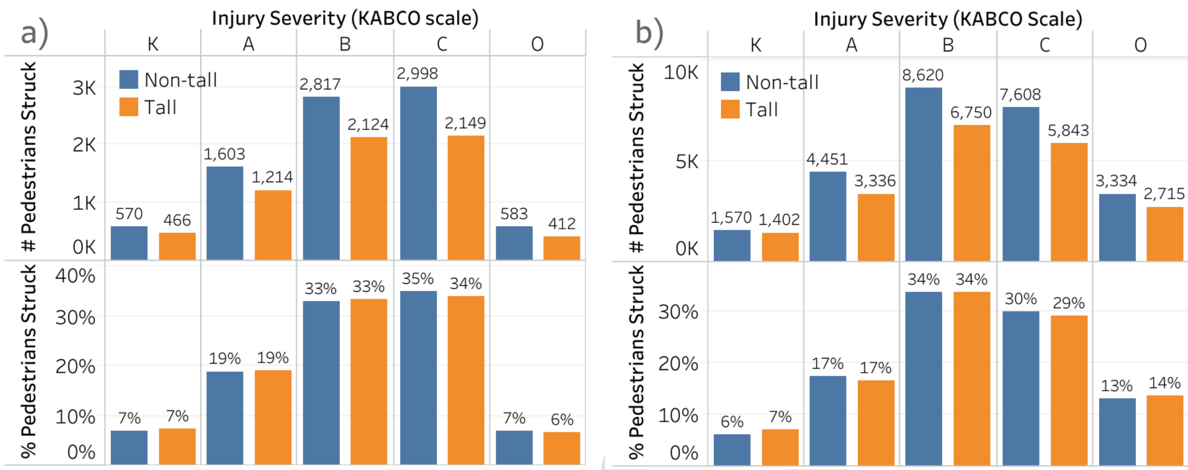

Figure 11. SVSP Crashes by Pedestrian Injury Severity a) TN, 2009-2024 b) FL, 2012-2020

Posted speed identifies the speed limit for a vehicle at the location where the crash occurred. Posted speed is a vital data field, as inferences can be made about the population density of the surrounding area. Moreover, posted speed is closely related to injury severity in pedestrian crashes. The crashes for both non-tall and tall vehicles categorized by posted speed for Wisconsin are shown in Figure 12, and Tennessee and Florida are shown in Figure 13. The figures indicate that tall vehicles are slightly overrepresented in the low-speed category (≤15 mph) across all three states. In Wisconsin, tall vehicles are notably overrepresented at higher posted speeds (≥45 mph), whereas they are slightly underrepresented in that range in Tennessee and Florida. Overall, only about 5% of crashes in Wisconsin occur at high speeds (≥45 mph), with the majority (approximately 38%) concentrated in the 20–25 mph range. This contrasts sharply with Tennessee and Florida, where crashes are least frequent at 20–25 mph, and higher-speed crashes (≥45 mph) account for a substantial share, around 16% in Tennessee and 19% in Florida.

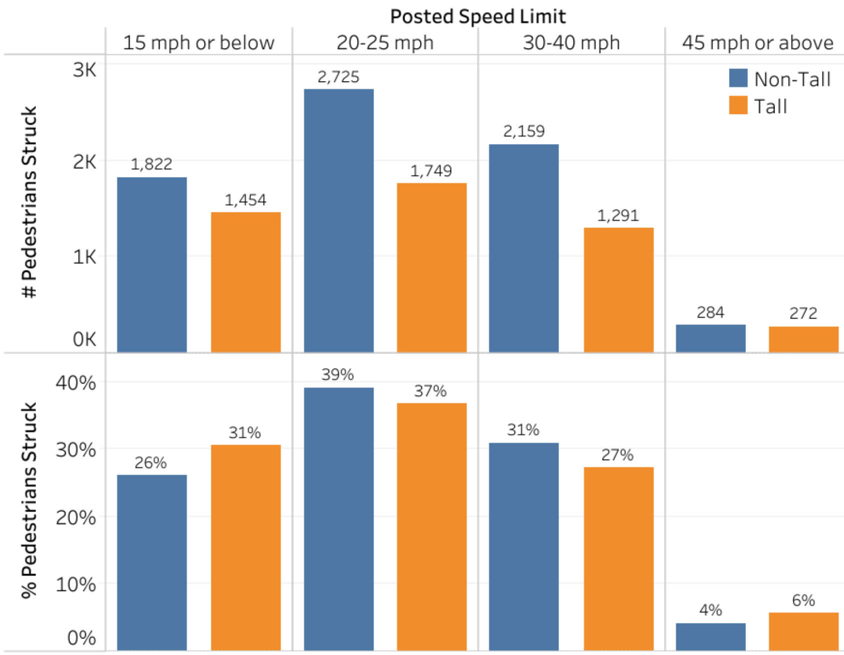

Figure 12. WI SVSP Crashes by Posted Speed, 2008-2022

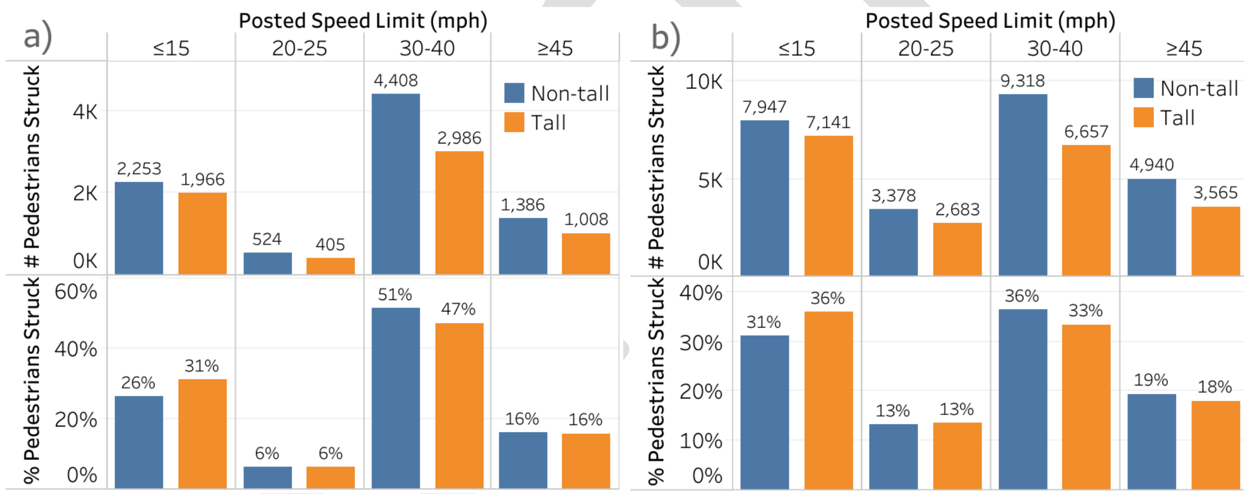

Figure 13. SVSP Crashes by Posted Speed a) TN, 2009-2024 b) FL, 2012-2020

In Wisconsin, most SVSP crashes involved straight maneuvers. Crashes with straight maneuvers could potentially be linked to midblock crossings or crossings at signalized intersection with a green light. The second leading driver action for both non-tall and tall vehicles is a left turning movement. While there were no driver actions where tall vehicles were being overrepresented, we will perform further investigation to determine whether there is a statistical significance when it comes to driver action as it relates to pedestrian injury severity for both non-tall and tall vehicles. The "other" category for driver actions or vehicle maneuvers typically includes activities such as starting or stopping in a traffic lane, parking-related maneuvers, and other uncommon or unclear actions that are often only described in crash narratives.

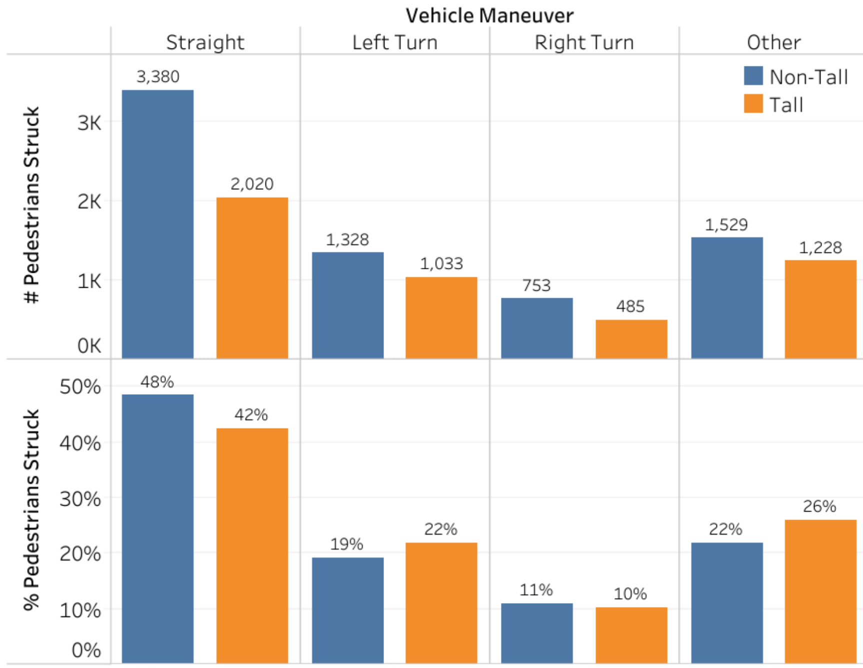

Figure 14. WI SVSP Crashes by Driver Action, 2008-2022

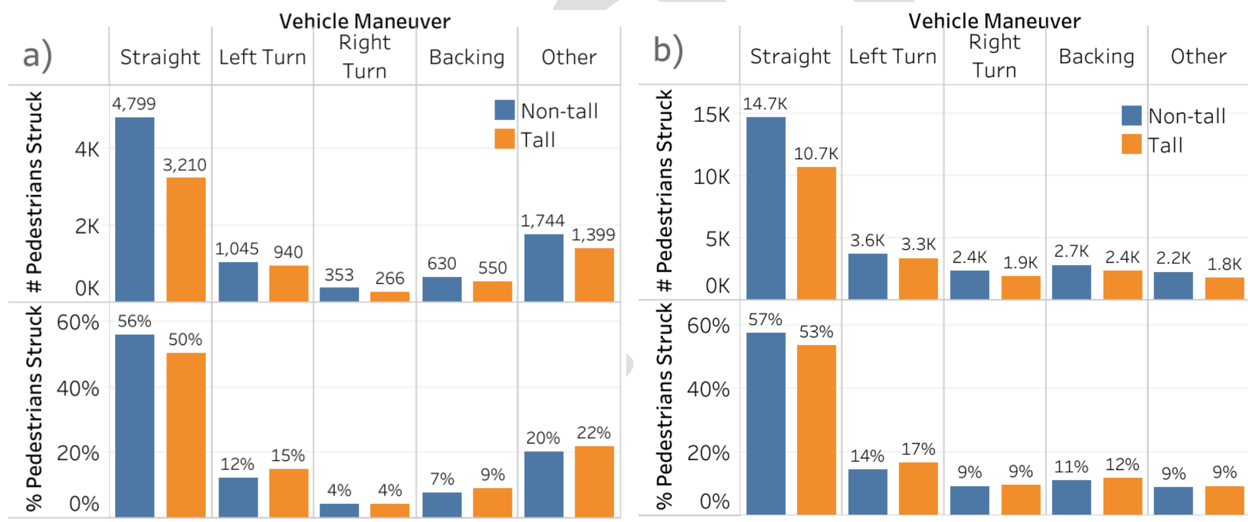

Figure 15. Crashes by Driver Action a) TN, 2009-2024 b) FL, 2012-2020

In Tennessee and Florida, most pedestrian crashes involved straight maneuvers. Crash instances involving this type of maneuver potentially relate to midblock crossings or crossings during the green light for vehicles. Among the SVSP crashes involving tall vehicles in Tennessee, Figure 15 shows that 50% were straight maneuvers, 15% involved left turns, and 14% involved backing or parking-related maneuvers. The non-tall vehicle distribution was largely similar, with marginal decrements in the proportion of backing-and-parking and left-turning maneuvers, with 12% each for both, and a marginal increase for straight maneuvers, with 56% of non-tall vehicles involving straight maneuvers. The distribution is also similar in the case of Florida, shown in Figure 15, with small changes across the distribution.

Pedestrian action provides insight into the movement of the pedestrian at the time of the crash. For Wisconsin, pedestrian action has been consolidated into four actions: signal violation, wearing dark clothing, walking along the road, and sudden movement, and unknown/other. Walking along the road can refer to walking either with the flow of traffic or against it. The "unknown" or "other" actions primarily include those that are either unreported in crash data, described only in crash narratives, or represent specific and infrequent behaviors that do not fit into the general categories of pedestrian actions. Figure 16 shows that, in Wisconsin, tall vehicle SVSPs are slightly overrepresented in cases where pedestrians were walking along the road and wearing darker clothing and slightly underrepresented in cases involving signal violations and sudden entry into traffic.

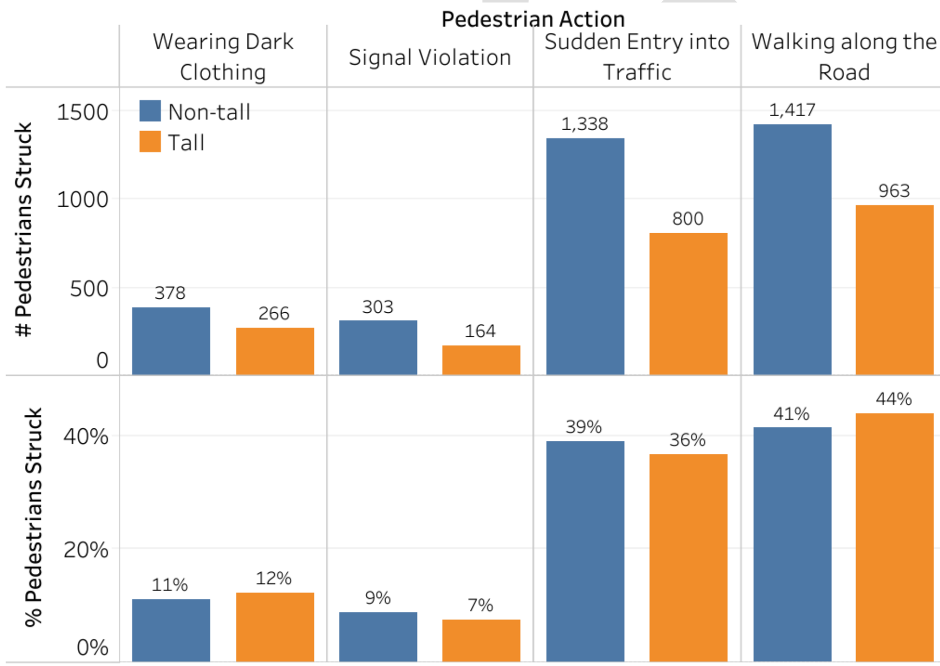

Figure 16. WI SVSP Crashes by Pedestrian Action, 2008-2022

Pedestrian actions before crashes are coded differently in the Tennessee and Florida datasets, as shown in Figure 17. In Tennessee, 66% of pedestrian actions before crashes are categorized as unknown. The remaining data is grouped into five major categories: crossing-related actions (e.g., crossing or waiting to cross), actions near roadways (e.g., working or playing), officer-reported carelessness, visibility-related issues (e.g., blocked by parked vehicles), and walking along roads or road facilities. While the Florida data follows a similar pattern, it is less comprehensive and relies on narrative information to describe more complex actions. Available data shows that visibility-related crashes are overrepresented for tall vehicles in Tennessee while walking along the road is slightly overrepresented for tall vehicles in both states.

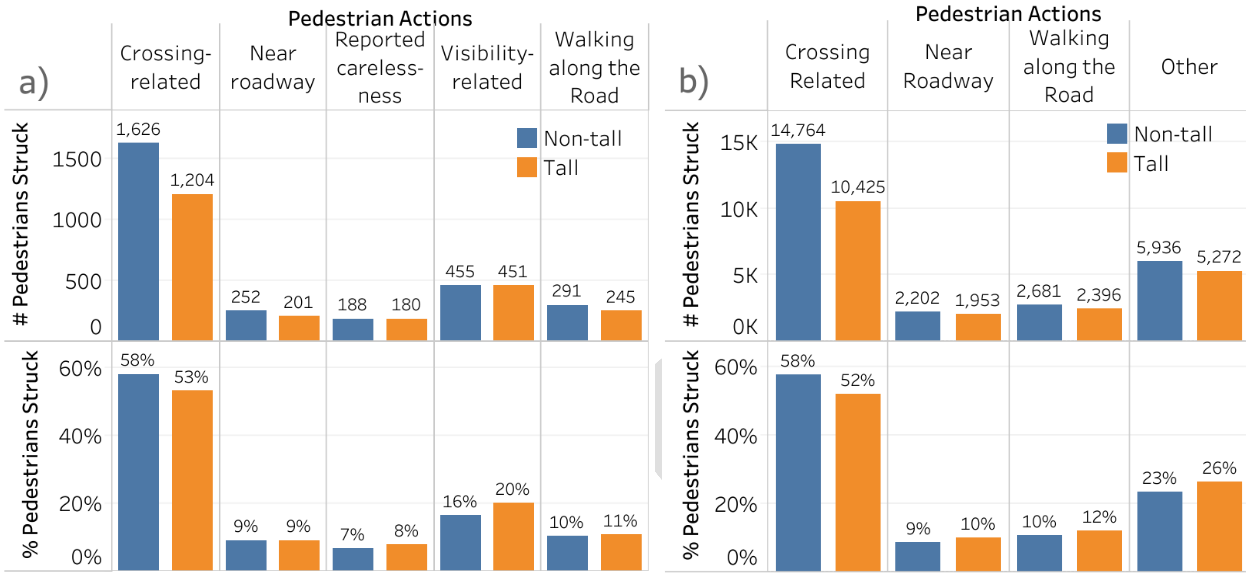

Figure 17. SVSP Crashes by Pedestrian Action a) TN, 2009-2024 b) FL, 2012-2020

Patterns and Scenarios – Typology Analysis[4]

There are data fields relating to the pedestrian and driver that can help characterize the crash scenarios. Within the roadway category, both driver action and pedestrian location are informative. Driver action provides detailed information on what movement the driver was making prior to the crash. Driver action has eighteen different movements that can be analyzed, including turn movements and parking maneuvers. These actions align very closely to the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) elements which can be further combined to create more succinct groupings. Similar to driver action, pedestrian location provides information on how the pedestrian was utilizing the roadway. Pedestrian location provides information on whether the pedestrian was using the crosswalk, sidewalk, or in the roadway. While PBCAT has a wider range of pedestrian locations, PBCAT typology guidelines can still be followed.

Using the information gained from both the literature review and tree modeling, as well as previous knowledge on SVSP crashes, we performed typology analysis to better understand what occurred both prior to and at the time of the crash. We performed the typology analysis using information regarding both the driver and the pedestrian to better understand the movements of each unit. Moreover, we performed typology analysis using roadway factors to get a better understanding of what type of roadways crashes are occurring on. Typologies are key to identifying whether visibility is one of the contributing factors, as it does not exist

[4]All tables calculating the percent difference in this section have the following conditional formatting:
Red fill with red text: -30% difference between non-tall and tall vehicle crashes
Green fill with green text: +5% difference between non-tall and tall vehicle crashes

as a data field. By getting a clear picture of what is happening with typologies, it is possible that crash scenarios relating to visibility will emerge.

Driver Action and Pedestrian Action

When we cross-examined driver action and pedestrian action, we noted that most non-tall vehicle crashes occurred when the driver was going straight, and the pedestrian action was classified as unknown or other. The second most prevalent non-tall vehicle crash typology once again involved the driver going straight and the pedestrian action being considered a "sudden movement." For tall vehicles, the driver going straight when the pedestrian action was unknown/other was once again the most common crash. However, the second most prevalent crash type involved the driver making a left turn when the pedestrian action was unknown or other. When we compared the percent difference between non-tall and tall vehicle crashes, we did not observe any typologies where tall vehicles were being overrepresented.

*Table 2. WI Non-Tall SVSP Crashes by Driver Action and Pedestrian Action**

	Non-tall Vehicle Crashes			
Driver Action	Unknown/Other	Walking in Traffic	Sudden Movement	Total
Going Straight	23.43%	9.00%	15.92%	48.35%
Left Turn	12.93%	5.24%	0.83%	19.00%
Right Turn	7.51%	2.62%	0.64%	10.77%
Backing	8.66%	1.63%	0.33%	10.62%
Other	8.05%	1.79%	1.42%	11.26%
	Tall Vehicle Crashes			
Going Straight	20.63%	8.22%	13.53%	42.38%
Left Turn	15.13%	5.43%	1.11%	21.67%
Right Turn	7.18%	2.48%	0.52%	10.18%
Backing	10.57%	1.93%	0.23%	12.74%
Other	9.50%	2.14%	1.38%	13.03%
	Difference between Non-tall and Tall Vehicle Crashes			
Going Straight	2.81%	0.77%	2.39%	5.97%
Left Turn	-2.20%	-0.20%	-0.28%*	-2.68%
Right Turn	0.33%	0.14%	0.12%	0.60%
Backing	-1.92%	-0.30%	0.10%	-2.12%
Other	-1.45%	-0.35%	0.03%	-1.77%

* Highlighted cell shows the type of crash percentage involving tall vehicles is higher than non-tall vehicles.

Driver Action and Pedestrian Location

We analyzed both non-tall and tall vehicle crashes by driver action and pedestrian location for both crashes that occurred at intersections and non-intersections (roadway segments, parking lots, private property). For non-tall vehicle crashes at intersections, the most common crash type occurred when drivers were making a left turn, and the pedestrian was in the crosswalk. For non-tall vehicle crashes at non-intersections, more crashes occurred when the driver was going straight, and the pedestrian was in the roadway. The same was true of tall vehicle crashes both at intersections and non-intersections. Another important observation is that tall vehicles are overrepresented in crashes occurring “not in roadway” for both intersections and non-intersections. “Not in roadway” areas include parking lane, bike lane, shoulder, median, crossing island/refuse island. Apparently, pedestrians in these spaces often fall outside a driver’s line of sight, leading to significant visibility challenges, especially for the driver of a tall vehicle. For crashes at non-intersections, tall vehicles were involved in more crashes than non-tall vehicles where the pedestrian was on the sidewalk while the driver was making a left turn.

*Table 3. Percent Difference in Non-Tall and Tall Vehicle Crashes by Driver Action and Pedestrian Location (WI SVSP)**

Driver Action	Intersection				Non-Intersection				Total
	Sidewalk	Crosswalk	In Roadway	Not in Roadway	Sidewalk	Crosswalk	In Roadway	Not in Roadway	
Non-Tall Vehicle Crashes									
Going Straight	1.24%	8.27%	6.22%	0.13%	4.78%	2.36%	20.82%	4.54%	48.35%
Left Turn	0.96%	12.10%	1.93%	0.04%	0.67%	0.83%	1.19%	1.27%	19.00%
Right Turn	0.77%	7.11%	0.96%	0.06%	0.60%	0.54%	0.37%	0.36%	10.77%
Backing	0.04%	0.11%	0.14%	0.00%	3.08%	0.16%	1.75%	5.34%	10.62%
Other	0.16%	1.79%	1.04%	0.00%	1.92%	0.49%	2.82%	3.05%	11.26%
Tall Vehicle Crashes									
Going Straight	1.11%	6.53%	4.85%	0.17%	4.41%	1.93%	17.79%	5.60%	42.38%
Left Turn	0.82%	13.09%	2.29%	0.02%	1.13%	1.05%	1.72%	1.55%	21.67%
Right Turn	0.73%	6.23%	1.03%	0.06%	0.86%	0.36%	0.42%	0.48%	10.18%
Backing	0.02%	0.04%	0.15%	0.04%	3.57%	0.10%	2.20%	6.61%	12.74%
Other	0.19%	1.78%	0.92%	0.19%	2.06%	0.61%	2.83%	4.45%	13.03%
Difference between Non-tall and Tall Vehicle Crashes									
Going Straight	0.13%	1.74%	1.38%	-0.04%	0.37%	0.43%	3.02%	-1.07%	5.97%
Left Turn	0.14%	-0.99%	-0.36%	0.02%	-0.46%	-0.22%	-0.53%	-0.28%	-2.68%
Right Turn	0.04%	0.88%	-0.07%	-0.01%	-0.26%	0.19%	-0.05%	-0.12%	0.60%
Backing	0.02%	0.07%	0.00%	-0.04%	-0.49%	0.05%	-0.46%	-1.27%	-2.12%
Other	-0.03%	0.00%	0.12%	-0.19%	-0.14%	-0.12%	-0.01%	-1.40%	-1.77%

* Highlighted cell shows the type of crash percentage involving tall vehicles is higher than non-tall vehicles.

Driver Action, Pedestrian Location, and Light Condition

Light condition can play a very large role in pedestrian visibility. We analyzed driver action, pedestrian location, and light condition to see the role of lighting on non-tall and tall vehicle crashes. For non-tall vehicles, most crashes occurred when the driver was going straight, and the pedestrian was in the roadway during the day. The second most prevalent type occurred when the driver was turning left, and the pedestrian was in the roadway during the day. The same two crash types were the most common for tall vehicles as well. Tall vehicles were overrepresented in cases where the driver was making a left turn when it was dark with no lighting. Other cases included when the driver’s action was classified as “other”. Finally, there was one case where tall vehicles were overrepresented when making a right turn in a lit condition.

*Table 4. Percent Difference between Non-Tall and Tall Vehicle Crashes by Driver Action, Light Condition, and Pedestrian Location in Wisconsin**

		Non-tall Vehicle Crashes					
Light Condition	Pedestrian Location	Driver Action					Total
		Going Straight	Left Turn	Right Turn	Backin g	Other	
Day	Sidewalk	4.06%	1.17%	1.19%	2.58%	1.47%	10.47 %
	Crosswalk	7.07%	8.51%	6.14%	0.24%	1.73%	23.69 %
	In Roadway	15.91%	2.05%	0.94%	1.49%	2.56%	22.95 %
	Not in Roadway	3.38%	1.10%	0.31%	4.45%	2.15%	11.39 %
Dark - Unlit	Sidewalk	0.26%	0.03%	0.00%	0.06%	0.06%	0.40%
	Crosswalk	0.16%	0.26%	0.06%	0.00%	0.04%	0.52%
	In Roadway	2.95%	0.14%	0.09%	0.11%	0.39%	3.68%
	Not in Roadway	0.40%	0.01%	0.04%	0.14%	0.14%	0.74%
Dark - Lit	Sidewalk	1.70%	0.43%	0.19%	0.49%	0.54%	3.35%
	Crosswalk	3.40%	4.16%	1.46%	0.03%	0.50%	9.56%
	In Roadway	8.18%	0.93%	0.30%	0.29%	0.92%	10.62 %
	Not in Roadway	0.89%	0.20%	0.06%	0.74%	0.76%	2.65%
		Tall Vehicle Crashes					
Day	Sidewalk	4.07%	1.30%	1.43%	3.25%	1.78%	11.83 %
	Crosswalk	5.67%	9.38%	5.46%	0.13%	1.64%	22.26 %
	In Roadway	13.43%	2.77%	0.92%	1.78%	2.35%	21.25 %
	Not in Roadway	4.09%	1.30%	0.46%	5.67%	3.21%	14.73 %
Dark - Unlit	Sidewalk	0.25%	0.04%	0.02%	0.02%	0.04%	0.38%
	Crosswalk	0.17%	0.27%	0.00%	0.00%	0.06%	0.50%
	In Roadway	3.08%	0.27%	0.00%	0.13%	0.63%	4.11%
	Not in Roadway	0.55%	0.04%	0.00%	0.17%	0.29%	1.05%
Dark - Lit	Sidewalk	1.20%	0.61%	0.15%	0.31%	0.42%	2.69%
	Crosswalk	2.62%	4.49%	1.13%	0.02%	0.69%	8.96%
	In Roadway	6.13%	0.97%	0.52%	0.44%	0.78%	8.83%
	Not in Roadway	1.13%	0.23%	0.08%	0.82%	1.13%	3.40%
		Difference between Non-tall and Tall Vehicle Crashes					
Day	Sidewalk	-0.01%	-0.13%	-0.24%	-0.68%	-0.31%	-1.36%
	Crosswalk	1.40%	-0.87%	0.68%	0.12%	0.09%	1.43%
	In Roadway	2.48%	-0.72%	0.02%	-0.30%	0.21%	1.69%
	Not in Roadway	-0.72%	-0.20%	-0.15%	-1.22%	-1.06%	-3.34%
Dark - Unlit	Sidewalk	0.01%	-0.01%	-0.02%	0.04%	0.02%	0.02%
	Crosswalk	-0.01%	-0.02%	0.06%	0.00%	-0.02%	0.01%
	In Roadway	-0.14%	-0.13%	0.09%	-0.01%	-0.24%	-0.44%

	Not in Roadway	-0.14%	-0.03%	0.04%	-0.02%	-0.15%	-0.31%
Dark - Lit	Sidewalk	0.51%	-0.18%	0.04%	0.17%	0.12%	0.66%
	Crosswalk	0.78%	-0.33%	0.33%	0.01%	-0.19%	0.60%
	In Roadway	2.06%	-0.04%	-0.22%	-0.15%	0.14%	1.78%
	Not in Roadway	-0.25%	-0.03%	-0.03%	-0.07%	-0.37%	-0.75%

* Highlighted cell shows the type of crash percentage involving tall vehicles is higher than non-tall vehicles.

Driver Action, Driver Factor, and Pedestrian Location

We once again looked at driver action and driver contributing factors. Instead of pedestrian action, we classified these typologies using pedestrian location. The majority of non-tall vehicle crashes occurred when the driver was going straight with no improper action and the pedestrian was in the roadway. The same was true for tall vehicle crashes, however a smaller proportion of crashes occurred when the driver was going straight. Tall vehicles were not overrepresented in any cases when the driver was going straight. However, tall vehicles were overrepresented at least once in the remainder of the driver actions: left turn, right turn, backing, and other. Table 5 shows "failure to yield" to pedestrians in the "crosswalk" is the highest among all with an alarming percentage of 18.24% and 17.25% for non-tall and tall vehicles, respectively; where tall vehicles are overrepresented in left turning movement. No other new outstanding issues by driver contributing factors have been observed.

*Table 5. Percent Difference between Non-Tall and Tall Vehicle Crashes by Driver Action, Driver Contributing Factor, and Pedestrian Location (WI SVSP)**

		Non-tall Vehicle Crashes					
Driver Contributing Factor	Pedestrian Location	Driver Action					
		Going Straight	Left Turn	Right Turn	Backing	Other	Total
No Improper Action	Sidewalk	3.25%	0.57%	0.37%	1.02%	0.70%	5.91%
	Crosswalk	4.94%	2.55%	1.80%	0.07%	0.62%	9.97%
	In Roadway	20.10%	1.60%	0.70%	0.56%	2.12%	25.08%
	Not in Roadway	1.83%	0.41%	0.13%	1.33%	0.93%	4.64%
Speeding	Sidewalk	0.26%	0.04%	0.03%	0.01%	0.06%	0.40%
	Crosswalk	0.49%	0.07%	0.01%	0.00%	0.07%	0.64%
	In Roadway	0.94%	0.07%	0.03%	0.00%	0.17%	1.22%
	Not in Roadway	0.24%	0.10%	0.06%	0.04%	0.19%	0.63%
Failed to Yield	Sidewalk	0.62%	0.52%	0.59%	0.07%	0.14%	1.93%
	Crosswalk	3.68%	8.83%	4.65%	0.03%	1.06%	18.24%
	In Roadway	1.04%	0.83%	0.31%	0.03%	0.31%	2.53%
	Not in Roadway	0.26%	0.30%	0.06%	0.10%	0.11%	0.83%
Unsafe Driving	Sidewalk	1.13%	0.36%	0.34%	1.89%	0.74%	4.46%
	Crosswalk	1.22%	1.20%	0.90%	0.17%	0.39%	3.88%
	In Roadway	3.02%	0.49%	0.26%	1.19%	0.70%	5.65%
	Not in Roadway	1.63%	0.36%	0.13%	3.58%	1.09%	6.78%
Other	Sidewalk	0.77%	0.14%	0.04%	0.13%	0.43%	1.52%
	Crosswalk	0.31%	0.29%	0.29%	0.00%	0.14%	1.03%
	In Roadway	1.93%	0.13%	0.03%	0.11%	0.56%	2.76%

	Not in Roadway	0.70%	0.14%	0.04%	0.29%	0.73%	1.90%
	Tall Vehicle Crashes						
No Improper Action	Sidewalk	2.73%	0.84%	0.65%	1.24%	0.99%	6.44%
	Crosswalk	3.92%	3.48%	1.66%	0.13%	0.73%	9.92%
	In Roadway	17.54%	2.35%	0.86%	0.76%	2.25%	23.75%
	Not in Roadway	2.62%	0.67%	0.23%	2.52%	2.01%	8.06%
Speeding	Sidewalk	0.25%	0.02%	0.00%	0.02%	0.06%	0.36%
	Crosswalk	0.29%	0.06%	0.02%	0.00%	0.04%	0.42%
	In Roadway	0.61%	0.02%	0.00%	0.00%	0.13%	0.76%
	Not in Roadway	0.31%	0.00%	0.00%	0.02%	0.17%	0.50%
Failed to Yield	Sidewalk	0.42%	0.52%	0.55%	0.23%	0.13%	1.85%
	Crosswalk	2.98%	9.06%	3.99%	0.00%	1.22%	17.25%
	In Roadway	0.52%	0.94%	0.36%	0.08%	0.27%	2.18%
	Not in Roadway	0.17%	0.36%	0.13%	0.10%	0.23%	0.99%
Unsafe Driving	Sidewalk	1.43%	0.50%	0.31%	1.97%	0.61%	4.83%
	Crosswalk	0.97%	1.30%	0.78%	0.02%	0.31%	3.38%
	In Roadway	2.37%	0.61%	0.17%	1.45%	0.59%	5.18%
	Not in Roadway	1.89%	0.50%	0.13%	3.78%	1.28%	7.57%
Other	Sidewalk	0.69%	0.06%	0.08%	0.13%	0.46%	1.43%
	Crosswalk	0.29%	0.23%	0.15%	0.00%	0.08%	0.76%
	In Roadway	1.59%	0.08%	0.06%	0.06%	0.52%	2.33%
	Not in Roadway	0.78%	0.04%	0.06%	0.23%	0.94%	2.06%
	Difference between Non-tall and Tall Vehicle Crashes						
No Improper Action	Sidewalk	0.52%	-0.27%	-0.28%	-0.22%	-0.29%	-0.53%
	Crosswalk	1.01%	-0.94%	0.15%	-0.05%	-0.12%	0.05%
	In Roadway	2.56%	-0.75%	-0.16%	-0.20%	-0.13%	1.33%
	Not in Roadway	-0.79%	-0.26%	-0.10%	-1.19%	-1.08%	-3.42%
Speeding	Sidewalk	0.01%	0.02%	0.03%	-0.01%	-0.01%	0.04%
	Crosswalk	0.19%	0.01%	-0.01%	0.00%	0.03%	0.22%
	In Roadway	0.34%	0.05%	0.03%	0.00%	0.05%	0.46%
	Not in Roadway	-0.07%	0.10%	0.06%	0.02%	0.02%	0.13%
Failed to Yield	Sidewalk	0.20%	-0.01%	0.04%	-0.16%	0.02%	0.08%
	Crosswalk	0.70%	-0.24%	0.66%	0.03%	-0.16%	0.99%
	In Roadway	0.52%	-0.11%	-0.04%	-0.06%	0.04%	0.35%
	Not in Roadway	0.09%	-0.06%	-0.07%	0.00%	-0.12%	-0.16%
Unsafe Driving	Sidewalk	-0.30%	-0.15%	0.03%	-0.08%	0.14%	-0.36%
	Crosswalk	0.25%	-0.10%	0.12%	0.15%	0.07%	0.50%
	In Roadway	0.65%	-0.12%	0.09%	-0.26%	0.11%	0.47%
	Not in Roadway	-0.26%	-0.15%	0.00%	-0.20%	-0.19%	-0.79%
Other	Sidewalk	0.08%	0.08%	-0.04%	0.00%	-0.03%	0.09%
	Crosswalk	0.02%	0.06%	0.14%	0.00%	0.06%	0.27%
	In Roadway	0.34%	0.04%	-0.03%	0.05%	0.03%	0.43%
	Not in Roadway	-0.08%	0.10%	-0.02%	0.06%	-0.21%	-0.15%

* Highlighted cell shows the type of crash percentage involving tall vehicles is higher than non-tall vehicles.

Summary

Within Wisconsin, tall vehicles have become a much larger contributor to SVSP crashes since 2008. Moreover, tall SVSP crashes have risen by over 30% since 2008, compared to non-tall vehicles which have dropped by over 30%. Both Tennessee and Florida SVSP crash data shows that tall vehicles cause fatal injuries at the same rate as non-tall vehicles; Wisconsin SVSP crash data shows that tall vehicles result in a fatal injury two times as often as a non-tall vehicle.

In Wisconsin, a majority of SVSP crashes occur when the posted speed falls between 20-25 mph with similar share taking place when the posted speed falls between 30-40 mph. In Tennessee and Florida, most of the crashes took place when the posted speed is between 30-40 mph with almost 50% of Tennessee's SVSP crashes for both non-tall and tall vehicles falling in this range.

When comparing non-tall and tall SVSP crashes in Wisconsin, tall vehicles have a higher crash percentage for any given pedestrian action when the driver is turning left or backing, apart from a pedestrian sudden movement while backing. Once again, tall vehicles have a higher crash percentage when turning left or backing for nearly every pedestrian location and crash location. Lastly, tall vehicles have a higher crash percentage for most driver action-pedestrian location scenarios, no matter the light condition. Overall, tall vehicles have a higher crash percentage than non-tall vehicles in Wisconsin.

CRASH MODELS

Predicting Tall-Vehicle Related Crashes

After identifying the crash typologies where tall vehicles are overrepresented, we looked to quantify the effect of key variables associated with tall SVSP crashes. To do this, we ran a binary logit model with vehicle height classification as our dependent variable. The summary of results of the binary logit model involving both human factors and roadway characteristics is shown in Table 6.

Table 6. Binary Logit Model for Vehicle Height Classification (WI SVSP, 2008-2022)

Data Field	Factor	Estimate	Probability	Standard Error	P Value	Statistical Significance
	Intercept	-0.2445	44%	0.0424	0.0000	***
Driver Action Base: Going Straight	Left Turn	0.0907	52%	0.0492	0.0653	.
	Right Turn	-0.1229	47%	0.0532	0.0210	*
	Backing	0.1889	55%	0.0548	0.0006	***
	Other Action	-0.1077	47%	0.0571	0.0592	.
Driver Contributing Factor Base: No Improper Action	Speeding	-0.0861	48%	0.0657	0.1899	
	Failed to Yield	0.1471	54%	0.0614	0.0166	*
	Unsafe Driving	-0.2392	44%	0.0881	0.0066	**
	Other Factor	0.1754	54%	0.0738	0.0175	*
Pedestrian Location Base: Sidewalk	Crosswalk	0.0917	52%	0.0491	0.0616	.
	In Roadway	0.1574	54%	0.0574	0.0061	**
	Not in Roadway	0.0470	51%	0.0399	0.2397	
Posted Speed Base: 20-25 mph	<15 mph	0.1287	53%	0.0701	0.0663	.
	30-40 mph	0.1174	53%	0.0649	0.0704	.
	>45 mph	0.0975	52%	0.0624	0.1186	
Highway Class, Base: Urban	Rural	0.2637	57%	0.0401	0.0000	***
Trafficway Base: Undivided	Divided	0.0521	51%	0.0647	0.4209	
	Parking Lot/Private Property	0.0652	52%	0.0591	0.2704	

Notes: *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05, **.** p-value < 0.1

Driver action was classified into five different factors: going straight (base case), left turns, right turns, backing, and other actions. Left turns were identified as a strong predictor of tall SVSP crashes in Wisconsin with 90% confidence. SVSP crashes involving left turns are 52% more likely to involve tall vehicles. On the other hand, right turns are negatively associated with tall SVSP crashes in Wisconsin with 95% confidence, despite tall vehicles having significantly larger blind zones during turning movements. Backing is a strong predictor of tall SVSP crashes with 99.9% confidence. SVSP crashes involved backing are 55% more likely to involve a tall vehicle. Other actions, like merging and parking, are negatively associated with tall SVSP crashes in Wisconsin.

Driver contributing factors indicate any behavior that could have contributed to the crash. Unsafe driving was negatively associated with tall SVSP crashes with 99% confidence. However, failing to yield was a strong predictor of tall SVSP crashes with 99% confidence. A failure to yield suggests a larger visibility issue at play, since the driver did not see and slow down for the pedestrian in ample time. SVSP crashes involving failure to yield are 54% more likely to involve tall vehicles. Other factors, including driver condition and physical disability, were strong predictors of tall SVSP crashes as well. SVSP crashes with these factors are 54% more likely to involve a tall vehicle.

Pedestrian location was classified into four factors: sidewalk, crosswalk, in the roadway, and not in roadway. Crashes that occurred when the pedestrian was in either the crosswalk or roadway were strong predictors of tall vehicle crashes with 90% and 99% confidence, respectively. SVSP crashes when pedestrians are using crosswalks or in the roadway are at least 50% more likely to involve a tall vehicle.

Highway class has been separated into two factors: urban and rural. Rural roadways were a strong predictor of tall SVSP crashes with a 99.9% confidence level. SVSP crashes that occur on rural roads are 56% more likely to involve tall vehicles. Intuitively, the larger number of tall SVSP crashes could be explained by the greater amounts of manual labor, like farming, in rural environments.

Owing to driver action, driver contributing factor and pedestrian location, posted speed and trafficway are either marginally or not statistically significant. An additional binary logit model was performed with posted speed and trafficway only. The results (in Appendix D) suggest that all posted speed categories were strong indicators of tall vehicle involvement in SVSP crashes and they are statistically significant with 99% confidence. Crashes at posted speeds ≤15 mph, typically in parking lots or school zones, posted speed of 30–40 mph, and speeds ≥45 mph were increased likelihood of involving tall vehicles with 56%, 55%, and 54%, respectively when compared to the base condition of 20-25mph. Trafficway types also offered valuable context with undivided highway being the baseline. Divided trafficways were strong predictors of tall vehicle SVSP crashes with 90% confidence and a 53% increased likelihood. Despite their low-speed nature, parking lots and private properties were associated with large vehicle blind zones and showed the same 90% confidence and 53% increased likelihood of tall vehicle involvement.

Modeling Crash Injury Severity

Table 7 presents results from three ordinal logit models estimating pedestrian injury severity in crashes across three U.S. states: Wisconsin (Model 1), Tennessee (Model 2), and Florida (Model 3). Since Models 1, 2, and 3 are separately modeled for each state, we are unable to compare the coefficients across the models. The table also includes results from the pooled generalized ordinal logit model (Model 4), including data from all states, facilitating state-level interactions with tall vehicles.

In terms of vehicle height alone (main effects), only Wisconsin shows a statistically significant effect, with tall vehicles associated with higher injury severity (coefficient = 0.307, $p < 0.001$). In Tennessee and Florida, the coefficients for tall vehicles are small and not statistically significant. Across all three states, driver maneuvers such as backing, turning left or right, and "other" maneuvers are consistently associated with significantly lower injury severity compared to going straight. This pattern is strongest in Tennessee and Florida, with large negative coefficients, particularly for right-turning drivers. These results likely reflect reduced vehicle speed and pedestrian exposure during non-straight maneuvers.

Speed limits, lighting, and vehicle age all show strong associations with pedestrian injury severity. Crashes occurring at lower posted speed limits (≤25 mph) are significantly less severe, while those at high speeds (≥45 mph) are consistently linked to higher severity, especially in Wisconsin. Poor visibility conditions—both dark but lighted and dark unlighted—substantially increase injury severity, with the largest effects seen in Florida. Vehicle age has a small but statistically significant effect in Tennessee and Florida, suggesting that older vehicles slightly elevate injury severity risk.

Differences by pedestrian and driver characteristics also reveal meaningful patterns. Male pedestrians show no significant effect in Wisconsin or Tennessee, but are slightly more likely to experience severe outcomes in Florida. In contrast, male drivers are consistently associated with higher severity across all states. The presence of alcohol or drugs significantly increases severity for both pedestrians and drivers, with the largest effect observed for impaired drivers in Tennessee. Pedestrian age also matters: older adults (60+) are at significantly greater risk of severe injury, while teenagers (13–18) appear to experience less severe outcomes. Driver age is mostly non-significant, though younger drivers (16-24 years) in Wisconsin show a slight positive association ($p < 0.05$) with increased injury severity.

Finally, the models include year fixed effects to account for time-related changes in crash environments, spanning 2008–2022 (WI), 2009–2024 (TN), and 2012–2020 (FL). All models are highly significant ($p < 0.001$), with reasonable fit statistics for injury severity modeling. Pseudo R^2 values range from 0.088 to 0.107, indicating modest explanatory power, and Model 3 (Florida), with the largest sample size, shows the strongest overall model performance.

The interaction terms in Table 7 offer important insights into how the relationship between vehicle height and injury severity depends on driver maneuver. In backing maneuvers, both Tennessee and Florida exhibit statistically significant positive interactions (0.639 and 0.284, respectively), indicating that tall vehicles are particularly hazardous in these situations—likely due to limited rearward visibility or larger blind zones. In contrast, Wisconsin shows a marginally significant negative interaction (–0.309), suggesting that tall vehicles may be somewhat less risky during backing, though this effect is weak and should be interpreted cautiously.

For left-turn and miscellaneous maneuvers, interaction effects are generally small and non-significant across all states. The case of right turns reveals a more striking contrast: Wisconsin reports a significantly negative interaction (–0.439), implying that tall vehicles may reduce injury severity during right turns in that setting. Meanwhile, Florida shows a significant positive interaction (0.208), suggesting a higher risk. Tennessee reports no significant interaction in this category.

Taken together, the interaction patterns in Tennessee and Florida point toward a consistent trend: tall vehicles amplify injury risk in certain maneuvers beyond their baseline effect. In Wisconsin, however, the interaction terms tend to suggest a neutral or slightly protective influence. Importantly, these findings should not be interpreted in isolation. While interaction effects are informative, they must be understood alongside the main effect of vehicle height. In Wisconsin, the main effect for tall vehicles is significant and positive (0.307), indicating that tall vehicles are associated with a 36% increase in the odds of more severe injuries. This substantial main effect may obscure the detection of interaction terms in that context.

Model 4 broadly aligns with state-specific results, with tall vehicles showing significant main effects for fatal outcomes but not for severe versus non-severe injuries. Similar to Models 2 and 3, driver maneuver interactions indicate that backing and left turns pose greater risks than straight maneuvers for tall vehicles, beyond their main effect. Furthermore, state-level interactions reveal that in Wisconsin, tall vehicles are 22% more likely to result in higher severity crashes, potentially due to greater average vehicle height (Figure 6 and Figure 7) and a higher share of low-speed (20–25 mph) crashes, which account for 38% in Wisconsin compared to 6% in Tennessee and 13% in Florida (Figure 12 and Figure 13). This significant interaction term also explains why the main effect associated with tall vehicles was disproportionately more dangerous for the Wisconsin-only model.

Table 7. Ordinal Logistic Regression Modeling Pedestrian Injury Severity Outcome in traffic crashes in Wisconsin, Tennessee, and Florida (states modeled separately)

Injury Severity	**Model 1 (WI)**	**Model 2 (TN)**	**Model 3 (FL)**	**Model 4 (Pooled)**	
				K v. ABCO	**KA v. BCO**
Tall vehicle vs non-tall vehicle	0.307*** (0.066)	0.071 (0.047)	0.040 (0.029)	0.219*** (0.038)	0.009 (0.028)
Driver Maneuver (Base: Going Straight)					
Backing	-0.447*** (0.123)	-0.838*** (0.138)	-0.928*** (0.068)	-0.835*** (0.058)	-0.835*** (0.058)
Left Turn	-0.754*** (0.099)	-1.106*** (0.098)	-0.756*** (0.051)	-1.487*** (0.100)	-0.790*** (0.044)
Other	-0.317** (0.107)	-0.458*** (0.071)	-0.721*** (0.061)	-0.587*** (0.047)	-0.587*** (0.047)
Right Turn	-1.031*** (0.136)	-1.453*** (0.186)	-1.165*** (0.071)	-1.714*** (0.147)	-1.107*** (0.063)
Interaction: Tallness x Maneuver					
Backing	-0.309· (0.171)	0.639*** (0.174)	0.284** (0.098)	0.278** (0.082)	0.278** (0.082)
Left Turn	-0.214 (0.138)	0.181 (0.134)	0.131· (0.074)	0.127* (0.064)	0.127* (0.064)
Other	-0.023 (0.150)	-0.021 (0.104)	0.216* (0.093)	0.184** (0.070)	0.184** (0.070)
Right Turn	-0.439* (0.217)	0.319 (0.259)	0.208* (0.105)	0.151 (0.094)	0.151 (0.094)
At the Intersection	-0.119· (0.061)	-0.214*** (0.049)	-0.015 (0.027)	-0.053* (0.023)	-0.053* (0.023)
Posted Speed Limit (Base: 30-40 mph)					
15 mph and less	-0.649*** (0.078)	-0.781*** (0.060)	-0.697*** (0.045)	-1.213*** (0.078)	-0.538*** (0.030)
20-25 mph	-0.219*** (0.058)	-0.594*** (0.075)	-0.628*** (0.035)	-1.412*** (0.101)	-0.636*** (0.035)
45 mph and more	0.973*** (0.104)	0.594*** (0.050)	0.362*** (0.027)	0.677*** (0.038)	0.354*** (0.025)
Light Condition (Base: Non-dark conditions)					
Dark Lighted	0.432*** (0.057)	0.546*** (0.044)	0.715*** (0.027)	1.043*** (0.043)	0.594*** (0.024)
Dark Unlighted	0.621*** (0.097)	0.701*** (0.059)	0.934*** (0.034)	1.221*** (0.049)	0.811*** (0.031)
Vehicle Age	0.004 (0.004)	0.011** (0.003)	0.012*** (0.002)	0.011*** (0.002)	0.011*** (0.002)
Male Pedestrian vs otherwise	-0.054 (0.049)	0.028 (0.040)	0.069** (0.024)	0.053** (0.020)	0.053** (0.020)
Male Driver vs otherwise	0.165** (0.051)	0.118** (0.039)	0.162*** (0.024)	0.144*** (0.020)	0.144*** (0.020)
Pedestrian Alcohol/Drug Presence	0.660*** (0.112)	0.626*** (0.064)	0.476*** (0.039)	0.500*** (0.034)	0.500*** (0.034)
Driver Alcohol/Drug Presence	0.883*** (0.140)	1.106*** (0.090)	0.819*** (0.071)	1.069*** (0.073)	0.775*** (0.060)

Pedestrian Age (Base: 19 - 59 years)					
12 years and below	-0.045 (0.082)	-0.082 (0.066)	na		
13 - 18 years	-0.454*** (0.090)	-0.254*** (0.070)	na		
60 years and above	0.861*** (0.061)	0.609*** (0.050)	na		
Driver Age (Base: 25 - 64 years)					
16 - 24 years	0.145* (0.063)	-0.005 (0.050)	na		
65 years and above	-0.057 (0.070)	-0.093 (0.057)	na		
Unknown/ Others	0.186 (0.173)	0.090 (0.121)	na		
State (Base: Florida)					
Tennessee				-0.184** (0.054)	-0.030 (0.037)
Wisconsin				0.033 (0.045)	0.033 (0.045)
Interaction: Tall Vehicle x State					
Tennessee				0.035 (0.055)	0.035 (0.055)
Wisconsin				0.202** (0.067)	0.202** (0.067)
Threshold at 1	1.465 (0.126)	1.263 (0.104)	1.347 (0.050)	-3.274*** (0.059)	-1.322*** (0.044)
Threshold at 2	3.544 (0.134)	3.080 (0.109)	3.002 (0.052)		
Number of Observations	*11,756*	*16,907*	*45,627*	*62,802*	
Year Fixed Effects	*2008-2022*	*2009-2024*	*2012-2020*	*2012-2020*	
Log-likelihood	*-6396.54*	*-10550.83*	*-28149.90*	*-37810.81*	
Degrees of Freedom (DoF)	*40*	*41*	*28*	*45*	
LR χ^2 (DoF)	*1238.32*	*2518.83*	*6224.46*	*8995.21*	
Prob > χ^2	*0.000*	*0.000*	*0.000*	*0.000*	
Pseudo R^2	*0.088*	*0.107*	*0.100*	*0.106*	

Notes: *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05, ˙ p-value < 0.1; na – missing data for FL
Highlighted cells with red and green represent significant (p < 0.05) positive and negative associations, respectively.

Summary

A binary logit model was used to identify factors associated with tall vehicle involvement in Wisconsin SVSP crashes, revealing several key predictors. Left turns and backing maneuvers significantly increased the likelihood of tall vehicle involvement, while right turns and actions like merging or parking were negatively associated. Driver behaviors such as failure to yield were also strong predictors, each linked to a 54% higher chance of tall vehicle involvement, highlighting visibility challenges. Pedestrian location being in the crosswalk or roadway increased the likelihood of a tall vehicle crash by at least 50%. Rural roads, likely due to the prevalence of large vehicles, were associated with a 56% increase in tall SVSP crashes. Additionally, posted speed limits of ≤15 mph, 30–40 mph, and ≥45 mph were all significantly associated with higher tall vehicle involvement (increases of 56%, 55%, and 54%, respectively), compared to 20–25 mph zones. Divided roadways and parking lots/private property also showed strong associations, each linked to a 53% higher likelihood of tall vehicle involvement, underscoring the influence of roadway design and visibility limitations.

The ordinal logistic model result for pedestrian injury severity across Wisconsin, Tennessee, and Florida reveal that tall vehicles significantly increase injury severity only in Wisconsin, where they raise the odds of more severe outcomes by 36%. Across all states, non-straight driver maneuvers (e.g., turning or backing) are associated with lower injury severity, likely due to reduced speeds and exposure. However, interaction terms suggest that tall vehicles increase the risk of injury during backing maneuvers, highlighting the potential danger associated with poor rear visibility. Right-turn interactions show mixed results—reduced severity in Wisconsin but increased severity in Florida. Generally, tall vehicles in Wisconsin exhibit 22% higher severity risk, likely due to greater average height and more low-speed crashes than in other states. Other key predictors of injury severity include high speed limits, poor lighting, alcohol or drug impairment (especially in drivers), and older pedestrian age. Male drivers were consistently associated with higher injury severity, while vehicle age had significant negative effects in Tennessee and Florida. Overall, the models show a modest fit, and the findings reveal a significant association between higher injury severity and tall vehicles in state-level variations.

COUNTERMEASURE DESCRIPTION AND SELECTION

Description of Countermeasures

Pedestrian crashes have surged as SUVs, pickups and vans dominate the fleet. Research finds that drivers of large vehicles are 23–42% more likely than passenger car drivers to strike pedestrians while making turns, due largely to the blind zones created by tall hoods, A-pillars, and mirrors. To compensate, roadways can be designed so pedestrians are more visible, drivers have better sightlines, and crashes are less severe when they happen. The following proven countermeasures improve pedestrian visibility for all drivers, with noted effectiveness to tall-vehicle drivers. We cover engineering treatments at intersections, and midblock crossings, prioritizing low-cost and easily implemented solutions. We also highlight the importance of having a holistic approach to address these pressing issues, with concerted efforts from automobile industry, policy makers, law enforcement and traffic safety educators.

Roadway Infrastructure and Traffic Engineering Improvements

We generated a wide range of roadway infrastructure and traffic control countermeasures. The potential countermeasures aim to improve pedestrian safety through a variety of methods. We identified five purposes for the proposed countermeasures:

- Increase pedestrian visibility: Make it easier for pedestrians to see and communicate with drivers before entering the roadway
- Increase driver visibility: Make it easier for drivers to see and yield to pedestrians to allow for safer crossings
- Mitigate multiple threat: Reduces instances where one vehicle blocks the view of another's, especially at pedestrian crossings
- Reduce speeds: Enforce slower speed roadways to shorten stopping distance, increase range of vision, and reduce injury fatality
- Shorten pedestrian crossing distance: Reduce the amount of time the pedestrian is vulnerable to vehicles in the roadway.

The purposes of the potential countermeasures were generated based on contributing factors to SVSP crashes. Nine potential countermeasures were identified in total. These countermeasures aim to target various crash types, locations, and scenarios, but they should not be applied in all cases. However, all the countermeasures identified have been proven to reduce crash rates. Our top nine countermeasures, their purposes, WisDOT crash modification factor (CMF)[5], and average cost[6] are described below.

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[5] (Wisconsin Department of Transportation, 2024)
[6] (Wyoming Pathways, 2022)

Pavement Marking and Signage

Advance stop/yield lines aim to increase driver visibility, increase pedestrian visibility, and mitigate multiple threat scenarios. These markings are to be placed 20 to 30 feet in advance of a marked crosswalk at a midblock crossing. Both driver and pedestrian visibility is increased by growing the sight triangle due to the offset of vehicles. (City of Minneapolis, 2021). Advance stop/yield lines are helpful at mitigating multiple threat scenarios on multilane roadways. In a multiple threat scenario, a vehicle, especially a tall vehicle, in the nearest lane can block the sightline of a vehicle in the adjacent lane. The use of advance stop/yield lines allows the sight line of a vehicle in the inside lane to be maintained. As vehicles approach, pedestrians will have more confidence as to whether a vehicle will let them cross because they will be required to slow down sooner than when advance stop/yield lines are not present.

Advance Yield/Stop Markings	Tall-Vehicle Visibility Benefit
	"Yield Here to Pedestrians" signs (R1-5 in MUTCD) and advance yield markings, commonly referred to as shark's teeth, force all vehicles (including trucks) to stop short of crosswalk, particularly effective for "multiple threat" scenarios. **Average Cost:** $320 each direction **Benefit (WisDOT CMF):** 0.886

Figure 18. Advance Yield Marking at Midblock Crossing (Zegeer, et al., 2013)

High-visibility crosswalk markings are cost-effective measures that increase pedestrian visibility. The high-visibility markings stand out against the pavement, making it easier for drivers to be aware that pedestrians may be entering the roadway. It also provides guidance to both pedestrians and drivers on where to cross or expect a crossing. The same can be said of marked crossings. Drivers do not expect pedestrians to cross the street where there are no crosswalk markings, even if curb ramps are placed on both sides of the street. The clear delineation increases driver expectation of pedestrian presence. High visibility crossings (shown in Figure 19) run perpendicular to the pedestrian's path with two-foot markings spaced two feet apart (City of Minneapolis, 2021) in contrast with transverse crossing that run along the pedestrian's path.

High visibility crosswalk markings	Tall-Vehicle Visibility Benefit
	Larger, thicker patterns are seen at farther distances even under peripheral vision. **Average Cost:** $2,540 each *By Material:* 4” Standard: $0.15 per linear foot (LF) 4” Epoxy: $0.25 per LF 4” Thermoplastic: $0.75 per LF 6” Thermoplastic: $0.97 per LF 4” Tape: $2.00 per LF **Benefit (WisDOT CMF):** 0.60

Figure 19. High Visibility Crosswalk (pedbikeimages.org / Laura Sandt)

The MUTCD specifies three types of high visibility crossings, Longitudinal Bar, Ladder, or Bar Pair. Currently, WisDOT’s Standard Detail Drawings outline that high visibility crosswalk markings should only be used at mid-block crossings (Wisconsin Department of Transportation, 2024). However, we believe this standard should be changed to be used whenever updating crosswalks to increase pedestrian visibility, especially in urban environments. High visibility crosswalk markings can be supplemented by appropriate signage, discussed in the next countermeasure.

In street signing is located along the centerline, lane line, edge line, or median island of the roadway on either side of the crosswalk to indicate a pedestrian crossing. The use of these signs can reduce pedestrian crashes by up to 25% as it promotes yielding. Since these signs sit at hood height, they furthermore increase pedestrian visibility. To provide a more advanced warning, pedestrian crossing signs posted on the outside of the travel lane can be used in conjunction with the in-street signing. In street pedestrian crossing signs can be used at both intersections and mid-block crossings (Federal Highway Administration, 2023). In street pedestrian crossing signs (R1-6 in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)) have dimensions of 12 inches by 36 inches. To target tall vehicles, an oversized version of in street pedestrian crossing signs may be appropriate. Tall vehicles have higher hoods, so increasing the sign to be 48 inches in height would increase the likelihood that a tall vehicle spots the sign and responds accordingly.

<table>
<tr><th>In street pedestrian crossing signing</th><th>Tall-Vehicle Visibility Benefit</th></tr>
<tr><td>
</td><td>A sign mounted at hood level (in the lane) directly catches a tall driver’s eye, reinforcing stop/yield.
Average Cost: $300 each
Benefit (WisDOT CMF): 0.75[7]</td></tr>
</table>

Figure 20. In Street Pedestrian Crossing Signage (Federal Highway Administration, 2023)

Traffic Signal and Control

Rectangular rapid-flashing beacons (RRFBs) must be activated by a pedestrian via push button or with motion activation. Upon activation, two rectangular beacons flash quickly to alert drivers of a pedestrian in the roadway. RRFBs increase both driver and pedestrian visibility. Driver visibility is increased as there is clearer communication between drivers and pedestrians. Moreover, pedestrian visibility is increased using signage and high-visibility strobe-like lights because these beacons catch driver’s attention much sooner (Zegeer, et al., 2013). RRFBs should be used where speed limits are below 40 mph (Albee & Boblitz, 2021). RRFBs should be placed at the crosswalk. An additional RRFB can be placed in advance of the crosswalk, but it should not be a replacement for the RRFB at the crosswalk (Federal Highway Administration, 2023). Since tall vehicles create larger blind zones to vehicles behind it or in an adjacent lane, the additional RRFB in advance of the crosswalk should be placed to further reduce multiple threat.

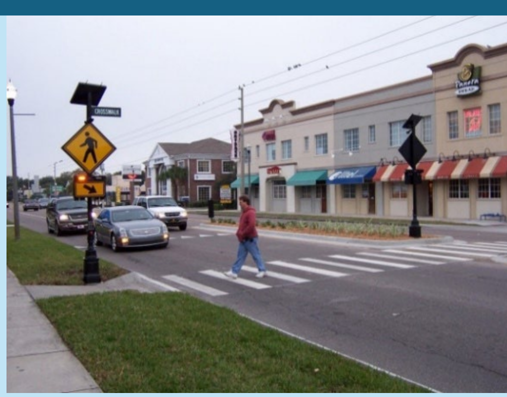
<table>
<tr><th>Rectangular rapid-flashing beacons (RRFBs)</th><th>Tall-Vehicle Visibility Benefit</th></tr>
<tr><td></td><td>Flashing beacon signals at eye level draw driver’s attention. Even if an SUV’s hood blocks a driver’s view momentarily, the beacon cues the driver to stop.
Average Cost: $22,250 each
Benefit (WisDOT CMF): 0.526</td></tr>
</table>

Figure 21. Rectangular Rapid-Flashing Beacons (pedbikeimages.org / Michael Frederick)

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[7] (National Academies of Sciences, Engineering, and Medicine, 2017)

High-intensity activated crosswalk (HAWKs) pedestrian hybrid beacon are a traffic control device that can be used at unsignalized locations like mid-block crossings. HAWKs should be installed at locations with more than two lanes of traffic where there are high volumes of traffic and/or higher speed limits (above 35 mph) (Albee & Boblitz, 2021). HAWKs must be activated by the pedestrian through a push button. Once the HAWK is activated, a yellow indication warns vehicles to slow down and prepare to stop on red. The red indication remains active until the pedestrian interval is completed. When inactive, vehicles travel as normal. HAWKs are effective at increasing pedestrian visibility and yielding since they are located above the roadway like a traffic signal (Zegeer, et al., 2013). Since they remain off unless activated by a pedestrian, there is more certainty for both the driver and pedestrian when making their respective movements. Moreover, HAWKs mitigate multiple threat scenarios as drivers in both lanes should have unobstructed visibility to the HAWK. Rather than having to redirect their eyes to the side of the road, the HAWK keeps drivers' focus forward and provides clear indication of when to stop, eliminating confusion as to what drivers in other lanes are doing. Without HAWKs, tall vehicles create larger obstructions to vehicles in the inner lane, increasing the chances of a crash caused by a multiple threat scenario. HAWKs should have at least two faces for *each* approach along the major street. Additionally, a marked crosswalk and advance stop bar must be present or added if not currently present at the given crossing. Additionally, all parking and other sight obstructions should be prohibited for at least 100 feet in advance of the marked crosswalk and 20 feet beyond the marked crosswalk. If this is not feasible pedestrian visibility should be increased using other countermeasures like curb extensions (Federal Highway Administration, 2023).

Hybrid Pedestrian Beacon	Tall-Vehicle Visibility Benefit
	Flashing beacon signals above eye level draw driver's attention. Even if an SUV's hood blocks a driver's view momentarily, the beacon cues the driver to stop. **Average Cost:** \$51,460 each **Benefit (WisDOT CMF):** 0.453

Figure 22. High-intensity activated crosswalk beacon (pedbikeimages.org / Mike Cynecki)

Leading pedestrian intervals (LPIs) are an effective measure to reduce SVSP crashes that occur at signalized intersections. LPIs allow the pedestrians to begin crossing three to seven seconds before the vehicles are given the green light (Albee & Boblitz, 2021). These three to seven extra seconds allow the pedestrian to begin to cross without conflict while simultaneously improving pedestrian visibility as they are further into the roadway, rather than off to the side. Tall vehicles have larger blind zones during turning movements because of the larger A-pillars and mirrors; the few extra seconds helps pedestrians escape these blind zones. With an LPI, the pedestrian is already established in the crosswalk when a tall vehicle begins to turn. LPIs are effective at intersections with frequent crashes during turning movements. Moreover, LPIs are cost effective as they frequently only require a slight modification to the existing signal timing. If an LPI is used, it should be timed to allow pedestrians to cross at least one lane of traffic. If a large corner radius is in place, the LPI should be timed such that the pedestrian can establish their position ahead of turning traffic before said turning traffic is given the green indication (Federal Highway Administration, 2023). These safeguards in timing ensure the LPI is effective in improving pedestrian safety.

Leading pedestrian intervals **(LPIs)**	Tall-Vehicle Visibility Benefit
	Pedestrians enter the crosswalk early, ensuring pedestrians are visible to turning drivers, even with A-pillar blockage. **Average Cost:** low **Benefit (WisDOT CMF):** 0.87

Figure 23. Leading Pedestrian Interval in Action (pedbikeimages.org / Toole Design Group)

Infrastructure Improvements

Tight corner/turning radii can increase pedestrian visibility, reduce driver speeds, and shorten pedestrian crossing distance. Standard curb radii fall between ten and fifteen feet, however many cities use corner radii as small as two feet (National Association of City Transportation Officials, 2013). Smaller corner radii help to create compact intersections with safe turning speeds for pedestrians. Smaller corner radii forces trucks and SUVs to slow and turn more sharply, which improves sightlines across the corner. A tight radius (2–10 feet) also shifts the vehicle position closer to the pedestrian, making crossing pedestrians visible earlier. To improve pedestrian safety, corner radii should be limited to ten feet to slow vehicles and better align pedestrian crosswalks. Designers are encouraged to provide the smallest yet appropriate corner radius. One design option is to provide various effective radii (RE) given an actual radius (RA) of the intersection corner using truck aprons. A truck apron is a practical design feature that accommodates the turning characteristics of larger vehicles while slowing the turning speeds of smaller design vehicles without widening the entire corner radius. Note that NACTO recommends a parcel delivery vehicle (DL-23) as a residential neighborhood design vehicle. When large vehicles are regularly present at intersections where pedestrians and bicyclists are expected and the effective turning (RE) radius exceeds 15', a truck apron is highly recommended.

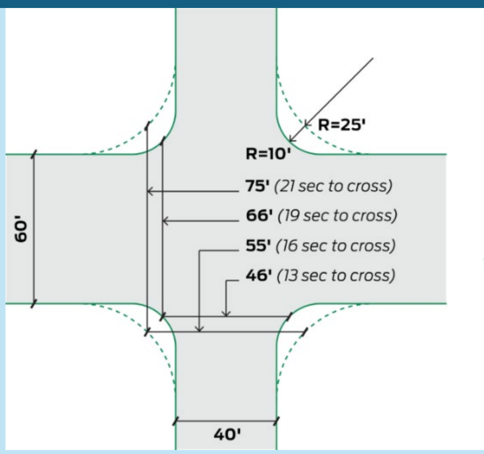
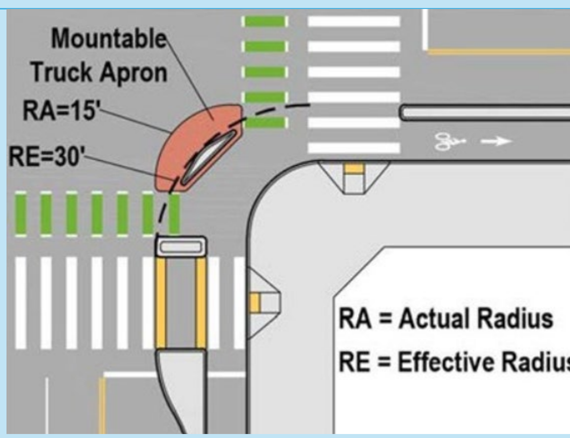
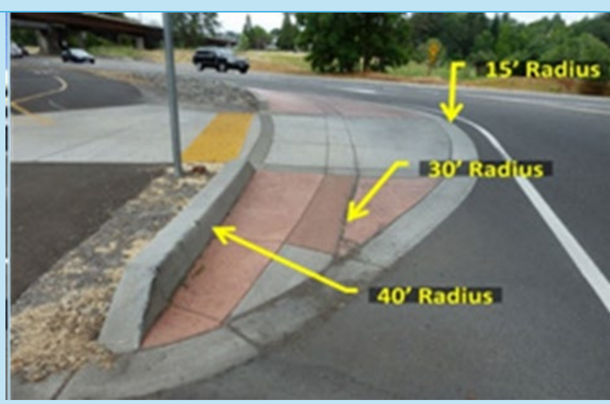
Tight corner/turning radii	Tall-Vehicle Visibility Benefit
	Forces slower, sharper turns; tall vehicles remain closer to the sidewalk, improving line-of-sight to crossing pedestrians. The smaller radii can be created by tight corners (for right turns) or raised median refuge islands (for left turns). **Average Cost:** $2,000 to $20,000 (Albee & Boblitz, 2021) **Benefit (WisDOT CMF):** NA
	Typical truck apron layout at a protected intersection. (Source: Ohio DOT's Multimodal Design Guide Section 7 "*Motor Vehicle Facilities Supporting Multimodal Accommodation*")
	Tiered truck apron with colored concrete. (Source: Ohio DOT's Multimodal Design Guide Section 7 "*Motor Vehicle Facilities Supporting Multimodal Accommodation*")

Figure 24. Pedestrian Crossing Time and Distance by Curb Radii (National Association of City Transportation Officials, 2013) and Truck Aprons at Intersections (Ohio DOT, Multimodal Design Guide).

Curb extensions meet all the desired purposes: increase driver visibility, increase pedestrian visibility, mitigate multiple threat scenarios, shorten pedestrian crossing distance, and reduce speeds. Curb extensions narrow the roadway, reducing the distance a pedestrian must cross. Like short radius returns, curb extensions bring the pedestrian into the sightline of a driver before the pedestrian enters the crosswalk, giving the driver time to react. Moreover, pedestrians can see traffic better as well since they are closer to the travel lane. The effective width of the roadway is reduced when curb extensions are used, causing drivers to reduce their speeds, especially when making turns. Curb extensions can be implemented at both intersections and midblock crossings; however, they are not suitable when there is no on-street parking. Curb extensions mitigate dual-threat scenarios involving parked cars as well. When cars are parked too close to an intersection, the vehicle can hide a pedestrian entering the crosswalk.

For tall vehicles, setting up no-parking zones or removing parked cars near the corner brings waiting pedestrians into direct line-of-sight, reducing large blind zones caused by high hoods. Moreover, when a tall vehicle is parked too close to an intersection, the space in which a pedestrian is hidden is larger, increasing the likelihood of a crash. Offsetting parking with a curb extension prevents a blind zone being created by a vehicle.

To be effective, curb extensions should extend far enough into the roadway to narrow the travel lanes to the recommended widths (e.g. reducing a travel lane from 12 feet to 10 feet). Curb extensions should be a minimum of three feet wide with parking offset by a 30-foot minimum if a stop sign is present to ensure the pedestrian is in the driver’s sight line (City of Minneapolis, 2021).

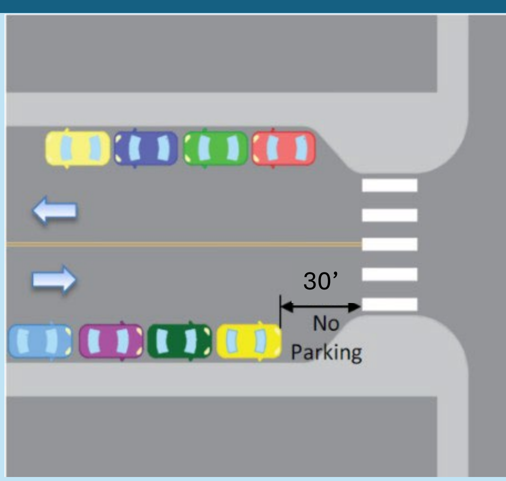
Curb extension (with daylighting)	Tall-Vehicle Visibility Benefit
 	Brings pedestrians closer and force vehicles to slow down and make a tight turn. Additional benefits through parking restrictions at or near intersections (daylighting) can eliminate parked-car blind zones. The restrictions prevent the high hoods associated with tall vehicles from hiding pedestrians about to cross. **Average Cost:** $13,000 each corner **Benefit (WisDOT CMF):** 0.63

Figure 25. Curb Extension at Intersection (City of Lodi, CA)

Pedestrian refuge islands can be implemented along roadways with raised medians. They are designed to increase both driver and pedestrian visibility while mitigating multiple threat scenarios and shortening pedestrian crossing distance. Pedestrian refuge islands allow for pedestrians to focus on one direction of travel at a time when crossing the road, improving driver visibility. Moreover, pedestrian refuge islands increase pedestrian visibility as they allow for the pedestrian to be closer to the driver's line of sight while keeping the pedestrian protected. Not only are pedestrians spending less time on the roadway unsheltered, but they also have a shorter distance to cross since the island allows for a half-crossing into a safe space, reducing pedestrian stress and rushed crossing behavior. Pedestrian refuge islands and medians also encourage drivers to slow and scan before proceeding. Pedestrian refuge islands should be used on roadways with four or more lanes, especially when there are either high traffic volumes or greater speed limits (Zegeer, et al., 2013).

In most cases, a pedestrian refuge island must be six feet in width to better protect all road users (including cyclists, people with disabilities, people with strollers). Moreover, pedestrian refuge islands should be 40 feet long with a nose that extends past the crosswalk (See Figure 26). The nose further protects pedestrians waiting on the median and slows turning drivers (City of Minneapolis, 2021). The nose works similar to a tight corner radius for tall vehicles, forcing them to slow and take sharper turns further improving their sight lines.

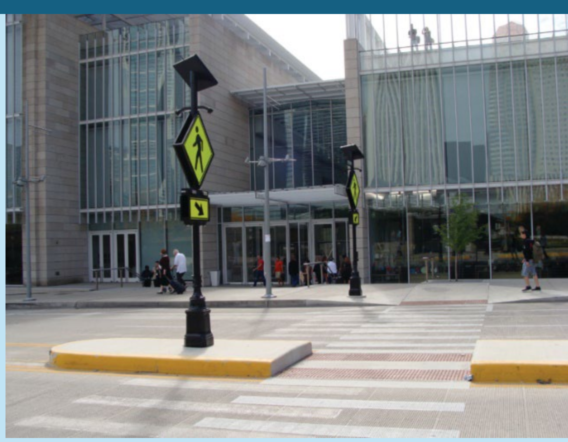
Pedestrian refuge islands	Tall-Vehicle Visibility Benefit
	Shortens each crossing stage and provides waiting pedestrians as visible target; tall vehicle must stop before island. **Average Cost:** $13,520 each **Benefit (WisDOT CMF):** 0.742

Figure 26. Pedestrian Refuge Island (National Association of City Transportation Officials, 2013).

Raised crosswalks aim to increase pedestrian visibility and reduce speeds. Rather than a curb ramp bringing a pedestrian down into the road, a raised crosswalk is a crosswalk placed atop a speed table. Raised crosswalks elevate the pedestrian so they are more likely to be within the driver's field of vision, especially pedestrians of shorter stature, like children or those in wheelchairs. Additionally, raised crosswalks facilitate slower speeds as drivers must reduce their speed. Raised crosswalks are especially beneficial at midblock crossings but should only be placed on roads with slower speeds (less than 30 mph) and low traffic volumes (Zegeer, et al., 2013).

Tall vehicles have higher windshields by design. While tall vehicles are more dangerous to pedestrians, the driver's eye line is much higher and drivers can see farther compared to a driver of a non-tall vehicle. Raised crosswalks elevate the height of pedestrians, bringing them into the driver's line of sight. The additional height provided by the raised crosswalk allows for drivers of tall vehicles to spot the pedestrian from a farther distance and alter their speed to yield appropriately.

Raised crosswalks are similar to speed humps, but the crosswalk sits atop the speed hump before bringing vehicles back down. Generally, the crosswalk portion should be as wide as the sidewalk with an additional foot on each side, much like traditional crosswalk pavement markings. Raised crosswalks tend to range between three and six inches tall (City of Minneapolis, 2021). When developing raised crosswalks, it is important to build sufficient ramps lengths to generate grade breaks that balance vehicle slowing effects with clearance requirements for passenger cars and vehicles towing low clearance trailers. Special consideration is required for stormwater as well. We recommend that raised crosswalks should be curb height (e.g. six inches) whenever possible so pedestrians can be seen by drivers of tall vehicles when using the raised crosswalk. Raised intersections are an extension of a raised crosswalk, where the raised portion of the roadway extends throughout the intersection and encompasses all crosswalks within the intersection at the raised elevation. Raised intersections have similar traffic calming and visibility effects as raised crosswalks.

Raised crosswalks/Intersections	Tall-Vehicle Visibility Benefit
	Lifts pedestrians to sidewalk level so they are in the view of drivers earlier; also slows approach speed of tall vehicles. **Average Cost:** $8,170 each raised crosswalk (for a two-lane roadway) **Benefit (WisDOT CMF):** 0.55 (raised crosswalk)

Figure 27. Raised Crosswalk (Zegeer, et al., 2013)

In summary, improving pedestrian visibility to all vehicles, particularly to drivers of tall vehicles, can be effectively achieved through raised and compact intersections, along with shorter midblock crossings enhanced high-visibility pavement marking, in-street signage, and pedestrian-specific signals. Elevating the entire intersection or crosswalk using a flat-topped speed table creates a physical slope as well as a visual cue as vehicles approach. By elevating pedestrians, this design helps bring them into the driver's direct line of sight. Compact intersections and curb extensions further enhance safety by reducing pedestrian exposure, slowing vehicles near pedestrian conflict points, and improving visibility for all road users. The design also requires the removal of unnecessary turning, slip, and pocket lanes, while incorporating curb extensions and/or median refuge islands to create shorter and safer crossings.

Vehicle Design and Technology

A-pillars are a major component in vehicle occupant safety; however, they create large blind zones in which pedestrians can be hidden. As vehicles get taller, their A-pillars increase in size, creating larger blind zones. Expandable A-pillars are a technology where slim A-pillars are expanded in the event of a crash, increasing strength. They are an effective way to reduce the blind zone while still maintaining structural stability in the event of an accident. Extensive research determined that expandable A-pillars can reduce the obstruction angle by 25% while maintaining the same safety standards of the A-pillars we see in vehicles on the road today (Pipkorn, Lundstrom, & Ericsson, 2011). The common practice of expandable A-pillars in future vehicle design would allow for pedestrians to be made more visible to drivers.

As autonomous vehicles become more commonplace, advancements in in-cab technology can help reduce SVSP crashes using pedestrian detection systems. The use of advanced driver-assistance systems (ADASs) can reduce the number of crashes involving pedestrians using LiDAR. Existing ADASs can brake automatically if a pedestrian is detected. A variety of classifiers are used in pedestrian detection as pedestrians come in all shapes and sizes (Kukkala, Tunnell, Pasricha, & Bradley, 2018).

Policy and Regulation

As mentioned previously, lower speeds reduce pedestrian fatality risk and increase pedestrian visibility. Multiple cities around the United States, including New York, Washington D.C., Seattle, Minneapolis, and Madison, among others, have reduced local speed limits. To do so, State legislative authorization is often required (Albee & Boblitz, 2021). Wisconsin should consider authorizing and encouraging reduced speed limits in urban areas to reduce pedestrian fatality risk.

Moreover, state and local jurisdictions should adopt stricter no turn on red policies at intersections with high pedestrian volumes. As drivers make their right turn on red (RTOR) movement, they frequently only look to the left, failing to check for pedestrians crossing the road from the right. When Wisconsin implemented RTOR in the mid-1970s, SVSP crashes involving right turn movements at signalized intersections increased by 107% (Preusser, Leaf, DeBartolo, Blomberg, & Levy, 1982). Implementing stricter no-turn-on-red policies would reduce the number of vehicle-pedestrian conflict points at a very low cost. While no-turn-on-red may not be appropriate at all signalized intersections, it would be an effective way to reduce SVSP crashes at signalized intersections with high pedestrian volumes.

As vehicles grow taller, the likelihood of fatality increases. Pickups, SUVs, and vans with hood heights exceeding 40 inches are 45% more likely to result in pedestrian fatalities compared to vehicles with lower hood heights (Hu, Monfort, & Chicchino, 2024). Moreover, a 10-centimeter (3.94 inch) increase in vehicle front end height increases fatality risk by 22% (Tyndall, 2024). To reduce pedestrian fatalities and align better with a Safe Systems approach, the maximum front-end height or overall height should be limited for commercial vehicles. Tyndall estimates that annual pedestrian fatalities in the United States would be reduced by 509 deaths if vehicle front-end height was limited to 1.25 meters (4 feet, 1.2 inches) (Tyndall, 2024).

Along a similar vein, United States House Representative Scanlon proposed the Pedestrian Protection Act in 2024. The passage of the Pedestrian Protection Act would require NHTSA to enforce stronger fleet safety regulations through the development of vehicle safety standards and the implementation of a minimum visibility standard (Scanlon, 2024). The development of vehicle safety standards would limit the most dangerous features of a car: vehicle height, hood, and bumper design. Moreover, NHTSA would be required to enforce car manufacturers to require a minimum visibility standard regarding blind zones associated with pedestrian crashes. To meet this standard, car manufacturers could investigate the addition of side guards, larger windshields, and improved mirror design. The Pedestrian Protection Act would require NHTSA to include a driver visibility rating in their New Car Assessment Program (Scanlon, 2024). This would educate consumers on the effects of vehicle size on pedestrian safety and would allow them to make a more informed decision before purchasing a taller vehicle.

Education, Enforcement and Outreach

It can be difficult to understand the experiences of a pedestrian in a car-centric world if you do not frequently walk. Similarly, it can be hard to understand the views of a driver if you do not frequently drive. To combat this, the Massachusetts Department of Transportation (MassDOT) prepared an experience: *Empathy at the Intersection*. Empathy at the Intersection helped participants gain perspective through three methods: direct vision, urban driving simulation, and crossing with mobility impairment. Direct vision allowed participants to climb into the cab of large vehicles to see how their view was affected. Urban driving simulations allowed participants to attempt to navigate heavy pedestrian conflict zones to understand how important roadway safety is. Lastly, crossing with mobility impairments allowed participants to simulate what it would be like to use the roads as someone who is less able-bodied (Massachusetts Department of Transportation, 2024). Overall, the Empathy at the Intersection experience was a success. WisDOT should consider creating a similar experience for not only practitioners, but for drivers and non-drivers alike to see from both sides.

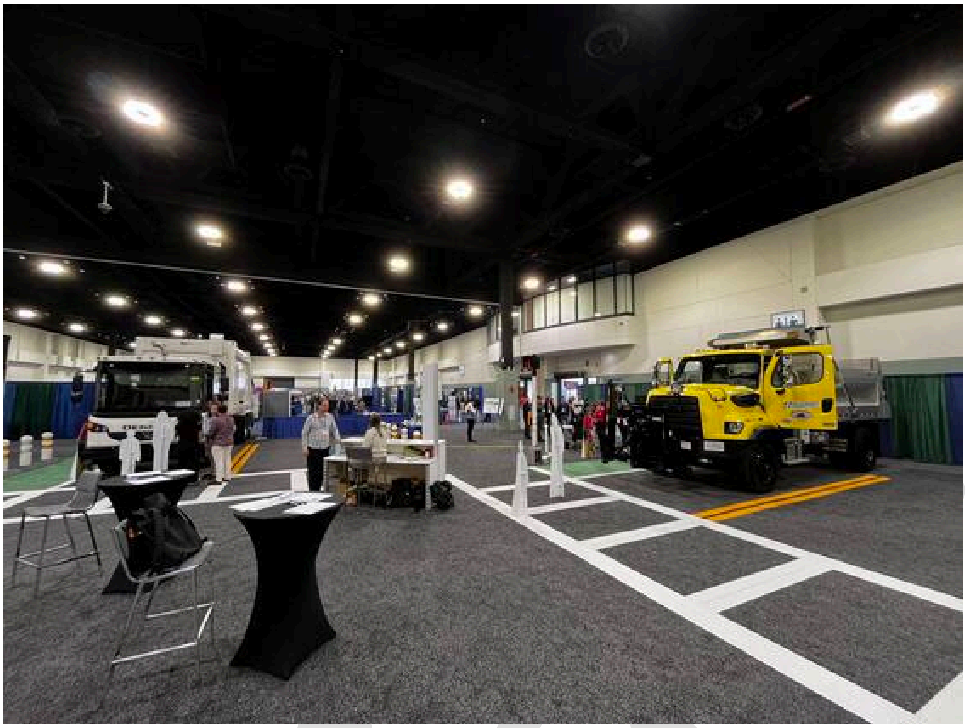


Figure 28. Empathy at the Intersection (Massachusetts Department of Transportation, 2024)

Safety campaigns can improve both driver and pedestrian behavior for the better. In 2013, the North Jersey Transportation Planning Authority implemented a safety campaign called Street Smart NJ. The main goal of Street Smart NJ was to improve pedestrian safety by increasing awareness and improving compliance. Both the observational and behavioral studies suggested that the Street Smart NJ campaign reduced risky behaviors by both drivers and pedestrians and increased knowledge of traffic laws (Patel, 2020). When used in conjunction with safety countermeasures, safety campaigns can improve behavior, making roads safer for everyone.

Countermeasure Selection Guiding Principle: A Safe System Approach

A comprehensive countermeasure strategy should follow a Safe System approach. We have slightly modified the Safe System approach to target tall vehicles, but our key principles remain the same. The Safe System approach emphasizes sharing responsibility between drivers, pedestrians, engineers and any other involved parties, designing redundancy into the system, prioritizing high risk locations, and proactively implementing safety measures to mitigate pedestrian visibility issues involving tall vehicles.

Within the Safe System approach, everyone has a role to play in creating a safe environment. Everyone involved in the system shares a piece of that responsibility as well. Designers, engineers, and planners share responsibility for creating safe roads for everyone and not only prioritizing vehicular travel. Car manufacturers have a responsibility to ensure that their vehicles are safe for everyone, not just those inside them. Policymakers and government officials share a responsibility to make decisions about speed limits, traffic control practices, and vehicle size regulations. Educators share a responsibility to emphasize pedestrian safety both inside and outside of the vehicle.

Moreover, the system should incorporate multiple layers of protection. If one layer fails, others can mitigate the impact. Redundancy is essential because there is no way to eliminate mistakes. This is particularly true with pedestrian crashes, who do not benefit from occupant protection.

When designing the system, we should take a proactive approach. A proactive approach prevents crashes before they happen, rather than reacting to them. Through systematically reducing factors that we know cause more SVSP crashes, we can build a safer environment. Narrower roadways, safer speeds, and additional pedestrian protections help reduce the likelihood that a crash will occur in the first place.

Our approach should be data driven. In order to make roads safer, we can use data to identify and address safety issues and prioritize resources. After identifying key indicators, like multi-lane roads, we can use the results to perform network screening based on risk factors. Based on our research, we have identified many contributing factors to tall SVSP crashes. In the future we believe fatal and serious injury crashes should be prioritized, high-priority communities should feature enhanced safety, systems should be both redundant and proactive, and speeding needs to be addressed.

Prioritizing Fatal and Serious Injury Crashes

Countermeasures should be prioritized in locations where pedestrian crashes result in severe and fatal injuries. One way to identify these priority locations is by identifying a region's pedestrian high injury network (HIN). A HIN identifies roadway segments and intersections where the most severe and fatal injuries occur and are predicted to continue to occur without any changes to the street design (Schooley, et al., 2023). A pedestrian HIN identifies the intersections and segments where the most pedestrian crashes result in severe and fatal injuries. Milwaukee's pedestrian HIN is shown in Figure 29. The streets identified in Milwaukee's HIN have pedestrian risk factors identified previously, including higher vehicle speeds and traffic volumes (Schooley, et al., 2023).

Identifying the HIN for communities in Wisconsin would allow for roadway improvements to be systemically implemented to reduce severe and fatal injuries. Reducing the injury outcome from SVSP crashes is imperative to making Wisconsin safer. Prioritizing serious and fatal crashes while simultaneously focusing on countermeasures for tall vehicles will help reduce the danger tall vehicles pose to pedestrians.

Enhancing Safety in High-Priority Communities

Certain areas, such as school zones, senior communities, and transit hubs require more aggressive implementation of safety treatments as pedestrians in these environments are the most vulnerable. Higher design standards such as larger font sizes for signage, wider crosswalk stripes, and increased illumination levels should be implemented in these areas. Additionally, more frequent applications of countermeasures such as pedestrian crossing signals and speed-calming treatments should be applied in and around these communities. Targeted enforcement strategies can also benefit high-priority communities.

The City of Milwaukee has three "Safe Routes" programs to further enhance safety in high-priority communities. These programs include Safe Routes to School, Safe Routes to Transit, and Safe Routes to Parks. All three of these programs aim to improve pedestrian safety, accessibility, and comfortability through infrastructure improvements, education, and engagement (City of Milwaukee, n.d.).

Figure 29. Safe Routes to School - Infrastructure and Signage Improvements (City of Milwaukee, n.d.)

Safe Routes to School programs have had great success in various states across the country. Local investment in Safe Routes to School programs in Florida, Mississippi, Washington and Wisconsin found that the percentage of children walking to school jumped from 9.8% to 14.2% (Centers for Disease Control and Prevention, 2018).

Addressing Speed and Speeding

As speeds increase, it takes a driver more time to stop and their field of vision is significantly smaller. Moreover, the likelihood of a pedestrian fatality or serious injury increases exponentially. (City of

Milwaukee, 2024). Lower speed limits improve pedestrian visibility because they give drivers more time to spot and slow down for a pedestrian. Lower speed limits also reduce the likelihood of pedestrian fatality. In Seattle, traffic fatalities decreased by 26% after setting a speed limit of 20 mph on non-arterial streets (Albee & Boblitz, 2021). As vehicle heights increase, the likelihood of fatality increases (Tyndall, 2021), compounding this with higher speeds makes for a deadly combination. Reducing speeds would reduce fatalities caused by tall vehicles. Systemwide speed limit reductions have shown promise in cities globally because they create new norms around speeding culture, However, changing speed limits in limited settings, without education or enforcement or design changes has shown limited effectiveness.

Safe speeds are paramount to reducing pedestrian injury levels. While enhancing a driver's ability to see pedestrians reduces the likelihood of crashes, it can also encourage higher speeds, as drivers may feel more confident and perceive reduced risk. For example, pedestrian refuge islands located in raised medians can greatly assist pedestrians crossing the street. However, the raised median can encourage faster vehicle speeds as there is a lower "perceived friction" along the roadway as opposing traffic flows are physically separated (Zegeer, et al., 2013).

To effectively manage the tradeoffs between improved visibility and increased speed, we need to use a balanced approach that enhances visibility without unintentionally promoting excessive speed. Self-enforcing roadways effectively mitigate speed by using a variety of treatments. Narrow lane widths, raised crosswalks, speed tables, chicanes, and curb extensions all create a self-enforcing roadway. Common practice has resulted in the standard lane width often being twelve feet, although lanes as narrow as nine feet are allowed, depending on the situation (American Association of State Highway and Transportation Officials, 2018). According to the Federal Highway Administration, as lane width increases, the 85th percentile operating speed increases because drivers feel more comfortable (Donnell, Kersavage, & Tierney, 2018).

Raised crosswalks and speed tables effectively reduce speeds along the roadway. The main difference between raised crosswalks and speed tables is that raised crosswalks have a crosswalk on top of the speed table. To make it over a raised crosswalk and speed table safely, drivers must reduce their speed to 15-20 mph (Zegeer, et al., 2013). Utilizing these countermeasures promotes slower speeds, while enhancing pedestrian visibility.

Chicanes and curb extensions help reduce speeds along the roadway while increasing pedestrian visibility. Both chicanes and curb extensions can be developed through rapid implementation or permanent construction. Chicanes create a horizonal diversion along the road to make lanes feel narrower, causing drivers to slow down. They can be developed using pavement markings, islands, or a combination of both.

The example shown in Figure 30 utilizes both pavement markings and islands, but the chicane would remain effective without the islands if rapid implementation is necessary.

Before **After**

Figure 30. Before and After Installment of a Chicane (National Association of City Transportation Officials, 2013)

Variable speed limits (VSLs) can also be used to reduce speeds along roadways while increasing pedestrian visibility. VSLs can reduce 85th percentile speeds by 5 mph (Donnell, Kersavage, & Tierney, 2018). The implementation of VSLs that adjust based on peak pedestrian activity, such as school zones during arrival/dismissal times, can help reduce speeds.

Lastly, pedestrian improvements can be made carefully to keep pedestrian visibility paramount. Rather than improving lighting along entire roadways, lighting improvements can be focused at crosswalk as to not make the entire roadway feel open and fast. It's important to consider the tradeoffs between speeds and pedestrian visibility throughout every step of the process when developing pedestrian countermeasures.

Building Redundancy into the System

While overloading countermeasures is not desirable, some level of redundance must be built into the system. Multiple layers of protection can be implemented together to mitigate risks from different angles. For example, RRFBs should be used in conjunction with high-visibility crosswalks to provide advance warning and increase pedestrian detection. Advance stop/yields can also be paired with RRFBs and high-visibility crosswalks to reinforce driver compliance.

Figure 31. RRFB with High Visibility Crosswalk Marking (Albee & Boblitz, 2021)

Raised crosswalks can be combined with advance stop/yield lines and signage to improve visibility and slow vehicle speeds. Moreover, signage can alert the driver of the raised crosswalk ahead to ensure they reduce their speeds enough to cross the raised crosswalk. In addition to speed reduction, pedestrian visibility is improved. The use of both countermeasures creates a safer walking environment that helps drivers recognize how to drive safely in pedestrian-dense environments.

At a mid-block crossing, we can implement a multitude of countermeasures to ensure pedestrians are safeguarded. In the rendered mid-block crossing below (Figure 33), four countermeasures are used: high visibility crosswalk markings, curb extensions, in-street pedestrian crossing signs (and additional roadside signs), and lighting. The curb extensions shorten the pedestrian crossing distance, limiting the time the pedestrian spends in the road. Additionally, curb extensions shown here effectively increase the driver's sight triangles by restricting parking near the crosswalk (daylighting) and can make it easier for drivers to see when a pedestrian is about to enter the crosswalk. Moreover, the high visibility markings and in street pedestrian crossing signs signal to drivers to prepare to yield for a pedestrian. The lighting provides additional redundancy during nighttime conditions when it is more difficult to see pedestrians.

Figure 32. Redundancy at a Mid-Block Crossing (Zegeer, et al., 2013)

If the redundancy shown above is not enough to protect pedestrians, further redundancy can be built into the system using advance stop/yield markings and a raised crosswalk. The advance stop/yield markings, placed at least four to ten feet back from the crosswalk, delineate where vehicles should stop to maintain visibility for other drivers and provide a buffer distance. The raised crosswalk effectively slows vehicle speeds along the road. Raised crosswalks at the maximum height also greatly improves pedestrian visibility to tall vehicles as the crosswalk ensures the pedestrian can be seen by a driver in a tall vehicle.

While some countermeasures are incredibly effective alone, many are much more likely to reduce crashes in conjunction with another countermeasure. On strategy is pairing geometric countermeasures with a marking and/or signage countermeasure, such as curb extensions with high visibility crosswalks. Building redundancy into the system makes the roadway safer for everyone and ensures that the roadway will continue to protect pedestrians even if one countermeasure fails.

CONCLUSIONS AND RECOMMENDATIONS

To better understand pedestrian visibility as it relates to tall vehicles, we performed an extensive literature review. Our literature review informed us on how vehicle bodies and vehicle heights have changed over time, as well as how those changes contribute to pedestrian crashes involving tall vehicles. Upon completion of our literature review, we began to collect SVSP data for Wisconsin, Tennessee, and Florida. After collecting the data, we processed our data and identified the important correlations between vehicle size and pedestrian harm. Once our data was processed, we began to analyze the crashes using a variety of methods: descriptive analysis, tree modeling analysis, typology analysis. After analyzing our data at a high level, we developed detailed logistic and ordinal crash models. Those models aimed to predict crash injury severity as well as to explain tall-vehicle crashes. Our models allowed us to identify issues that lead to SVSP crashes and their severity, especially those involving tall vehicles. The culmination of our literature review, data analysis, and modeling guided our countermeasure identification. Lastly, we evaluated our countermeasures using principles guided by a Safe System approach.

We found that tall vehicles are significantly associated with more severe pedestrian injuries in traffic crashes compared to non-tall vehicles across all three states. In Wisconsin, this disparity appears stronger, potentially due to state-level differences such as generally higher vehicle heights and a greater proportion of low-speed crashes (25 mph or less) than other states. In general, straight maneuvers, higher posted speed, and dark lighting conditions result in higher levels of pedestrian injury severity. The following factors are strong indicators of a tall vehicle-related crash specifically:

- Left turns and backing movements
- Failure to yield
- Pedestrians in the crosswalk or in the roadway
- Posted speed
- Rural roadways

Through careful consideration, we were able to identify a multitude of countermeasures relating to roadway infrastructure, vehicle design and technology, policy and regulation, and education, enforcement, and outreach. When making decisions regarding countermeasure selection, we recommend an analysis of the existing roadway characteristics and crash history. Countermeasures will be most effective when they are selected using our aforementioned guiding principles.

Planning

Historically, transportation planning has prioritized vehicular speed and capacity over pedestrian safety. To reverse this trend, pedestrian accommodation must be fully integrated into every stage of the planning process, from land use and corridor studies to project scoping and funding prioritization. Specific strategies include identifying and mapping high-pedestrian activity zones, incorporating pedestrian safety performance measures into long-range transportation plans, and ensuring pedestrian infrastructure is contextually appropriate (e.g., mid-block crossings near transit stops, curb extensions in high-foot-traffic areas). This is especially critical as tall vehicles, which pose increased visibility risks, continue to make up a growing share of the vehicle fleet. Applying the Safe System approach in planning helps design a transportation system that anticipates errors and minimizes their consequences. This includes reducing vehicle speeds through road diets and traffic calming, separating pedestrian and vehicle movements, and integrating safe accessibility into planning. Pedestrian-centered planning not only reduces crashes including those involving tall vehicles but also fosters more vibrant, inclusive, and connected communities.

Roadway Design and Traffic Operations

As we move forward, the primary focus of roadway design needs to focus on safety in addition to mobility. While traffic flow and operational efficiency are important, they should be optimized within the framework of a safety-first approach. Reducing roadway widths and posted speeds can significantly improve pedestrian visibility, shorten their crossing time, and provide adequate reaction times for drivers, especially those operating tall vehicles with larger blind zones. Roadway design should be reimagined with a stronger emphasis on pedestrian movement, visibility, and protection.

To support this paradigm shift, design manuals such as the Facilities Development Manual (FDM) should offer clearer guidance on selecting and implementing pedestrian safety countermeasures. In addition, greater consideration should be given to proven traffic control devices in the Manual on Uniform and Traffic Control Devices such as PHBs, RRFBs, and LPI. Utilization of these devices should be more common, provided the appropriate standards are met. These traffic control devices can greatly increase pedestrian visibility, especially for those driving tall vehicles as the devices are placed at or above driver eye height.

Safety Analysis and Evaluation

To improve pedestrian visibility particularly around tall vehicles, agencies should prioritize safety analysis to identify high-risk locations and conditions where visibility issues are most pronounced. This study outlines several analytical methods, including descriptive statistics, crash typology analysis, and statistical testing and modeling, to uncover patterns specific to tall vehicle involvement. Incorporating vehicle height as a variable in crash prediction models can significantly enhance the precision of safety evaluations. Additionally, agencies can utilize video analytics, field observations, and near-miss data to assess pedestrian visibility challenge in real-world settings, particularly during left turns, backing maneuvers, and under low-light conditions.

Evaluation should be an integral part of the implementation process. Before-and-after studies using crash, speed, and conflict data can provide valuable feedback to refine visibility-focused interventions. In this study, the benefits of safety treatments are mostly cited from the WisDOT CMF table which compiled information from various sources (Wisconsin Department of Transportation, 2024). Agencies are encouraged to keep updating the CMFs when available or conduct their own evaluations of the countermeasures recommended in this study, especially in scenarios where multiple treatments may be deployed simultaneously. Rigorous evaluation is also strongly recommended for new or emerging safety strategies that have not yet been widely tested or piloted to ensure that resources are directed toward the most effective and context-appropriate solutions.

Driver Education and Outreach

Our study shows that driver factor (e.g., speeding, failing to yield) is one of the leading factors in crashes involving tall vehicles. Driver errors and reckless behavior can exacerbate situations where tall vehicle blind zones already pose heightened risks. Hence, agencies should update driver training materials and licensing exams to include content on the risks tall vehicles pose to pedestrians, particularly in situations involving blind zones during left turns, backing, and low-speed maneuvers in parking lots. Targeted campaigns can reinforce these messages by highlighting the limitations of visibility from taller vehicles and encouraging cautious behaviors in pedestrian-heavy environments.

Agency outreach efforts should also focus on building partnerships with community organizations, schools, and local businesses to promote pedestrian visibility and safe driving behaviors. Outreach initiatives might include distributing educational materials, hosting safety workshops, or conducting interactive demonstrations such as the MassDOT's "Empathy at the Intersection" initiative that help drivers understand pedestrian visibility challenges from a tall vehicle's perspective. These efforts should prioritize vulnerable populations such as children, older adults, and people with disabilities who are disproportionately affected by poor visibility. By fostering a culture of shared responsibility and raising public awareness, agencies can complement infrastructure improvements with behavior change.

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APPENDIX A: LITERATURE REVIEW

The project team reviewed past pedestrian safety studies and established a foundation for defining tall vehicles, the relationship between visibility issues and vehicle height, pedestrian crash typologies linked to these factors, and related countermeasures suggested in the literature.

Vehicle Body and Height Trends

Studies on vehicle design and size generally categorize vehicles into passenger cars, either separate or combined groups of light-truck vehicles, such as SUVs, pickup trucks, minivans, and larger commercial vehicles (Ballesteros, Dischinger, & Langenberg, 2004), (Liu, Hainen, Li, Nie, & Nambisan, 2019). Recent research goes further by dividing SUVs into small and large categories (Tyndall, 2021) (Tyndall, 2024). This categorization accounts for smaller SUVs like crossovers, which have recently driven consumer vehicle sales. According to a report, the market share of crossovers has been steadily increasing since 2004, reaching approximately 40% of consumer vehicles by 2018, as illustrated in Figure 33 (Consumer Reports, 2019). This growth has largely come at the expense of conventional SUVs and passenger car models such as sedans and coupes.

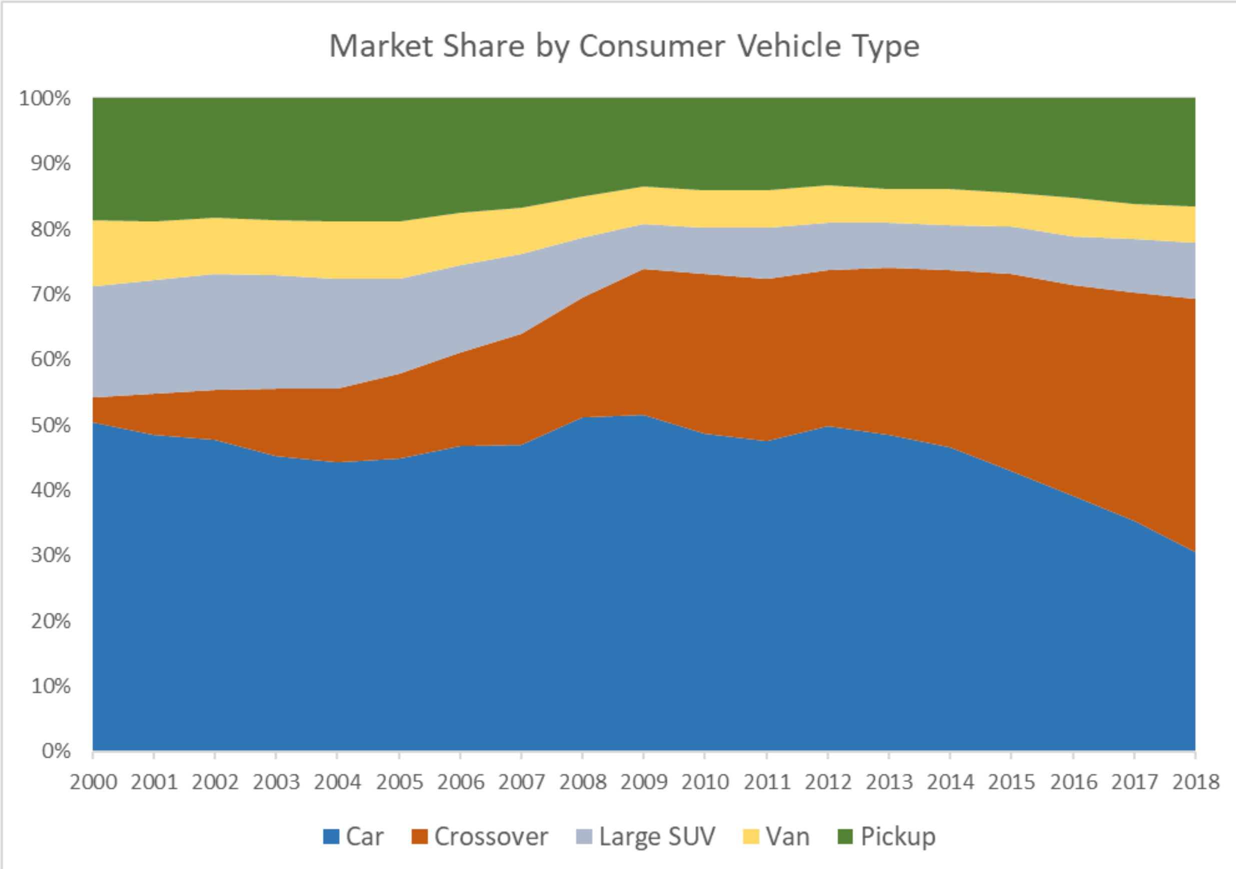

Figure 33. Consumer Vehicle Market Share. Modified from (Consumer Reports, 2019) (Originally Sourced from Wards Intelligence)

Although some studies have started using more detailed vehicle type categories, very few have incorporated vehicle dimensions for classification or included these measurements in their analyses (Tyndall, 2024). A common explanation for this omission is that many studies treat vehicle type as a control variable and extend this control to account for vehicle dimensions. Figure 2 supports this by demonstrating a notable correlation between vehicle type and dimensions, particularly vehicle height.

Figure 34 presents the distribution of vehicle heights for 23,240 consumer vehicles from the Canadian Vehicle Specifications (CVS) dataset, spanning the past 30 years and categorized by their specific year, make, and model combinations (The Canadian Association of Road Safety Professionals, 2024). Over time, this distribution reveals significant shifts. In the 1995–2004 decade, two primary peaks emerge, one representing consumer vehicles with lower heights (4 to 5 feet), possibly representing passenger cars, and another representing light trucks with higher heights (5 feet and above). In contrast, the most recent decade shows three distinct peaks, likely reflecting crossovers (approximately 5.25 to 6 feet) alongside large SUVs and pickup trucks (6 feet above). This trend aligns with the growing popularity of crossovers as consumer vehicles (Consumer Reports, 2019). Furthermore, the histograms provide valuable insight into defining tall vehicles and ensuring that the categorization appropriately encompasses vehicles that pose visibility challenges for pedestrians, including crossovers, large SUVs, minivans, and pickup trucks.

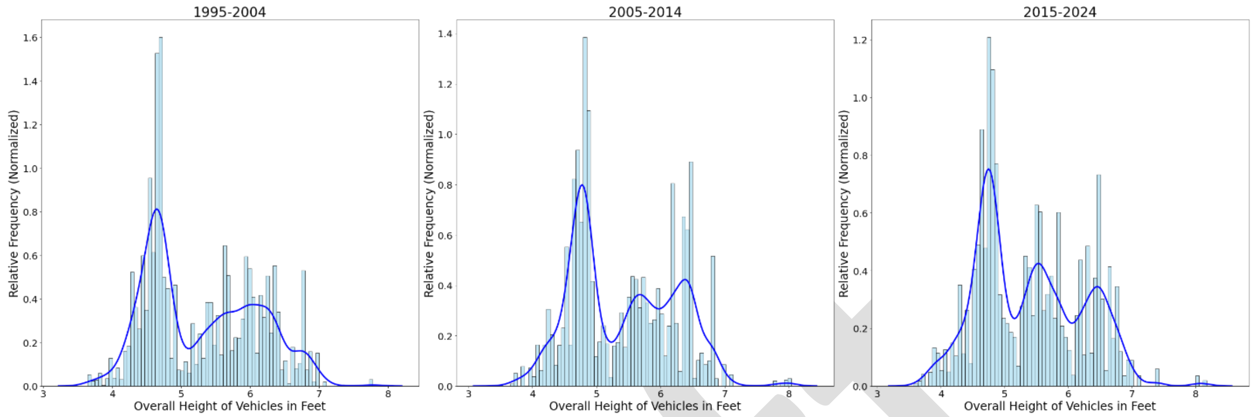

Figure 34. Distribution of Vehicle Height of Models listed in the CVS dataset over a period of 30 years

Vehicle Height and Visibility

Existing studies have linked vehicle-related visibility issues with vehicle body type and design and have found mixed results. For instance, tall vehicles offer better visibility over vertical curves (Zwahlen & Schnell, 1999). Drivers can more easily spot pedestrians at a distance in taller vehicles than passenger cars, as illustrated by Figure 35. Conversely, pedestrians can also spot taller and larger vehicles more easily. Existing roadway design manuals adopt a design driver eye height of 3.5 ft, representing the 5th percentile driver eye height. This standard ensures that most vehicles, including 95% with driver eye heights greater than 3.5 ft, are adequately accommodated in the design process (Donnell, Hines, Mahoney, Porter, & McGee, 2009).

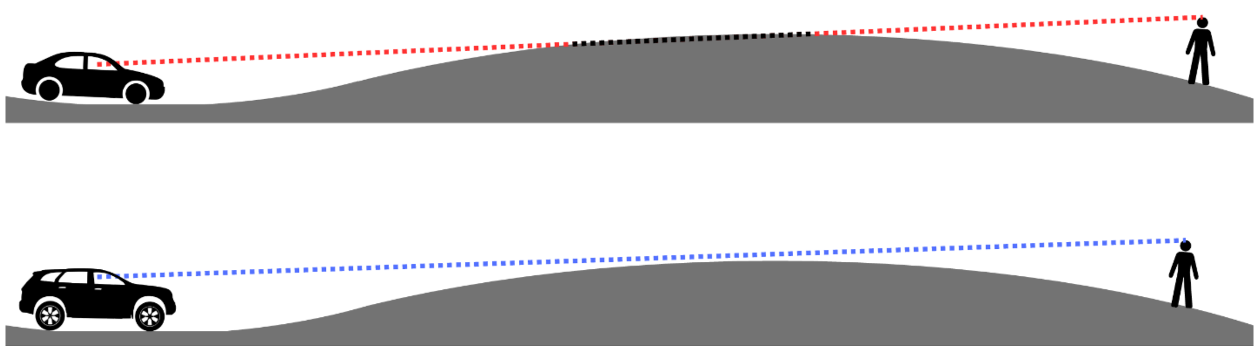

Figure 35. Visibility from the Driver's Eye Height in a Passenger Car and SUV over a Vertical Curve to spot a Pedestrian (Not to Scale)

Taller vehicles, however, come with larger blind zones, making it harder to detect nearby pedestrians or obstacles (Hu & Chicchino, 2022). For instance, A-pillar blind zones are a common visibility concern in all vehicles. Figure 36 shows how A-pillars could obscure vulnerable road users, such as motorcyclists and bicyclists, for the driver. In the case of taller and heavier vehicles, thicker A-pillars are required to support their weight during rollovers to protect vehicle occupants (Pipkorn, Lundstrom, & Ericsson, 2011). However, thicker A-pillars will make the A-pillar blind zone larger in these vehicles. Manufacturers also equip these vehicles with larger mirrors to address the reduced field of view caused by the greater distance between the driver and the mirror (Sivak, Devonshire, Flannagan, & Reed, 2008). The large mirrors and thicker A-pillars further obscure vulnerable road users, such as pedestrians. Further exacerbating visibility is the front hood height of these vehicles, which is generally higher than that of children, producing a substantial blind zone in the front (Schmitt, 2020). In vehicles without backup cameras, blind zones behind the vehicle range from 9 to 13 feet for sedans and 13 to 24 feet for SUVs and pickup trucks for an average driver (Consumer Reports, 2014), though backup cameras have been mandated since 2018.

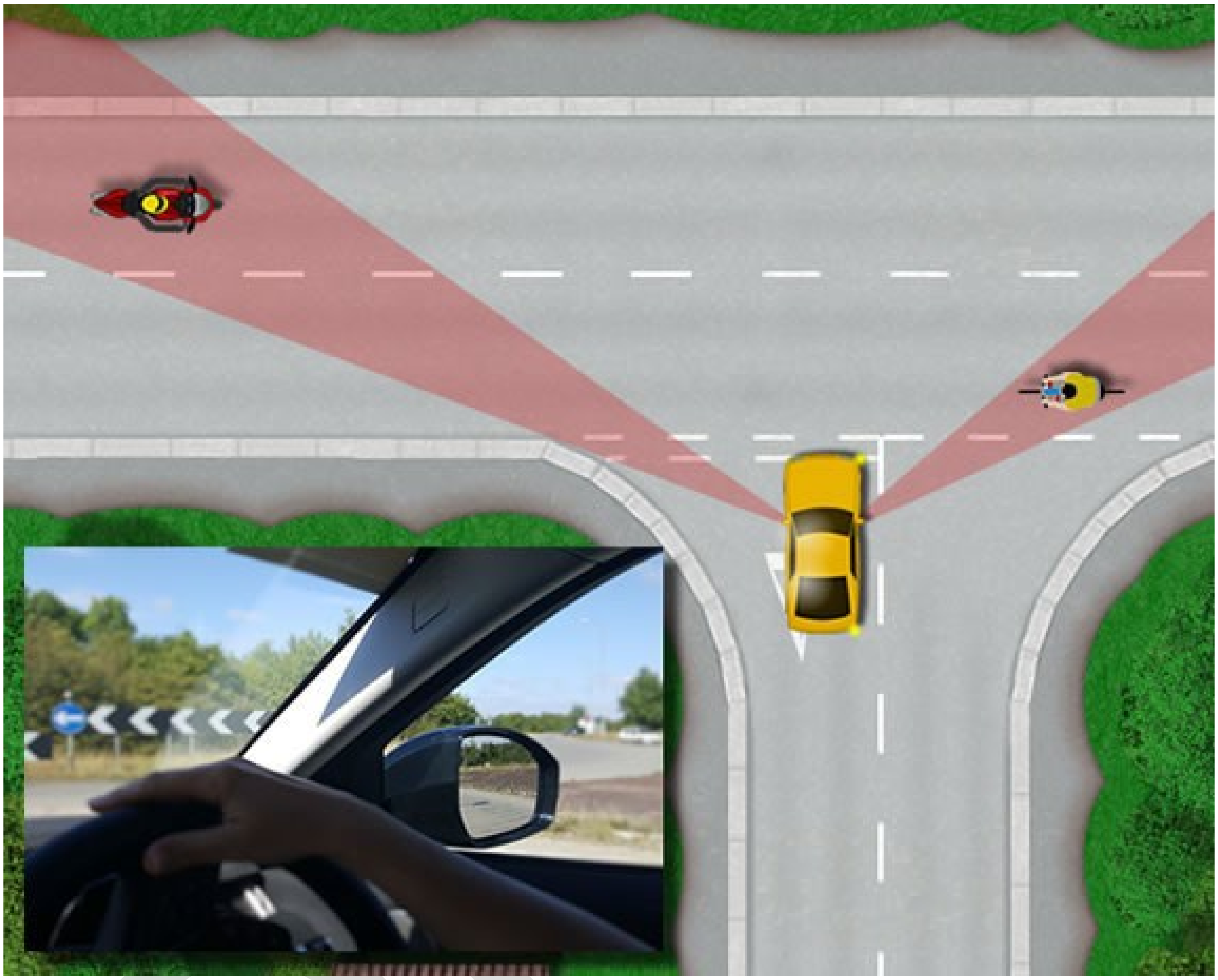

Figure 36. A-Pillar Blind Zones and Driver's Visibility (Driving Test Tips, 2024)

The effect of a thicker A-pillar, larger mirrors, and higher front hood height on blind zones is illustrated in Figure 37. The figure compares the blind zones of a sedan and a full-size SUV using a web-based application called VIEW Blindzone Calculator (Drake, et al., 2023). The figure shows that the ground blind zone and blind zone for a 37-inch-tall elementary school child are considerably larger in the SUV than in the sedan. For a 49-inch-tall pedestrian, the blind zone is nearly nonexistent in the sedan, while it remains substantial in the SUV. On this note, we can also assume that blind zones will be even larger on vehicles with increased heights due to after-market customization.

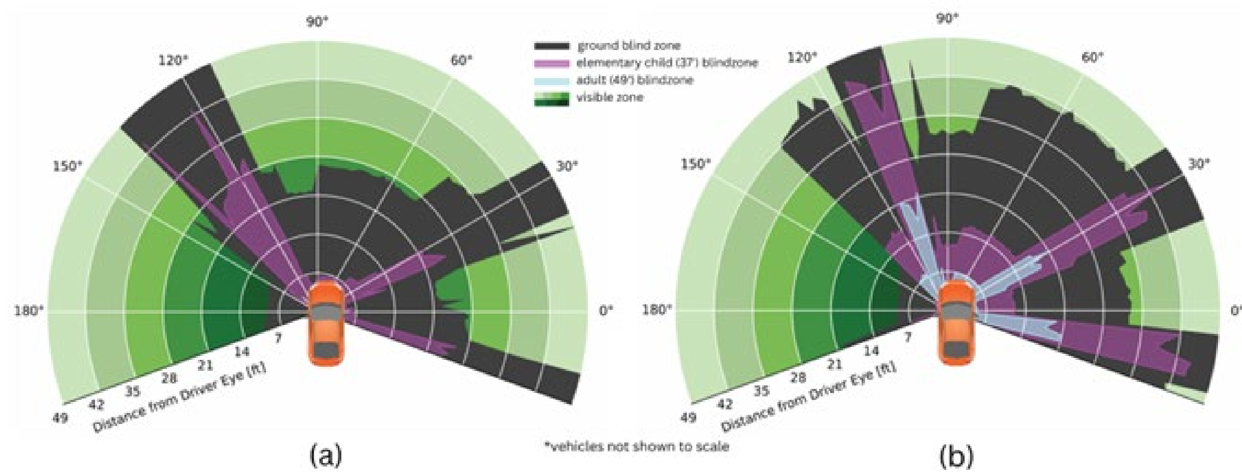

Figure 37. Comparison of Blind Zones for (a) 2024 Nissan Altima and (b) 2025 Honda Pilot (VIEW Blindzone Calculator, n.d.)

As shown above, the blind zones at the front of the tall vehicle extend much farther as compared to that of the non-tall vehicle. Recent studies confirm that taller vehicles have larger blind zones that contribute to reduced visibility. Researchers with the United States Department of Transportation (USDOT) and IIHS found that "outward visibility" decreased in all six vehicle models measured overtime, with SUV having a 58% reduction in visibility within a 10 meter radius. It's important to mention that non-tall vehicles have reductions in outward visibility, but they are much smaller, ranging from 7% to 19%. (Epstein, et al., 2025).

Pedestrian Crashes involving Tall Vehicles

Although there is no direct evidence suggesting tall vehicles are responsible for a higher number of pedestrian crashes, studies unanimously agree that these vehicles are responsible for a higher severity of pedestrian crashes (Desapriya, et al., 2009), (Edwards & Leonard, 2022), (Liu, Hainen, Li, Nie, & Nambisan, 2019). According to a meta-analysis of 11 studies, the risk of a pedestrian sustaining fatal injuries is 50 percent higher when struck by a light truck vehicle compared to a passenger car (Desapriya, et al., 2009).

The following subsections will examine the literature to explain why pedestrians struck by taller vehicles are more likely to suffer severe injuries. We will also identify the most common types of pedestrian crashes involving these vehicles and how visibility issues related to these vehicles play a role.

Pedestrian Injury Mechanisms

The crucial variables responsible for causing severe injury outcomes in pedestrian crashes are vehicle impact speed, size/weight, and design. Impact speed and vehicle weight contribute to the transfer of kinetic energy, and vehicle body type and design contribute to injury mechanisms during and just after the crash (Ballesteros, Dischinger, & Langenberg, 2004), (Hu, Monfort, & Chicchino, 2024), (Islam, 2023), (Tyndall, 2021). Existing research has extensively studied the relationship between vehicle impact speed and pedestrian safety risks, and design and policy-related strategies to minimize them (Hussain, Feng, Grzebieta, Brijs, & Oliver, 2019), (Tefft, 2013). On the other hand, the individual effects of vehicle weight and design remain underexplored, as most studies use vehicle body type as a proxy for weight, obfuscating the analysis. That said, Tyndall has shown that vehicle design aspects, indicated by the vehicle type and front hood heights, might be more crucial than weight in determining injury severity in pedestrian crashes (Tyndall, 2024). Very few studies have explored the correlation between vehicle design parameters and pedestrian injuries (Han, Yang, Mizuno, & Matsui, 2012), (Hu, Monfort, & Chicchino, 2024), (Tyndall, 2024).

In pedestrian-vehicle collisions, injury severity is heavily influenced by the impact force and the specific points of impact on the body. Strikes to the head or chest tend to cause more severe injuries, while impacts to the legs or arms are typically less severe. Most existing studies focus on frontal collisions and the initial and subsequent blunt trauma experienced by pedestrians. Han concluded that aside from impact velocity, the shape of the vehicle's front end significantly affects injury severity. That study found a higher risk of head and lower extremity injuries from medium-sized sedans and SUVs, a higher chance of chest injuries with vehicles like minivans, and a greater likelihood of pelvis fractures with both minivans and SUVs (Han, Yang, Mizuno, & Matsui, 2012). In contrast, minicars had a lower overall risk of injuries. Similarly, Simms reported more severe lower-body injuries from SUV impacts due to their larger front-end shape, which reduces body rotation and has more surface area to transfer the impact energy (Simms & Wood, 2006). Hu analyzed 17,897 crash reports and found that tall-blunt, tall-sloped, and medium-height-blunt front ends increased pedestrian fatality risks by 43.6%, 45.4%, and 25.6%, respectively (Hu, Monfort, & Chicchino, 2024). Tyndall reported a 22% increase in pedestrian fatality risk, in general, for every 10 cm increase in front-end height (Tyndall, 2024).

Research has also explored the effects of pedestrian biomechanics and the nature of secondary impacts following an initial collision with a vehicle's front end. Taller vehicles with higher hoods, like pickup trucks, are disproportionately responsible for running over child pedestrians, even at low speeds (Halari, et al., 2022). A qualitative comparison of secondary impacts found that vehicles with lower hoods, like compact cars, sedans, vans, and sports cars, posed "moderate" to "critical" risks. In contrast, SUVs and minivans were linked to "very critical" secondary impacts. Child impacts from vans were rated "very critical" compared to "critical" for adults (Hamacher, Eckstein, & Pass, 2012). Likewise, Simms studied ground contact mechanisms in pedestrian crashes and concluded that vehicles with higher front ends led to more severe ground-related injuries (Simms, Ormond, & Wood, 2011).

Pedestrian Crash Types Influenced by Visibility

The literature has established that collisions between tall vehicles and pedestrians generally result in more severe outcomes. However, the visibility benefits, primarily related to visibility over vertical or horizontal curves or obstructions, and the challenges, mainly near-range visibility, alter the likelihood and outcomes of pedestrian crashes. Dozza suggests that the time the pedestrian becomes visible, along with their speed and safe path, are key factors in enabling drivers to respond effectively at intersections (Dozza, Boda, Jaber, Thalya, & Lubbe, 2020). Identifying crash types influenced by the visibility issues of tall vehicles can be aided by tools like the Pedestrian and Bicycle Crash Analysis Tool (PBCAT), which classifies crash data based on factors such as vehicle movements, pedestrian actions, and environmental conditions (Thomas, et al., 2022). Several studies have examined pedestrian crashes related to visibility issues with tall vehicles, which will be discussed in the following sections.

Parking Lots and Driveway Crashes

Vehicles mostly drive slowly in parking lots and driveways, and pedestrian crashes are generally less dangerous (Parajuli, Cherry, Zavisca, & Roger III, 2023). However, several studies report a disproportionate number of young children involved in pedestrian crashes in parking lots and driveways, particularly in incidents where they are backed over and struck by taller vehicles (Desapriya, et al., 2009), (Fenton, Scaife, Meyers, Hansen, & Firth, 2005), (Muttart, Hurwitz, Pradhan, Fisher, & Knodler Jr., 2011), (Stanley, et al., 2011). A clear solution to these crash types is the proper use of rearview cameras, which is associated with an estimated 41% reduction in backing crashes involving pedestrians compared to vehicles without them (Austin, 2008), (Keall, Fildes, & Newstead, 2017). In recent years, we have seen a reduced focus on this issue in research, which may stem from NHTSA's mandate requiring backup cameras in all newly manufactured vehicles as of May 2018, effectively reducing rear blind zones by 90% (Consumer Reports, 2014). However, the risk remains in older vehicle models without backup cameras and in front of taller vehicles, where front blind zones continue to pose a hazard (Schmitt, 2020). Older pedestrians aged 65 years and above are also at higher risk from taller vehicles and in driveways compared to those aged 18 to 59 (Kim & Ulfarsson, 2019).

Turning Movements at Intersections

Recent research has also found that taller vehicles pose more injury risks to pedestrians during low-speed maneuvers such as turning movements (Cherry, Parajuli, & Barnhart, 2024). Drivers often fail to notice pedestrians during turning and merging maneuvers (Ulfarsson, Kim, & Booth, 2010). Reed reported that the driver-side A-pillar creates significant blind zones during left turns, particularly in the area immediately to the left of the intersection-departure lane entrance (Reed, 2008). For example, when a car begins a left turn off the major road at a four-way 90-degree intersection, pedestrians crossing the minor road remain obscured from the driver for a significant portion of the turn. This occurs because the blind zone accumulates progressively, blocking the driver's visibility as the vehicle turns left, as illustrated in Figure 38. This issue is more pronounced in taller vehicles with thicker A-pillars, which create larger blind zones, especially for vulnerable road users, including shorter pedestrians, children, individuals in wheelchairs, and bicyclists (Drake, et al., 2023), (Reed, 2008). A research gap exists in understanding how these blind zones affect the visibility of individuals using e-scooters and other mobility devices.

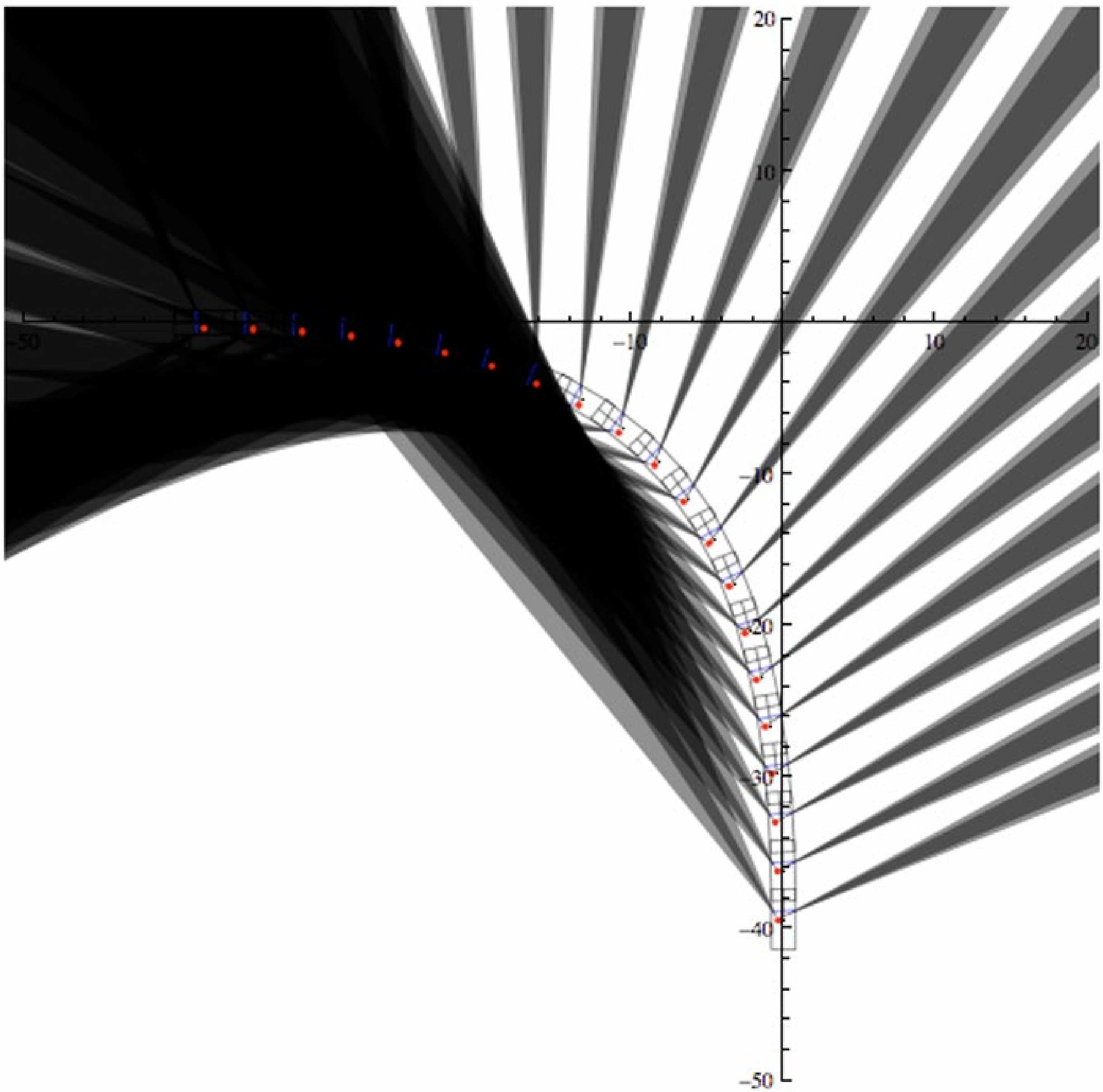

Figure 38. A-Pillar Blind zones at 20 Discrete Points during a 90-Degree Left Turn (Reed, 2008)

For 90-degree right turns at intersections, the obstructions caused by the passenger-side A-pillar do not stack as they do during left turns, resulting in a lesser impact on the driver's visibility. However, research has yet to address the impact of these blind zones during less sharp right turns. Nevertheless, right-turn pedestrian crashes are a significant concern, potentially caused by drivers overlooking pedestrians on their right while concentrating on oncoming traffic from the left (Roudsari, Kaufman, & Koepsell, 2007). The literature provides no clear evidence on how much harm we can attribute to passenger-side A-pillar and mirror blind zones in these crashes.

Multiple Threat Crashes

Multiple-threat crashes, as categorized in PBCAT 3.0, typically occur on multi-lane roads when one vehicle slows or stops to allow a pedestrian to cross in a crosswalk. However, a vehicle in an adjacent lane does not stop, resulting in a collision with the pedestrian. This crash type arises due to limited visibility between the pedestrian and the driver in the second lane, as the stopped vehicle obstructs the view (Thomas, et al., 2022). Unlike the other crash types, the striking vehicle tends to be a smaller vehicle, whose view and visibility is usually partially blocked by a larger vehicle, obscuring the pedestrian crossing, whether at an intersection or midblock. These crashes are underrepresented in the literature, with minimal connections to vehicle size. Fisher has also highlighted other variants of this crash type involving parking lanes and turning obstructions (Fisher & Garay-Vega, 2012).

Countermeasures

Recent countermeasure strategies in traffic safety have shifted focus towards adopting the Safe Systems principles. This approach acknowledges that deaths and serious injuries should be avoided without typical cost consideration and addresses human vulnerability and the possibility of mistakes by integrating various safety measures and redundancies to protect all road users, with a focus on those most vulnerable (U.S. Department of Transportation, 2022). It prioritizes safer people, roads, vehicles, speeds, and effective post-crash care.

In the context of pedestrian safety, most countermeasures focus on reducing vehicle speeds, as impact speed is a critical factor in determining pedestrian injury outcomes. These interventions include reactive measures like lowering the posted speed limit in response to a high number of pedestrian deaths along a corridor and proactive approaches like designing roads that make it difficult for drivers to exceed the intended speed limit (National Association of City Transportation Officials, 2013). A study suggested that the adverse effects of vehicle size and design on pedestrian outcomes could be mitigated by implementing safety measures to reduce vehicle impact speed (Cherry, Parajuli, & Barnhart, 2024). However, while this strategy reduces the severity of pedestrian crashes, it does not effectively address the visibility issues associated with tall vehicles.

Although visibility aids like fluorescent materials for daytime use and retroreflective or flashing materials for nighttime enhance the general visibility of pedestrians to the drivers, system-level improvements are crucial for addressing visibility risks posed by taller vehicles and do not transfer risk mitigation efforts to pedestrians (Kwan & Mapstone, 2006). One way to adopt this is by implementing safer vehicle strategies. Technological advancements in vehicles, such as pedestrian detection systems and automatic emergency braking, can help reduce vehicle impact speeds just before a collision, potentially preventing crashes or reducing the severity of injuries (Cicchino, 2022). Furthermore, advanced driver assistance systems, coupled with sensors and cameras designed to eliminate blind zones, can significantly enhance pedestrian safety. (Kukkala, Tunnell, Pasricha, & Bradley, 2018). To address visibility issues in taller vehicles, suggested vehicle design modifications include regulating front hood heights, incorporating pedestrian-friendly shapes, and using stronger yet thinner A-pillars to improve the driver's field of vision (Hu, Monfort, & Chicchino, 2024), (Pipkorn, Lundstrom, & Ericsson, 2011). Srinivasan provided a concept of using see-through A-pillars with holes to minimize A-pillar-related blind zone issues (Srinivasan & Demirel, 2022). Although these innovations are promising for the future, their effectiveness is limited by the slow turnover rate of the existing vehicle fleet. Consequently, it will take considerable time before newer, safer vehicles become widespread on the roads. Road infrastructure improvements are less studied as a specific countermeasure to reduce the severity of large vehicle crashes. Retrofitting existing roadways is a strategy that can potentially improve outcomes.

Quick-build projects are roadway design enhancements that immediately address visibility issues while operating within a limited budget. Quick build guides from several cities highlight interventions such as curb extensions, daylighting at intersections, medians or pedestrian refuge islands, high-visibility midblock crossings, and other projects designed to enhance pedestrian visibility in traffic (California Bicycle Coalition, Alta Planning and Design, 2020), (City of Orlando, 2023), (Nashville Department of Transportation, 2024). These projects creatively repurpose roadway space to enhance sightlines between pedestrians and drivers and separate pedestrian-vehicle traffic. Left-turn hardening is commonly used to reduce vehicle speeds while turning and prevent "corner cutting" (City of Orlando, 2023). Requiring drivers to make sharp turns at intersections could help prevent A-pillar blind zones that would otherwise obstruct pedestrians throughout the turn, as seen in Figure 38. Temporarily raised crosswalks elevate pedestrians to a higher level during the crossing, making them more visible to drivers at lower vantage points (California Bicycle Coalition, Alta Planning and Design, 2020). A study found that painted crosswalks and temporary curb extensions, which narrow vehicle lanes, increased pedestrian activity without significantly affecting vehicle traffic while improving pedestrians' overall sense of safety on the roads (Carlson, et al., 2019). Studies have shown that high-visibility crosswalks and uniquely designed crosswalks, such as those with brick or red-colored pavements, effectively capture drivers' attention, increasing their vigilance toward their surroundings and pedestrians (Iasmin, Kojima, & Kubota, 2016), (Pantangi, Ahmed, Fountas, Majka, & Anastasopoulos, 2021). Research has also proven the effectiveness of low-cost quick-build projects such as advance stop bars and refuge islands (Retting & Van Houten, 2000). Before-and-after studies have shown significant improvements in separating pedestrians and vehicles with drivers stopping at least four feet back from the crosswalks, improving from 74% to 92%, respectively (Retting & Van Houten, 2000). A more recent study found a direct association between advanced stop lines and fewer multiple threat passes (Morris, Craig, & Van Houten, 2020). Fisher proposed using advanced yield markings to prompt drivers to be more aware of pedestrians from a greater distance, allowing them to react quickly and avoid multi-threat crashes (Fisher & Garay-Vega, 2012). This increased separation from the crosswalk also helps maintain a safe distance, enabling drivers to notice pedestrians who may suddenly enter the roadway, such as children playing near the street.

As quick-build interventions prove effective, agencies often expand upon them with more advanced, long-term improvements that could take up to one year to build (Nashville Department of Transportation, 2024). Some examples are upgrading temporary raised crossings, curb extensions, and refuge islands to permanent ones. Protected intersections, although they ensure dedicated crossings for bicyclists, can also improve the visibility between drivers and people on foot and personal conveyances (National Association of City Transportation Officials, 2013). Grade-separated pedestrian crossings, such as overpasses and underpasses, are long-term solutions that practically eliminate visibility conflicts between pedestrians and vehicles, making them particularly valuable in areas with high volumes of pedestrian and vehicle traffic but are expensive and limited in their ability to cover all crossings (Axler, 1984). Although numerous studies address pedestrian visibility issues broadly, there is a significant gap in the literature regarding visibility challenges specific to tall vehicles and pedestrians.

Gaps in Existing Literature

Most existing design guidelines for vehicle visibility issues, such as driver eye height for determining sight distances, are tailored to the smallest passenger vehicles, like sedans and coupes. Particularly, addressing the issues with these vehicles will accommodate taller vehicles by default. However, existing research has proven that taller vehicles are associated with larger blind zones around the vehicle, posing a significant threat to pedestrians. These blind zones increase the risk of direct collisions with pedestrians and can contribute indirectly to multi-threat scenarios by becoming taller obstacles. The growing popularity of crossovers SUVs on U.S. roads and the increasing average height trends of pickup trucks—often exceeding 20 years in turnover and prone to height-related modifications—amplifies the risks associated with tall vehicles.

Despite this, there is a notable lack of research addressing visibility challenges related to vehicle height. There is also a lack of design-based countermeasures that can be implemented quickly rather than relying on vehicle modifications to solve the problem over time. For example, research should consider the potential of quick-build approaches coupled with policy-based countermeasures that can be adopted more rapidly and yield quicker results. Similarly, more systematic design standards should be considered that address specific challenges associated with larger vehicles. This study aims to investigate pedestrian crash types resulting from visibility issues and examine how these crashes relate to vehicle height and size. It seeks to address these gaps by exploring visibility challenges and proposing design and policy-based solutions that can be implemented quickly, while also offering recommendations for vehicle design improvements, which would be beneficial in the long run.

APPENDIX B: RELEVANT MV4000 DATA FIELDS

Table 8. MV4000 Data Fields

Data Field (Abbreviation)	Definition	Attribute Value
Roadway/Traffic		
Accident Location (ACCDLOC)	The type of location at which a crash occurred.	I = Intersection N = Non-Intersection PL = Parking lot PP = Private property
Highway Class (HWYCLASS)	A code which describes the type of road the crash took place on	BLNK = Blank U City = City street urban R City = City street rural R Town = Town road rural U CTH = County trunk urban R CTH = County trunk rural U STH = State highway urban R STH = State highway rural U IH = Interstate highway urban R IH = Interstate highway rural
Posted Speed (POSTSPD)	Posted speed for a vehicle unit at the location where a crash occurred	
Traffic Control (TRFCCNTL)	The traffic controls in effect at the time of the crash.	BLNK = Blank NONE = No control TS OP = Traffic signal operating TS FL = Traffic signal flashing SS = Stop sign SS FL = Stop sign with flasher WS = Warning sign WS FL = Warning sign with flasher YIELD = Yield sign TC PR = Traffic control person RRSIG = Railroad crossing signal OTHR = Other
Trafficway (TRFCWAY)	Text describing areas designed for motor vehicle operation	BLNK = Blank ND = Not physically divided D/WO = Divided highway without traffic barrier D/B = Divided highway with traffic barrier
Person-Level		
Driver Action (DRVRDOIN)	A code which identifies what a driver of unit was doing at the time of the crash	BLNK = Blank GO STR = Going straight LT TRN = Left turn RT TRN = Right turn SL/ST = Slow/stopping LG PARK = Legally parked

		NPASZN = Violated no passing zone IL PARK = Illegally parked PARKNG = Park maneuver BACKING = Backing CHG LN = Changing lanes OVT LT = Overtake left OVT RT = Overtake right UTURN = U turn RTOR = Turn on red MERGING = Merging NEGCRV = Negotiating curve OTHER = Other
Driver Factors (DRVRPC)	Code which describes the possible contributing circumstance for the highway on which a crash occurred	BLNK = Blank SPD = Exceed speed limit TFC = Too fast for conditions FTY = Failure to yield ID = Inattentive driving FTC = Following too close IT = Improper turn LOC = Left of center DTC = Disregard traffic control IO = Improper overtake UB = Unsafe backing FVC = Failure to keep vehicle under control DC = Driver condition DIS = Physically disabled OTHR = Other
Pedestrian Action (PEDACT_PD)	Code describing the pedestrian action in a crash	BLNK = Blank NF TRFC = Walking not facing traffic DISREG = Disregared signal SUDDEN = Darting into road DK CLTH = Dark clothing FC TRFC = Walking facing traffic
Pedestrian Injury Severity, KABCO Scale (INJSVR_PD)	Highest level injury severity for the pedestrian for a crash	K = Fatal injury A = Suspected serious injury B = Suspected minor injury C = Possible injury O = No apparent injury
Environmental		
Light Condition (LGTCOND)	Light condition at time of crash.	BLNK = Daylight DARK = Dark, unlit LIGT = Dark, lighted DAWN = Dawn DUSK = Dusk UNKN = Unknown

Road Surface Condition (ROADCOND)	Surface condition of the road at the point of origin for the unit apparently most at fault.	BLNK = Dry WET = Wet SNOW = Snow/slush ICE = Ice MUD = Sand/mud/dirt/oil OTHR = Other UNKN = Unknown
Weather Condition (WTHRCOND)	A code which identifies the weather condition at the time of crash.	BLNK = Blank CLR = Clear CLDY = Cloudy RAIN = Rain SNOW = Snow FOG = Fog/Smog/Smoke SLET = Sleet/Hail WIND = Blowing sand/dirt/snow XWIND = Severe crosswinds OTHR = Other UNKN = Unknown

APPENDIX C: STATISTICAL MODELS AND EQUATIONS

Machine-Learning Techniques: Random Forest and Gradient Boosting Trees

To determine the factors that contribute to tall SVSP crashes, we looked at two different forms of decision tree modeling: random forests and gradient boosting trees. Random forests build a collection of "de-correlated trees" and then averages them. They work by reducing the variance of an estimated prediction function, which is called "bagging" (McGill University). Random forests take a sample of the training data. To grow a random forest to the data sample, the random forest recursively repeats the following steps:

1. Select a group of variables at random from the total set of variables.
2. Pick the best variable among the selected group of variables.
3. Split the node into two daughter nodes

After the minimum node size is reached, the ensemble trees is output (McGill University) To make a prediction at a new point, class predictions were used for these random forests. The random forest analyzes data in two different ways: mean decrease accuracy and mean decrease Gini. Mean decreases accuracy measures the importance of variables based on how the model's accuracy decreases when the variable is removed. Mean decrease Gini measures the importance of variables based on the average decrease in impurity across all trees. Both accuracy methods can tell us which data fields have the largest impact on our data fields.

Gradient boosting trees differ slightly from random forests, which build deep independent trees. Gradient boosting models build shallow trees in sequence, always improving upon the previous tree. Boosting models address the tradeoffs between bias and variance through starting with a weak model and targeting the biggest mistakes in the tree prior. Gradient boosting models are considered a gradient descent algorithm which works to tweak parameters iteratively to minimize loss (Boehmke & Greenwell, 2020). Once the model is completed, the gradient boosting tree can inform us which data fields have the largest influence on our dependent variable.

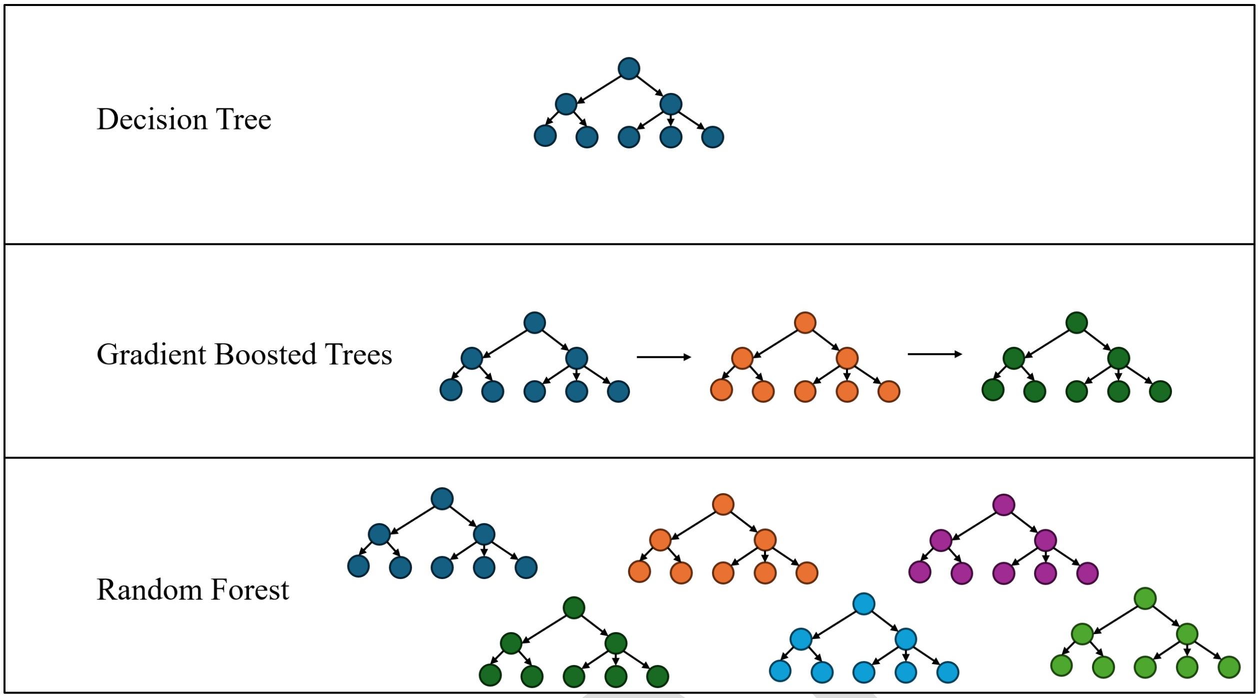

Figure 39. Machine Learning Techniques

Crash Modeling with Logistic Regression

Binary Logit Model

To predict the probability of a crash involving a tall vehicle, we used a binary logit model. Binary logit models are appropriate when the dependent variable has two categories. Binary logistic regression to determine the relationship between the independent variables and the dependent variables; and determine the accuracy of each classification (Fritz & Berger, 2015).

Binary logistic regression uses equation (1):

$$\Pr(y_n = 1) = \frac{exp(\boldsymbol{x}'_{ni}\boldsymbol{\beta}_i)}{\sum_{i=1}^{I} exp(\boldsymbol{x}'_{ni}\boldsymbol{\beta}_i)} \qquad (1)$$

where:

If crash *n* involving a tall vehicle, $y_n = 1$

$\mathbf{x}_n$ is a vector of independent variables that determines the involvement of tall vehicle in crash n, and $\boldsymbol{\beta}_i$ is a vector of estimable coefficients.

Ordinal Logit Model

The ordinal logit/probit model applies a latent continuous variable, z_n, as a basis for modeling the ordinal nature of crash severity data. z_n is specified as a linear function of $\mathbf{x}_n$:

$$z_n = \mathbf{x}_n'\boldsymbol{\beta} + \epsilon_n \qquad (2)$$

Where $\mathbf{x}_n$ is a vector of explanatory variables determining the discrete ordering (i.e., injury severity) for *n*th crash observation; $\boldsymbol{\beta}$ is a vector of estimable parameters; and, ε_n is an error term that accounts for unobserved factors influencing injury severity.

A high indexing of *z* is expected to result in a high level of observed injury *y* in the case of a crash. The observed discrete injury severity variable y_n is stratified by thresholds as follows:

$$y_n = \begin{cases} 1, if\ z_n \leq \mu_1 \text{ (C, B, PDO, or no injury)} \\ 2, if\ \mu_1 < z_n \leq \mu_2 \text{ (A or severe injury)} \\ 3, if\ \mu_2 < z_n \text{(K or fatal injury)} \end{cases} \qquad (3)$$

where the μs are estimable thresholds are, along with the parameter vector $\boldsymbol{\beta}$. The model is estimated using maximum likelihood estimation (Greene, 2000).

If the random error term ϵ is assumed to follow a standard normal distribution, the model is an ordered probit model. The probabilities associated with the observed responses of an ordered probit model are as follows:

$$\begin{aligned} P_n(1) &= \Pr(y_n = 1) = \Pr(z_n \leq \mu_1) = \Pr(\mathbf{x}_n'\boldsymbol{\beta} + \epsilon_n < \mu_1) \\ &= \Pr(\epsilon_n < \mu_1 - \mathbf{x}_n'\boldsymbol{\beta}) \\ &= \phi(\mu_1 - \mathbf{x}_n'\boldsymbol{\beta}) \end{aligned} \qquad (4)$$

$$\begin{aligned} P_n(2) &= \Pr(y_n = 2) = \Pr(\mu_1 < z_n \leq \mu_2) = \Pr(\mu_1 < \mathbf{x}_n'\boldsymbol{\beta} + \epsilon_n \leq \mu_2) \\ &= \Pr(\epsilon_n < \mu_2 - \mathbf{x}_n'\boldsymbol{\beta}) - \Pr(\epsilon_n < \mu_1 - \mathbf{x}_n'\boldsymbol{\beta}) \\ &= \phi(\mu_2 - \mathbf{x}_n'\boldsymbol{\beta}) - \phi(\mu_1 - \mathbf{x}_n'\boldsymbol{\beta}) \end{aligned} \qquad (5)$$

$$P_n(i+1) = \phi(\mu_{i+1} - \mathbf{x}_n'\boldsymbol{\beta}) - \phi(\mu_i - \mathbf{x}_n'\boldsymbol{\beta}) \qquad (6)$$

$$P_n(I) = \Pr(y_n = I) = \Pr(z_n > \ \mu_{I-1}) = \ 1 - \phi(\mu_{I-1} - \mathbf{x}_\mathrm{n}'\boldsymbol{\beta}) \tag{7}$$

Where i is the ith level of injury and i represents the highest injury level (i.e., fatal). $\Phi(.)$ is the cumulative standard normal distribution.

We employed ordinal logistic regression to examine how injury severity in pedestrian crashes relates to crash characteristics, including tall vehicle indicator and other covariates. Ordinal logistic regression is well-suited for modeling outcomes with a natural order but unknown spacing between levels. Pedestrian injury severity is typically recorded using the KABCO scale, ranging from fatal (K), serious (A), minor (B), possible (C), to no injury/property damage only (O). This ordered structure makes it appropriate for ordinal modeling. For analytical clarity and emphasis on high-severity outcomes, we grouped injury severity into three categories: fatal, serious, and minor or no injury.

The ordinal logit model is formulated as shown in equation (8):

$$\log\left(\frac{\Pr(\text{Injury Severity} \le j)}{\Pr(\text{Injury Severity} > j)}\right) = a_j - \mathbf{X}\beta \qquad for\ j = 1, 2 \tag{8}$$

where **Injury Severity** is the ordinal dependent variable with three categories: minor or no injury, serious injury, and fatal injury; j represents the thresholds separating the severity categories; a_j are the threshold parameters estimated for each level of j; $\mathbf{X}$ is the vector of explanatory variables; and β is the vector of coefficients.

The predictor vector **X** includes key variables such as the tall vehicle indicator, driver maneuvers (backing, left turn, right turn, and others, with going straight as the reference), interaction terms between vehicle tallness and maneuvers, intersection location, posted speed limit categories, and lighting conditions. Additional control variables include vehicle age, pedestrian and driver sex (male vs. otherwise), indicators for alcohol or drug involvement by either party, and categorical age groups for both pedestrians and drivers. We also controlled for year fixed effects to account for temporal changes, such as changes in reporting practices, policies, infrastructure improvements, and other unobserved factors varying over time.

We estimated separate ordinal logit models for three states, Wisconsin (2008–2022), Tennessee (2009–2023), and Florida (2012–2020), to account for state-specific crash patterns and policy contexts. We also developed a pooled model combining data from all three states to complement these state-specific analyses and offer a broader, more generalizable understanding of injury severity outcomes. This also allowed us to explore additional state × tall vehicle interaction relationships. The ordinal logit models were implemented using the `ologit` command, and the generalized ordinal logit model was implemented using the `gologit2` command in Stata, with violators of parallel lines assumptions identified at a 0.001 significance level. The goodness-of-fit was assessed using the log-likelihood ratio test and McFadden's pseudo R^2.

The generalized ordinal logit model formulation is expressed in equation (9).

$$\log\left(\frac{\Pr(\text{Injury Severity} \le j)}{\Pr(\text{Injury Severity} > j)}\right) = a_j - \mathbf{X}\beta - Z_j\gamma_j \qquad for\ j = 1, 2 \qquad (9)$$

Where **X** is the vector of predictors that satisfy the proportional odds assumption, and Z_j are the predictors that violate this assumption, and their effects vary by threshold.

APPENDIX D: TREE-MODELING AND ADDITIONAL MODEL RESULTS

To gain a better understanding of what data fields have the largest influence on pedestrian crashes involving tall vehicles including the variables relating to driver and pedestrian behavior, a few machine learning tests were conducted. Using RStudio, a statistical analysis tool, we ran both a random forest and gradient boosting tree. These tests help us determine the most influential variables on tall vehicles, making data analysis easier.

The mean decrease accuracy random forest identifies *highway class, driver action, driver contributing factors, pedestrian location, and trafficway* as the top five most influential variables. Mean decrease Gini measures the importance of variables based on how much it contributes to the homogeneity of the random forest's leaves and nodes. The mean decrease Gini identifies *driver contributing factor, driver action, weather condition, pedestrian location, and posted speed* as the top five most influential variables.

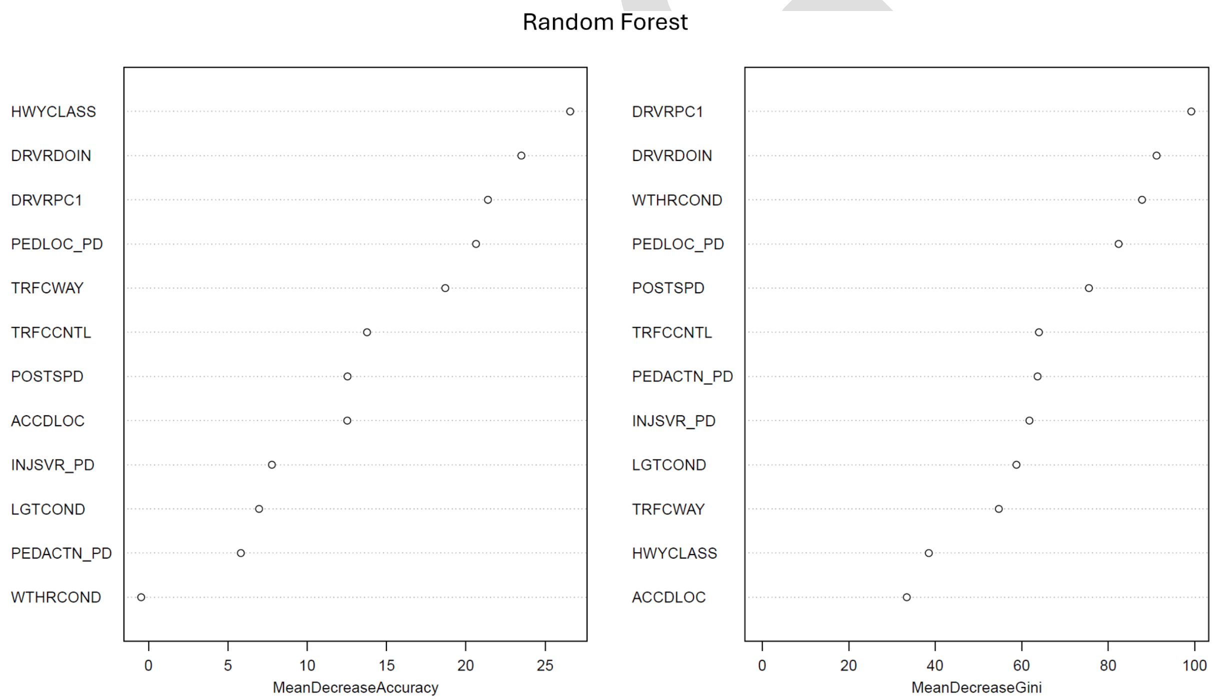

Figure 40. Random Forest for WI SVSP Crashes, 2008-2022

The gradient boosting tree identifies *highway class, driver action, driver contributing factors, pedestrian location, and trafficway* as the variables with the most influence. All of these variables were previously identified as influential by the random forest.

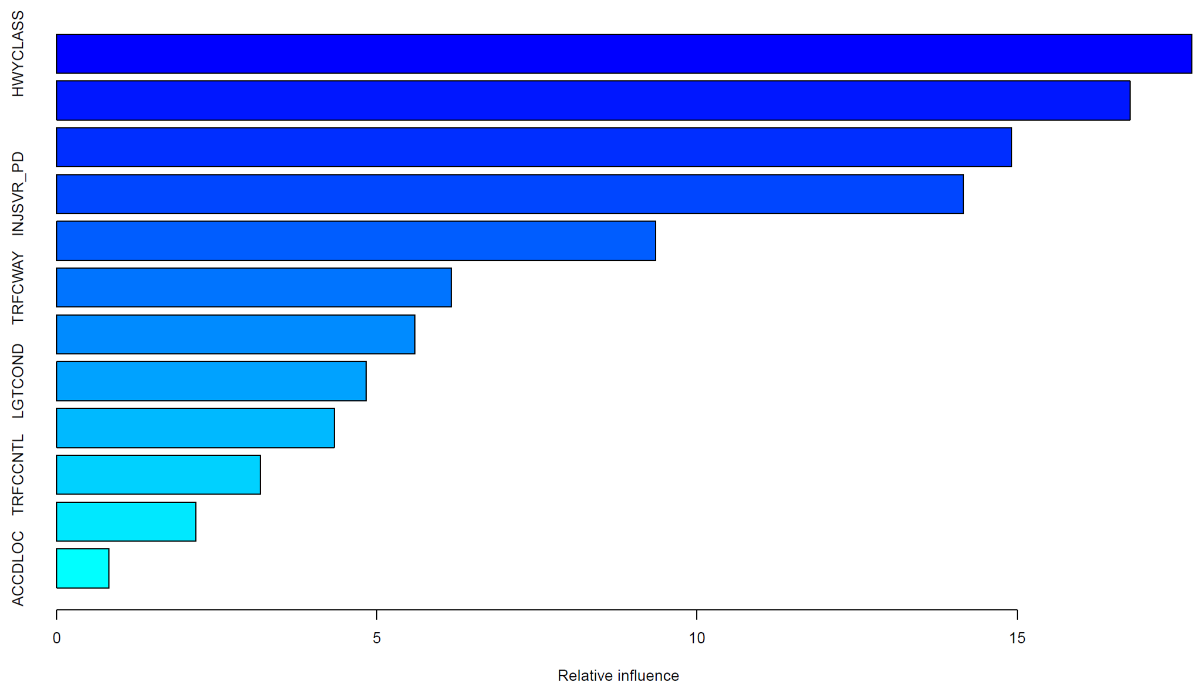

Figure 41. Gradient Boosting Tree for WI SVSP Crashes, 2008-2022

To better understand how the built environment affects WI SVSP crashes, we performed a random forest and gradient boosting tree using only the roadway related factors. The factors included in these trees are accident location, highway class, light condition, posted speed, traffic control, and trafficway.

When we focus on the roadway factors, *highway class, posted speed, and trafficway* are identified as the most influential factors using the mean decrease accuracy random forest. For the mean decrease Gini random forest, *posted speed, traffic control, and highway class* are the most influential factors.

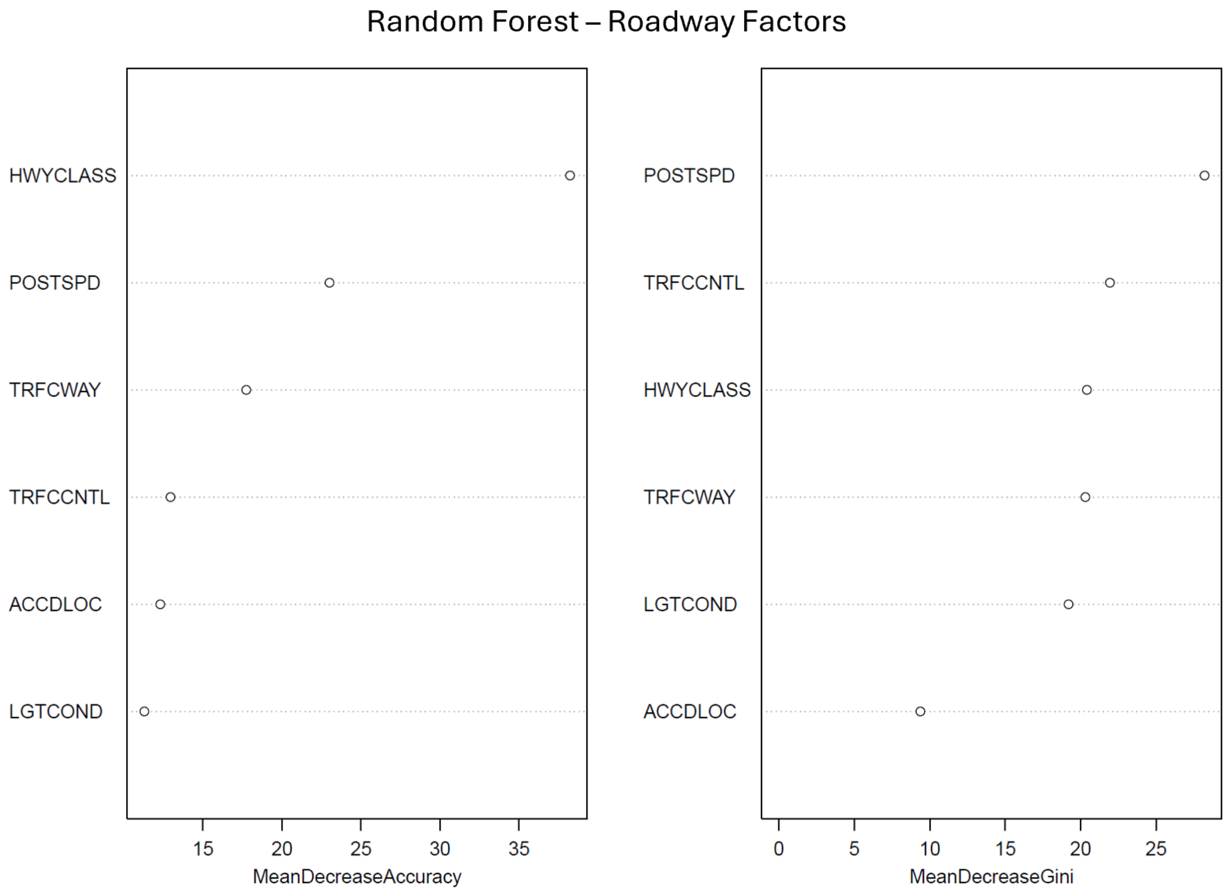

Figure 42. Roadway Factors Random Forest for WI SVSP Crashes, 2008-2022

When we analyzed the gradient boosting tree for roadway factors only, we found similar trends to that of the random forest for roadway factors. The gradient boosting tree identifies *highway class, posted speed, and traffic way* as the most influential factors. The mean decrease accuracy random forest shown previously identified these three factors as those with the most influence as well.

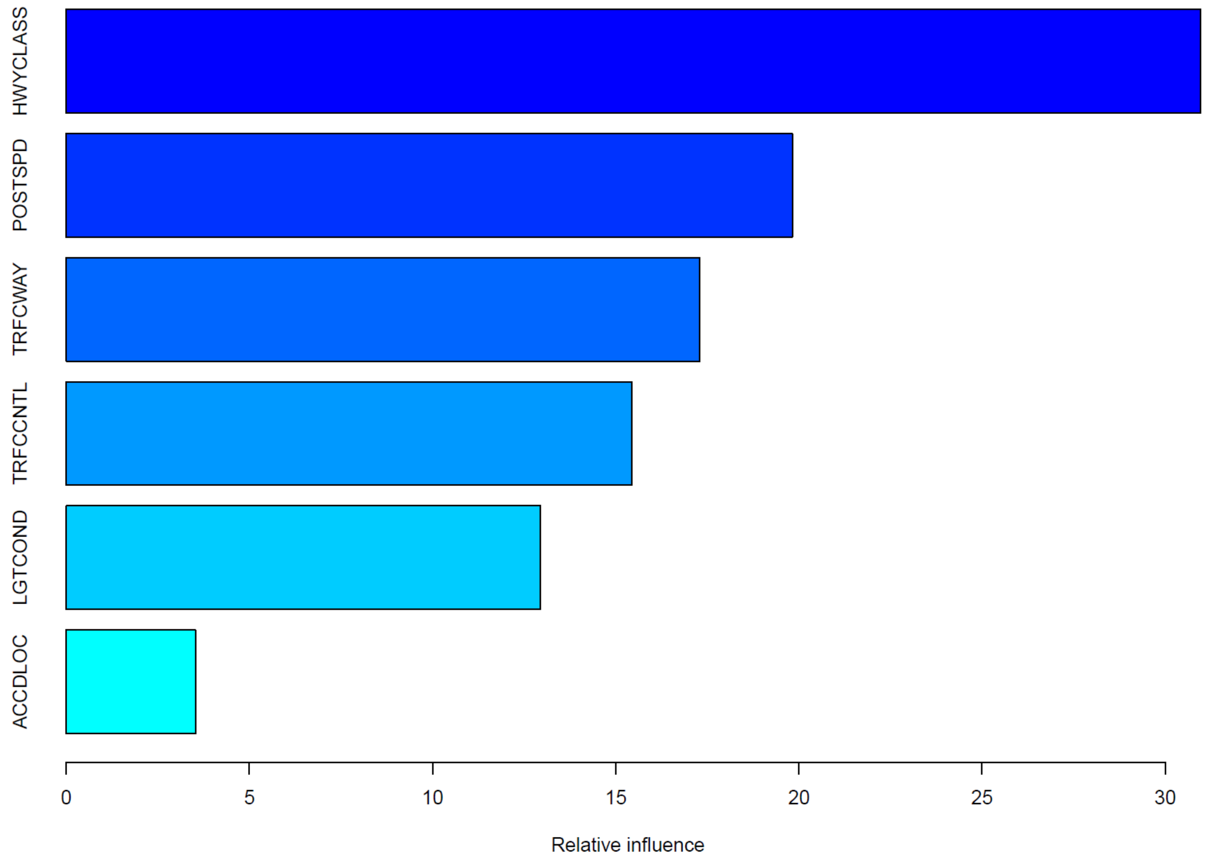

Figure 43. Roadway Factors Gradient Boosting Tree for WI SVSP Crashes, 2008-2022

Although accident location was not identified as one of the most influential factors by neither the random forest nor the gradient boosting model, we thought it was important to split the crash data into two groups: intersection and segment. Here, segment refers to crashes that occurred outside the bounds of an intersection. We believe that it is important to divide these two locations as their can be a lot of variability between these two crash locations.

Intersection Tree Modeling

Crashes occurring at an intersection make up approximately 40% of the SVSP crashes in Wisconsin. When we performed the random forest, we observed similar trends for both the mean decrease accuracy and mean decrease Gini random forests. The mean decrease accuracy random forest identified *driver action, driver contributing factor, traffic control, highway class, and weather condition* as the most influential factors. The mean decrease Gini random forest identified *driver action, driver contributing factor, traffic control, weather condition, and posted speed* as the most influential factors. At most intersections, drivers have more options as they can make left and right turns. As mentioned previously, there are significantly larger blind zones as drivers turn, so it is understandable that driver action emerges as the leading factor.

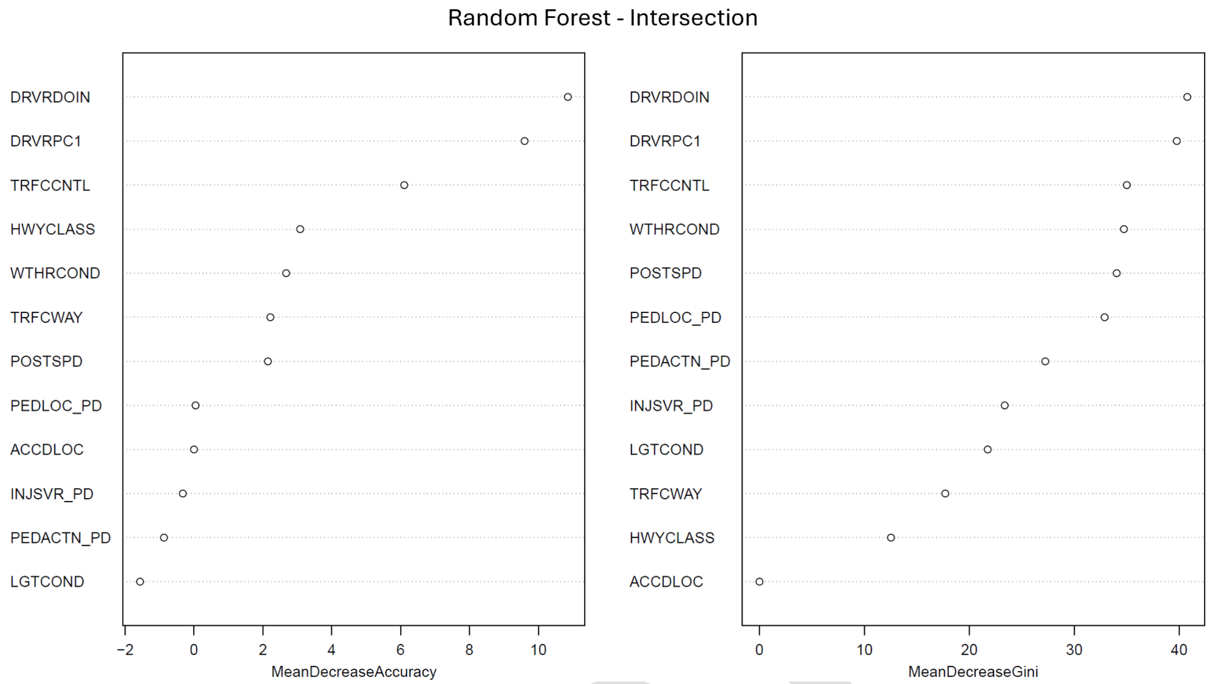

Figure 44. Random Forest for WI SVSP Intersection Crashes, 2008-2022

The gradient boosting tree identifies similar data fields to those identified by the random forest. *Driver action, highway class, driver contributing factor, pedestrian location, and weather condition* were identified as the most influential factors.

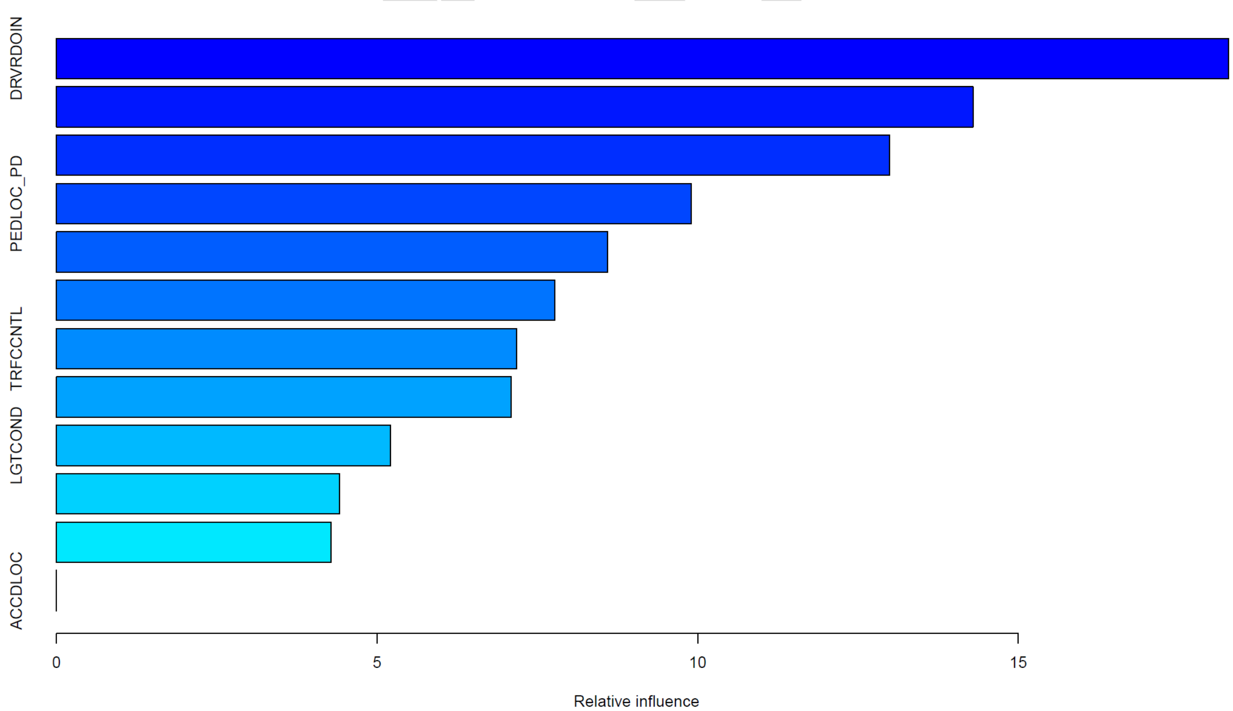

Figure 45. Gradient Boosting Tree for WI SVSP Intersection Crashes, 2008-2022

Once again, a random forest and gradient boosting tree were performed using only the roadway factors. When we looked at the results from the mean decrease accuracy random forest, *highway class, trafficway, and accident location* were identified as the most influential factors. The mean decrease Gini was slightly different with *posted speed, traffic control, and light condition* being the most influential factors. The gradient boosting tree identified *highway class, traffic control, and posted speed* as the most influential factors. The tree modeling clearly shows that the leading factors for tall vehicle crashes at intersections are *highway class, traffic control, trafficway, and posted speed.* It is important to note that both trafficway and posted speed are key factors because larger traffic ways imply longer crossing distances while higher posted speed implies less time to notice and stop for a pedestrian.

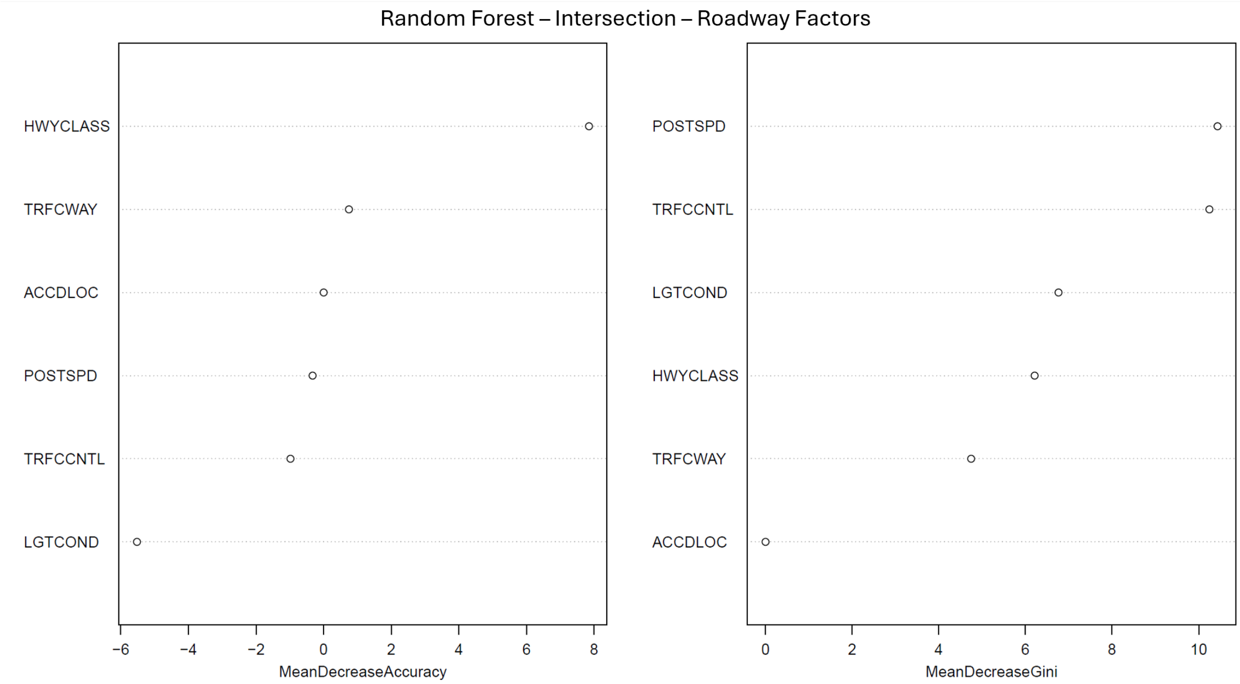

Figure 46. Roadway Factors Random Forest for WI SVSP Intersection Crashes, 2008-2022

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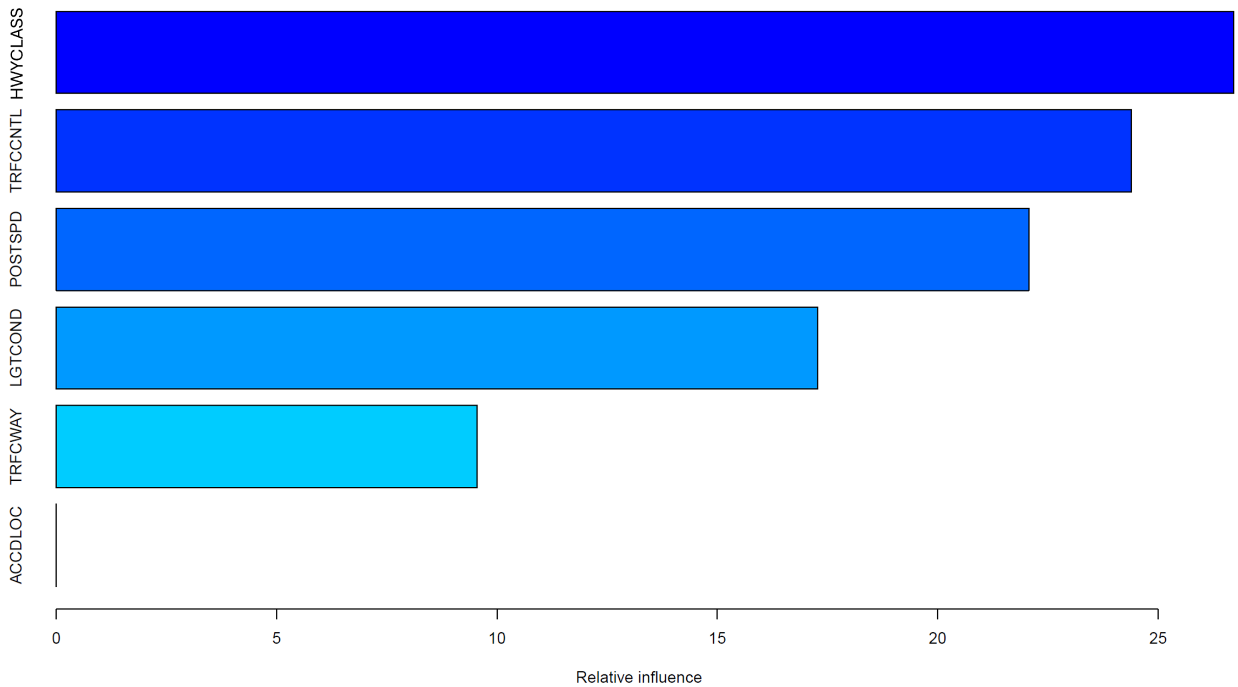

Figure 47. Roadway Factors Gradient Boosting Tree for WI SVSP Intersection Crashes, 2008-2022

Segment Tree Modeling

A similar analysis was performed for the SVSP crashes in Wisconsin that occur along roadway segments. These crashes make up approximately 60% of the total crashes. The mean decrease accuracy random forest asserts *driver action, driver contributing factor, pedestrian location, highway class, and pedestrian injury severity* as the most influential factors. Similarly, the mean decrease Gini asserts *driver contributing factor, driver action, pedestrian location, weather condition, and posted speed* as the most influential factors. The gradient boosting tree identified *driver contributing factor, pedestrian injury severity, driver action, highway class, and posted speed* as the most influential factors. Compared to intersection crashes, the most influential factors stayed very similar.

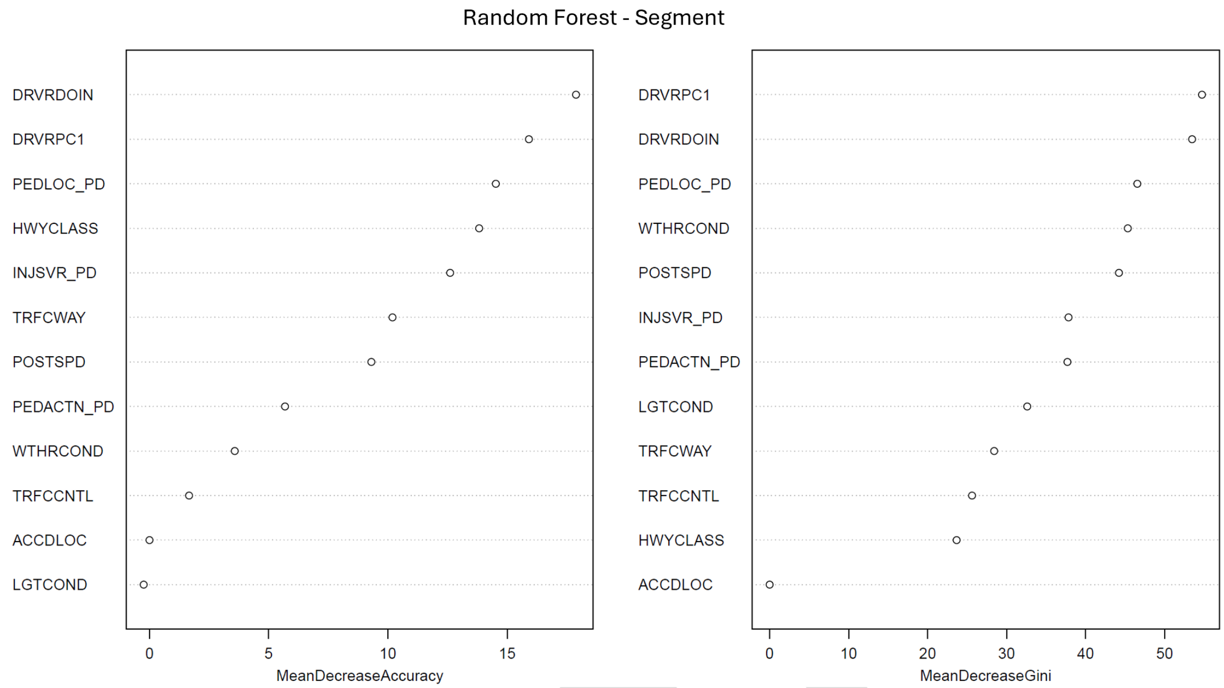

Figure 48. Random Forest for WI SVSP Segment Crashes, 2008-2022

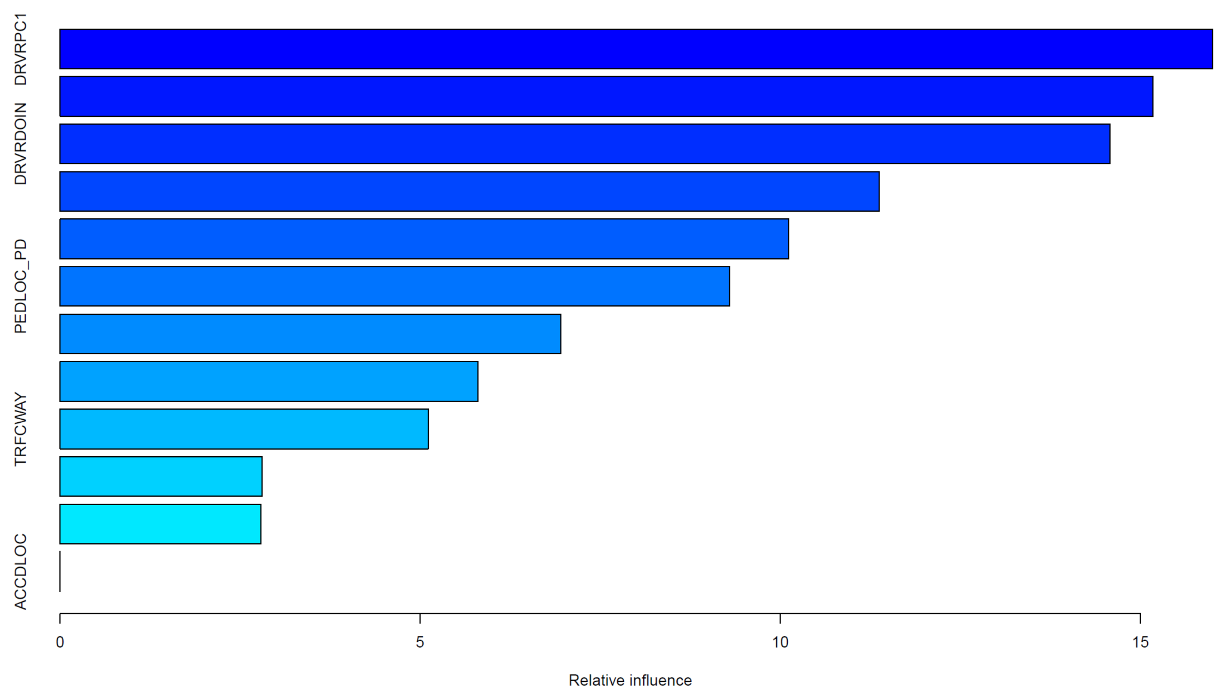

Figure 49. Gradient Boosting Tree for WI SVSP Segment Crashes, 2008-2022

We once again performed a random forest and gradient boosting tree for segment crashes using only the roadway factors. The mean decrease accuracy random forest indicated *highway class, posted speed, and trafficway* as the most influential factors. The mean decrease Gini identified the exact same factors as the most influential, with *posted speed* being the most influential followed by *highway class* and *trafficway*.

Similarly, the gradient boosting tree identified *posted speed, highway class, and trafficway* as the most influential factors. Once again, it is important to note that both trafficway and posted speed are key factors because larger traffic ways imply longer crossing distances while higher posted speed implies less time to notice and stop for a pedestrian.

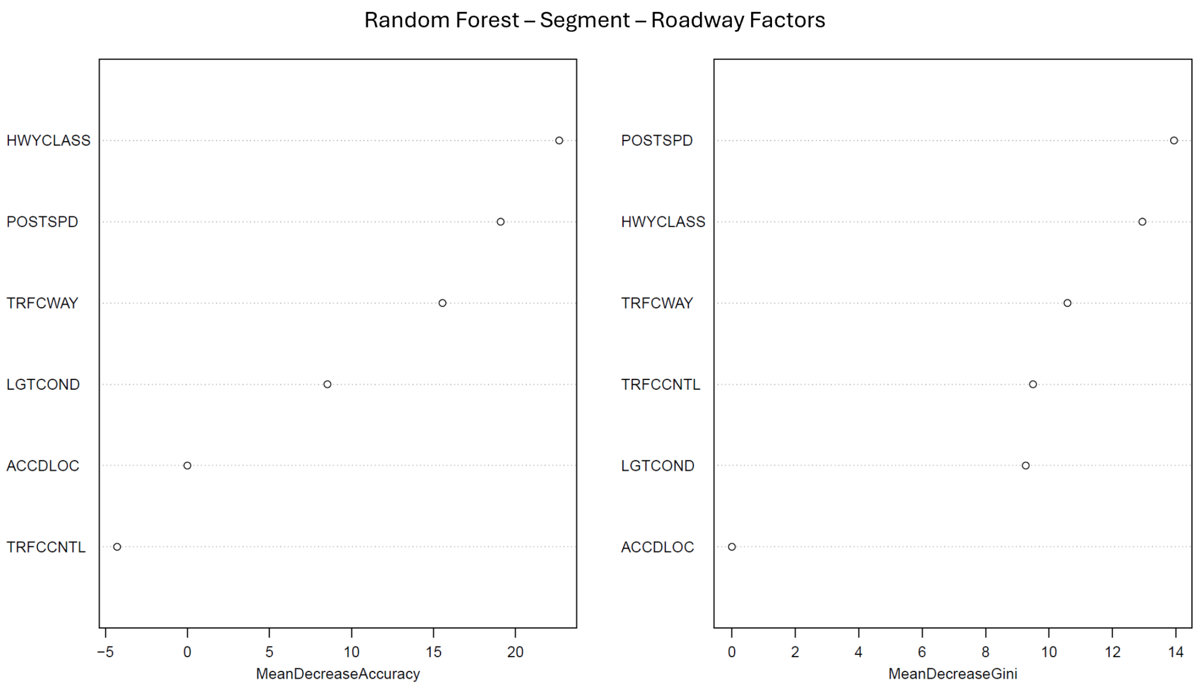

Figure 50. Roadway Factors Random Forest for WI SVSP Segment Crashes, 2008-2022

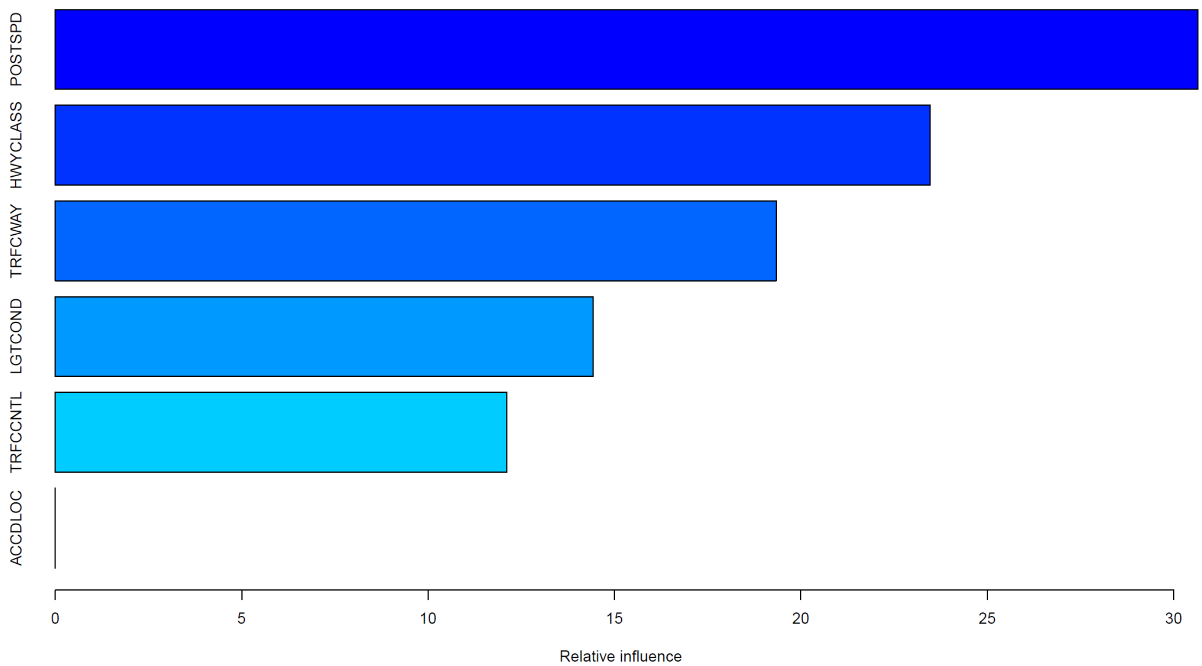

Figure 51. Roadway Factors Gradient Boosting Tree for WI SVSP Segment Crashes, 2008-2022

Surprisingly, there was little variation in the factors leading to tall vehicle crashes stayed very similar for both intersection and segment crashes. These patterns allowed us to identify what is contributing most to tall vehicle crashes. Having awareness of these various patterns helped guide the modeling of risk factors for SVSP crashes.

Table 9. Binary Logit Model with Roadway Factors for Vehicle Height Classification (WI SVSP 2008-2022)

Data Field	**Factor**	**Estimate**	**Probability**	**Standard Error**	**P Value**	**Statistical Significance**
	Intercept	-0.2951	43%	0.0292	0.0000	***
Posted Speed	<15 mph	0.2549	56%	0.0645	0.0001	***
Base: 20-25 mph	30-40 mph	0.1996	55%	0.0614	0.0012	**
	>45 mph	0.1681	54%	0.0603	0.0053	**
Trafficway	Divided	0.1318	53%	0.0592	0.0259	*
Base: Undivided	Parking Lot/Private Property	0.1369	53%	0.0561	0.0146	*

Notes: *** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05, **.** p-value < 0.1