Guidance to Support Vulnerable Road Users in the State of Alabama

by

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ABSTRACT

Over the past decade, communities across Alabama and the United States experienced significant increases in multi-modal traffic. While this growth has been shown to promote sustainable and livable communities, reduce traffic congestion, foster healthy environments, and boost local economies, there are still meaningful concerns about maintaining roadway safety for all users. Of particular interest are vulnerable road users (VRUs), defined by FHWA as "road users who are most at risk for serious injury or death when they are involved in a motor-vehicle related collision". This thesis provides guidance for improving Alabama state highways to support the safe travel of vulnerable road users. While the guidance presented herein is focused on Alabama and its specific needs, the recommendations were derived based on a synthesis of all the existing federal, state, and major city VRU documentation. This thesis provides information on: (a) Understanding VRU Considerations, (b) Trends in Alabama VRU Safety, (c) Models of Alabama Highway Factors Influencing VRU Safety, (d) Guidance on Selecting VRU Countermeasures, and (e) VRU Countermeasure Characteristics. This thesis provides guidance on pedestrians, bicyclists, motorcyclists and scooter users, younger drivers, older drivers, farm equipment, golf carts, and transport-service animals. Additionally, this thesis recognizes that guidance should vary based on the highway environment, so countermeasure suggestions are tailored based on urban/suburban/rural communities, roadway type, posted speeds, traffic volumes, and VRU volumes.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Over the past decade, communities across the United States experienced significant increases in multi-modal traffic. The U.S. Department of Transportation (USDOT) has identified a few trends through surveys like the National Household Travel Survey (NHTS) and the National Survey of Bicyclist and Pedestrian Attitudes and Behaviors; namely, that pedestrian trips are increasing, 40 percent of people self-report as cycling more often year over year, 14% of people self-report as walking more often year over year, and younger people are driving fewer miles and using more forms of public transportation (1). While this growth has been shown to promote sustainable and livable communities, reduce traffic congestion, foster healthy environments, and boost local economies (2-4), there are still meaningful concerns about maintaining roadway safety for all users. Of particular interest are vulnerable road users (VRUs), defined by FHWA as "road users who are most at risk for serious injury or death when they are involved in a motor-vehicle related collision" (5). Others define VRUs more broadly; for example, as "particularly susceptible to harm either due to (a) the lack of protection from external forces or (b) being incapable of performing tasks inherent to navigation" (6, 7). Pedestrians, bicyclists, and motorcyclists, and other similarly unprotected modes of travel fall under the first condition of VRUs. Younger drivers, with their comparative lack of experience operating an automobile on the road, and older drivers, with their decreased motor functionality that may impair driving ability, are classified as VRUs according to the second condition.

Based on these definitions it is not surprising that VRUs comprised 29.5% of traffic fatalities according to the 2014 US Census (8). In fact, out of a total 34,567 traffic fatalities in 2014, pedestrians accounted for 14.1% of traffic fatalities, bicyclists accounted for 13.3%, and motorcyclists accounted for 2.1% of US traffic fatalities. Over the past 15 years, the share of fatalities that pedestrians and bicyclists have suffered has increased, while the percentage of total fatalities experienced by motorcyclists has remained about the same (4). In terms of just injuries, in 2014 in the US, about 3.9% of total crash-related injuries were held by motorcyclists, 2.8% were pedestrians, and 2.1% were bicyclists. While crash injuries for pedestrians and bicyclists have decreased over the past 20 years, crash injuries for motorcyclists increased and have seemingly plateaued over that time period.

In response, a variety of federal agencies within the United States have designed programs aimed to provide guidance to support VRUs, such as FHWA's "Toward Zero Deaths: A National Strategy on Highway Safety" initiative and their two VRU safety programs Bikesafe and Pedsafe. FHWA's programs each include a countermeasure selection system to help guide engineers and planners towards the appropriate tools to improve road safety based on their situation, as well as offer other resources, case studies, and more (9-11). This guidance may target the VRUs themselves in the form of education or training, inform future transportation projects by requiring a new focus on designing for the safety of all users, or provide detailed recommendations, designs, and countermeasures to redefine the roadway. National Highway Traffic Safety Administration (NHTSA) provides safety tips for bicyclists, motorcycles, older drivers, teen drivers, pedestrians, drivers with disabilities, and more to ensure VRUs have the resources they need to travel safely (12). The Centers for Disease Control and Prevention (CDC) detail the risks that key VRU groups face on the road and outline the interventions that they

recommend to combat those risks (13). FHWA's Rural Highway Safety Innovation Program aimed to improve safety on rural roads by providing guidance and best practices (14).

Several independent professional engineering or planning organizations also have developed programs to promote the safety of VRUs. For some, this means guidebooks with countermeasures and recommendations to design ideal travel spaces for VRUs. The Active Transportation Alliance's (ATA) Complete Streets Complete Networks: A Manual for the Design of Active Transportation, the National Association of City Transportation Officials' (NACTO) Urban Bikeway Design Guide and Urban Street Design Guide, and the Institute of Transportation Engineers' (ITE) Designing Walkable Urban Thoroughfares: A Context Sensitive Approach are excellent examples of this type of resource (15-21). There are a multitude of organizations that aim to provide resources for a subset of VRUs. The AAA Foundation for Traffic Safety prioritizes research to identify and counter traffic safety problems among seniors, teen driving, and other VRUs (22). The League of American Bicyclists provides guidance and incentives for cities, colleges, and other organizations by ranking them on their bicycle friendliness, among other measures (23). America Walks, the Motorcycle Safety Foundation, the National Center for Rural Road Safety, and initiatives such as the Older Driver Safety Awareness Week all provide various resources that attempt to improve safety for pedestrians, motorcyclists, rural road users, and older drivers, respectively (25-27). Resources on less prominent VRUs such as service animals is much more limited, with groups such as the National Trails Training Partnership representing one of the few national programs with a dedicated focus on equestrians (28).

Many states and cities have recognized the need to improve their transportation system for VRUs and responded with programs and initiatives to focus on improving the safety of these

critical road users. These initiatives may include localized flavors of federal programs, policies set by the governing transportation authority, guidance and/or design books created by a DOT, MPO, or city, legislation from state or local governments, and more. Policies may take the form of the Complete Streets policies put forth by DOTs in California, Texas, and Washington, D.C. (29-31) The design guides – such as Massachusetts DOT's Separated Bicycle Lane Planning & Design Guide, the Complete Streets chapter of Georgia DOT's Design Policy Manual, or the Boston Transportation Department's Complete Streets Guidelines – varied in style, content, and recommendations based on the needs and conditions of the area (109, 113, 160). Oftentimes, policies are accompanied by a bill from a state legislature like Michigan's Enrolled House Bill No. 6151, which would, among other things, make VRUs a priority for the state (32). These are but a small sample of the programs that state and local governments have employed to elevate VRU safety. State initiatives are rarer than the multitude of city, county, or MPO programs. Considering national and independent programs as well, there are far too many to detail each here individually. The abundance of sources dedicated to improving road safety for these vulnerable groups is a good indicator of how important VRUs are to the country.

VRUs are especially important to Alabama, where pedestrians are recorded as the user at-fault in about 42% of all pedestrian-related crashes between 2006 and 2010. Pedestrian fatality rates in rural locations were double the rates of urban locations (2, 33). According to a random parameter logit model created by Islam, et. al., on urban streets in Alabama, pedestrians are more likely to be involved in a crash which results in major injuries on the weekend, in the winter or summer months, at intersections, and on dark, unlit roadways. On rural streets in Alabama, pedestrians are more likely to be involved in a crash which results in major injuries on dark, unlit county roads but less likely when they are walking against traffic. This difference in urban and

rural roads is critical, as 66% [544] of traffic fatalities in AL occurred on rural roads, while 33% [274] occurred on urban roads in 2014. In that same year, the average US national split for traffic fatalities was 51% [16,710 total] rural to 47% urban [15,487 total] (34).

This thesis provides guidance for improving Alabama state highways to support the safe travel of vulnerable road users. While the guidance presented herein is focused on Alabama and its specific needs, the recommendations were derived based on a synthesis of all the existing federal, state, and major city VRU documentation. This thesis details:

- **Understanding VRU Considerations**. This section of the thesis describes the current understanding of VRUs' behavior on different roadways as well as their specific safety requirements that need to be considered. The section also presents the current understanding of the general highway factors affecting VRU safety across the country.
- **Trends in Alabama VRU Safety**. This section outlines Alabama-specific trends in general VRU safety issues, including which groups, locations, or situations are more likely to be involved in VRU crashes. The graphs and statistics presented in this section were derived from the 2013-2015 CARE database.
- **Models of Alabama Highway Factors Influencing VRU Safety**. This section takes the generalized data from the previous section a step further and presents a series of ordered-probit models that identify the sets of highway, individual, and situational factors that are statistically most influential to VRU crashes in urban and rural areas.
- **Guidance on Selecting VRU Countermeasures**. This section compiles the VRU documentation from across the country to provide specific guidance on which highway countermeasures should be considered to improve VRU safety in different situations.

Countermeasure selection is based on community type, roadway type, posted speed, traffic volumes and VRU volumes.

- **VRU Countermeasure Characteristics**. This section details each of the countermeasures presented in the previous section, including the geometric design, potential issues and lessons learned from other areas.

This thesis provides guidance on improving safety for pedestrians, bicyclists, motorcyclists and scooter users, younger drivers, older drivers, farm equipment, golf carts, and transport-service animals. Additionally, this thesis recognizes that guidance should vary based on the highway environment, so countermeasure suggestions are tailored based on urban/suburban/rural communities, roadway type, posted speeds, traffic volumes, and VRU volumes.

II. UNDERSTANDING VRU CONSIDERATIONS

The body of literature regarding vulnerable road users has grown dramatically in recent years as researchers and transportation engineers at every level focus on improving road safety for all. To enhance design standards and develop transportation policies that lead to a safe and efficient travel network for the most vulnerable road user groups, it is vital to understand them. This section summarizes the current understanding of VRU safety. This discussion of safety is split into two sections: the first section introduces the current understanding of VRU travel behaviors and needs, while the second section presents the current understanding of the factors affecting VRU safety.

II.1 Current Understanding of VRU Travel Behaviors & Needs

When designing a transportation system or repairing and updating a section of the road network, it is important to consider the needs of all the groups that will use or be affected by changes. This is especially true of designing for VRUs, as any change to roadway infrastructure are likely to have the greatest impact on them. Many VRU groups share certain travel behaviors and have similar transportation needs, while others are specific to the type of VRU. As such, this analysis is framed by each VRU group identified in Alabama: pedestrians, bicyclists, motorcyclists, younger drivers, older drivers, farm equipment, and transport-service animals. The following section presents a discussion of the current understanding of vulnerable road user travel behavior

and needs based on a review of the relevant literature. This discussion provides the background to frame a review of how these behaviors vary in Alabama.

Pedestrians

As a group, the needs of pedestrians in traffic stem from a few similar sources: they tend to travel on direct routes, ignore directionality in traffic, cross roadways at their own convenience, and have the least physical protection of any VRU group. Pedestrians are a very diverse user group, encompassing a wide range of users with various capabilities and degrees of maneuverability (35). In the United States, all roadways designed for pedestrian use must comply with standards set by the Americans with Disabilities Act of 1990 (36). Designs which meet ADA standards clear the basic requirements for pedestrian safety, though several research groups consider the elderly to be the most vulnerable population among pedestrians (36-39). Thus, infrastructure and policy solutions should be geared towards the vulnerabilities of these groups to achieve the most success.

Pedestrians travel for a variety of purposes, including to shop or commute, for exercise or pleasure, and with or without a specific destination. This complicates the process of planning routes for pedestrian travel, as it is just one factor which causes pedestrian travel behavior to be so variable. Commuting pedestrians, those whose main intent is to get from point A to point B, often choose to traverse the shortest route (4). As such, they are most likely to travel along more dangerous routes, where most safety enhancements should be focused. According to a joint research study among countries in the Organization for Economic Co-operation and Development (OECD), commuting pedestrians have several increased risk factors. They may skip pedestrian crossings or other infrastructure designed to aid them if a more direct route is

available, even if it is less safe. Pedestrians may disobey traffic signals and signs if they determine that the wait is too long. Additionally, pedestrians traveling along familiar routes have been observed to pay less attention to their environment and traffic conditions. In general, pedestrians as a group tend to follow only those rules of the road which they deem to be reasonable and justifiable (4). Thus, it is important to understand where pedestrian traffic is concentrated in a community and where walking trips are generated and concluded. Delays and problem areas will cause pedestrians to seek alternate routes. It is up to the transportation planner to provide safe and efficient alternatives so that these VRUs always choose a safe path.

In addition to following the most direct path, pedestrians also ignore directionality in traffic (40). According to the Safe Routes to Schools program, when no sidewalk or other pedestrian facility is present, people should walk on the left-hand side of the road, facing oncoming traffic, in order to make eye-contact with the drivers (41). As such, a lack of directionality among pedestrian traffic is a safety concern primarily from a visibility standpoint and may be more significant in rural areas (42). The general consensus among researchers provides three reasons for this. First, in rural regions sidewalks are less common, often leaving people with no other option but to travel alongside the roadway. Furthermore, drivers are more likely to travel at faster speeds on rural roads and emergency medical services are more likely to have to travel farther distances (38, 42, 43). Pedestrians traveling in the same direction as traffic are more vulnerable to crashes with motor vehicles because each party is less likely to identify the other in time. This is especially true of younger drivers, who are less experienced at identifying and reacting to unexpected pedestrian movements (41, 44, 46). Pedestrians are at high risk of distraction, especially today with a variety of electronic devices such as mobile phones available. These distractions decrease pedestrians' awareness, making it less likely for

them to notice a vehicle, particularly one traveling in the same direction as the pedestrian (40, 47-49).

One of the most troubling travel behaviors that pedestrians are known to portray is a tendency to cross roadways where convenient, regardless of the presence of safety features like a crosswalk, as this greatly increases their risk of being involved in a crash (4). As previously discussed, pedestrians tend to only follow the rules of the road when they seem necessary and convenient to them. As such, pedestrians often cross roadways where no crosswalk is designated. A majority of pedestrian crashes involving injuries are a result of this jaywalking behavior (4, 39, 43, 44, 50). Many localities have attempted to tackle this issue, which is a major concern in many Complete Streets designs. In general, most agencies agree that in high-pedestrian volume areas, crosswalks should be placed at all intersections and mid-block crossings should be placed between blocks to ensure that a crossing exists every 400-600 ft. (51). Many pedestrians will follow the shortest path, so it is up to transportation planners to ensure that safe crosswalks are placed to discourage pedestrian travel into the roadway.

Finally, the main reason that pedestrians are a VRU group is that they have the least physical protection of any road user. Even at low speeds, a motor vehicle crash with a pedestrian is likely to result in severe injuries for the pedestrian. This is because unlike the passengers in a motor vehicle, a pedestrian has nothing to protect them from harm during the impact of a crash (4, 5, 51). This vulnerability is clear when examining pedestrian crash rates. According to traffic studies conducted by the U.S. DOT, there were 4,743 pedestrian fatalities in 2012. This was the highest they have been in five years. Pedestrian fatalities represented 14.1% of all traffic fatalities. In Alabama, there were 77 pedestrian fatalities in 2012, representing 8.9% of total

traffic fatalities. Additionally, 76,000 pedestrians were injured in traffic-related incidents across the U.S. in 2012 (1).

Bicyclists

In terms of their needs and travel behaviors, bicyclists have a lot in common with pedestrians, but a few behaviors set them apart. As with pedestrians, they tend to travel on direct routes and ignore directionality of traffic. As a group, cyclists can also fail to observe traffic laws, must contend directly with increased motor vehicle speeds, and often encounter conflicts during passing maneuvers. They are often paired with pedestrians due to their similar needs, but the great variations in their behavior are cause for their own concern (4).

As with pedestrians, cyclists travel for a variety of reasons, which creates difficulties for planners who are attempting to create safe routes for them to travel on. Again, like pedestrians, bicyclists who travel for commuting purposes tend to travel in the most direct route possible (4). This is problematic in many places across the country and the state of Alabama, where cycling infrastructure is often disjointed (52). Bicyclists may ignore a safer route with dedicated infrastructure if they determine it to be less quick than traveling on a route without a bike lane. Thus, as a planner it is vital to create connected cycling routes which balance safety and efficiency of travel to guide cyclists along a less dangerous course.

Cyclists also tend to ignore the directionality of traffic. In areas with defined directional bike lanes, this is typically less of a problem. However, on roads without a bike lane, many cyclists will ride in the opposite lane. This is possibly due to the cyclist employing the same reasoning as a pedestrian might, as they follow many of the same roadway guidelines. However,

in all 50 states, bicyclists are required by law to travel on the same side of the road (23). This is because cyclists are more likely to be seen by motorists when traveling on the same side of the road. Visibility is a major concern in cycling crashes, particularly in cases where the driver of the motor vehicle is at fault. Thus, cyclists traveling against the flow of traffic have been found to be particularly vulnerable to collisions, especially at intersections (53).

More so than other groups, bicyclists tend to disobey traffic rules (54). This is likely a result of traffic laws and regulations being developed primarily from a motor vehicle perspective and cyclists being unsure of where they fit into the system (6). In addition, cyclists often lack knowledge of appropriate traffic rules and regulations (55). A particular concern with bicyclists is over how they should handle traveling through intersections. Without dedicated signage or special lanes to instruct the cyclist on how to handle the intersection, many cyclists make mistakes such as turning right without stopping (50). It is vital to create educational programs to teach bicyclists the rules of the road and to design the roadway environment so that it is clear to them how to approach each situation.

Cyclists also have trouble with the speed differential between themselves and motor vehicle traffic on the road. Not only does it limit their mobility on the road, but their slower speeds make sharing the road with larger, heavier, faster motor vehicles intimidating for some bicyclists (4). This is especially true in rural areas where bicyclists typically do not have dedicated infrastructure and must either ride alongside traffic in the normal travel lane or on the extended shoulder, if one is available (39, 42, 43). Cyclists have more trouble with the speed of motor traffic than other road user groups, as bikes often travel alongside the road but cannot maneuver as quickly as motor vehicle traffic. As the speed on the road increases, so too does the severity of a typical cycling crash (5, 11, 42, 43, 56, 57, 58).

Cyclists have trouble with passing maneuvers on the road. Their limited size and speed mean that simple maneuvers like changing lanes or using a driveway to enter or exit the road come with a higher crash risk than for other road users as they must conflict with motor vehicles. While crashes between a motor vehicle and a bicycle result in the most severe injuries in bike crashes, cyclist crashes with pedestrians are also of great concern and can also result in extremely severe injuries for the bicyclist (though typically not for the pedestrian) (59). As previously stated, cyclists are at risk of crash with motor vehicles due to visibility concerns. Many drivers are still not used to the presence of cyclists on the roadway and thus may not be looking out for them. Because cyclists also typically travel alongside the rest of traffic, sharing the same space on the road as motor vehicles or traveling directly alongside it in a bike lane, they are at much greater risk of being hit by a motor vehicle than some other VRU groups. A motor vehicle attempting to make a passing maneuver or entering or leaving the roadway may fail to see the traveling cyclist and sideswipe them (54, 60).

Motorcyclists & Scooter Users

Motorcyclists are a unique VRU group due to their ability to travel at the same pace and in the same space as motor vehicles, but without any of the protection that motor vehicles afford their occupants. The needs of motorcyclists include that they tend to test the limits of their vehicles on rural roads, they are more likely to be involved in single-vehicle crashes, they may come into conflict when performing passing maneuvers, and they exhibit a reduced ability to make sharp turns and quick reactions.

Many motorcyclists, especially those of younger age, experience a similar call that compels them to test the limits of their machine on the open road. On local roads, typically in

rural locations, many motorcyclists tend to travel at higher speeds. This sort of aggressive driving behavior is most common among the young, and tends to result in increased crash severity and chance of fatality (56, 61, 62). Traveling at higher speeds like this has been positively correlated with increased crash severity for all VRUs (5, 41, 42, 43, 56, 57, 58).

A research group in Malaysia analyzed years of crash data and roadway geometries to model a safety performance function for motorcycle accident fatalities on Malaysian primary roads. Out of the successful models, two major predictive variables emerged: average daily traffic (ADT) and access per kilometer. As ADT increased, risk of fatal motorcycle crash increased as well. Other motor traffic volume was determined to be the single most significant factor in the number of motorcycle accidents that will occur. The second most important factor was as the number of access driveways on a roadway increased, the chance of motorcycle crash also increased (63).

Motorcyclists are also more likely than other VRUs to be involved in single-vehicle crashes. This is because they can travel at higher speeds than other VRU groups. This is also linked with aggressive driving behaviors (56, 61, 62). Motorcyclists are more likely to crash on their own. Thus, roadways should be designed to reduce the chance of striking a fixed object or running off the road and to discourage high speeds and aggressive driving.

Similar to bicyclists but to a lesser extent, motorcyclists are at risk of conflict during passing maneuvers, as they are often small enough to travel alongside motor vehicles in the same lane. Aggressive behaviors, often by younger users, can cause the motorcycle to be sideswiped. Additionally, motorcycles are at risk for these types of collisions due to their smaller size in respect to motor vehicles, who may fail to spot them on the roadway. Motorcyclists are at

increased risk of severe injury on high-access roads and during traffic merging maneuvers (64, 65, 66).

Motorcyclists as a group are also less able than other VRU groups to perform quick, tight cornering maneuvers. As a result, they may be unable to handle more severe turns (61). Presently, however, studies have been unable to confirm a roadway design methodology for motorcyclists that goes above and beyond the safety provided by standard roadway design methodologies presented by the AASHTO Green Book for example.

Younger Drivers

Younger and older drivers share many of the same limitations and behaviors on the road, though for different reasons. Younger drivers experience reduced perception of speeds, distances, and gaps; tentativeness or aggression that causes conflict with other traffic; and have many concerns regarding distracted driving. Studies disagree on whether their reaction time while driving is higher than average. However, they agree that regardless, the action they take in response is likely incorrect.

Younger drivers are less experienced than other motor vehicle drivers and road users, and this inexperience puts them more at risk of crash in every scenario. Despite the challenges they face, though, a study by Ralph et. al., found that as a group, young people ages 16 to 36 take the clear majority of their trips (74 - 90%) in a car (67). This is not surprising, as Americans in general take most trips by car. It is important, though, as it points out that with so many inexperienced young drivers constantly tackling the challenge of driving, it is vital to design the roadway environment to be safe for them. Due to a lack of experience with road hazards, hazard

studies with eye-tracking have shown that young drivers do not look in the right places to anticipate road hazards and are less likely to anticipate hazardous events than other drivers (68, 69). Researchers have identified that hazard identification is a skill that most younger drivers lack, simply because of their limited driving experience. Additionally, once the hazard is identified, younger drivers lack the experience to know how to properly evade it (50, 70). According to a study in New Zealand, inexperience was among the deadliest behavioral factors in crashes involving younger drivers (42). In cases like this, researchers differentiate experience from age by attempting to identify the number of years an individual has spent driving, or the number years they have had a driver's license. A study attempting to analyze young driver hazard reactions loosely defined inexperience as having two years or less of driving experience (70). This increased reaction time results in younger drivers being less likely than other drivers to correctly identify pedestrians, which could lead to crashes (45).

This inexperience bleeds over into the younger drivers' ability to perceive speed, distance, and gaps. Younger drivers are more likely than other users to crash because of this, especially when performing a maneuver such as entering a main roadway and incorrectly perceiving that there is a large enough gap in traffic for them to enter, resulting in a sideswipe or rear-end collision (41).

In a similar vein, younger drivers often act tentatively or aggressively in traffic, resulting in conflicts that cause a crash. Tentative behavior shows itself in the inexperience of young drivers when they are unsure what action to take. Aggressive behaviors show themselves in the tendency of young drivers to drive at increased speeds or operate their vehicle without carefully watching for other road users. These behaviors, such as disobeying traffic laws or regulations and failing to notice or properly react to road hazards are among young their most severe crash

factors (41). Some studies have found that young drivers are overly represented in speeding and failing to comply with other roadway rules, such as stopping at red lights (71). A study by researchers in Cyprus examined the role of personality in risky driving behaviors and found that in general, personality effects are not accurately predictive of negative driving outcomes. However, the team identified a few high-risk traits which were strongly correlated with aberrant driving behavior. These high-risk traits included sensation seeking, impulsivity, and sensitivity to punishment/reward. Additionally, these traits appeared to peak in young male adults (53).

Finally, there is great concern regarding young drivers and distracted driving. Many studies have been linked to increased crash risk and operating an electronic device such as a cell phone, especially among younger users, who are the most likely to own and operate such devices (47-49). This behavior is becoming a widespread problem. For example, a recent study by the University of Iowa found that in moderate to severe rear-end crashes involving teenage drivers where the driver was at fault for the incident, more than 75% of drivers were engaging in distracted behavior while driving. In over half of rear-end crashes, the teen driver did not even brake or attempt to maneuver out of the way because they were engaged with an electronic device. The most frequent distractions were cell phone use, observing something outside the vehicle, and interacting with passengers (73). Not only are younger drivers at risk on the road due to our increasingly connected technological world, but also because they are more likely to be distracted from the road by the presence of their peers in the vehicle. One study found that this is especially true when both males and females are present in the vehicle (42).

Older Drivers

Older drivers share many experiences with younger drivers on the road in terms of their needs and their behaviors. This includes decreased reaction time, reduced perception of speeds, distances, and gaps, and a tentativeness which causes conflict with other traffic. However, while younger drivers experience these safety concerns largely because of a lack of inexperience, for older drivers, these concerns spring primarily from decreased mental and physical faculties (3). The elderly are considered by many to be the most vulnerable road users (38, 73). They are more likely to be severely injured or killed in a traffic collision than any other age group (7, 37, 74) Older drivers are more likely to have rear-end, right-angle, or sideswipe collisions with other vehicles. Their crash risk increases in dark conditions, especially with inadequate street lighting (75).

Older drivers have decreased reaction time compared to many other VRUs. However, unlike younger drivers, this is due to impairments in various driving-related functions, including vision, cognition, and motor functions (3, 37, 73, 75, 76, 77, 78). However, there is some disagreement over how significant these needs are in older drivers when crash severity is concerned, as some studies have found that while elderly drivers take more time to perceive and react to hazards, many seem aware of their age-related limitations and drive more slowly to compensate. Thus, while their perception-reaction times are slower, they experience no impairment in perceiving and reacting to such hazards (36, 49, 70). Despite their ability to recognize hazards, though, older drivers are also overrepresented in crashes with other VRUs, especially pedestrians and motorcycles, suggesting that they have more difficulty identifying VRUs on the road (158, 159).

Like younger drivers, older drivers experience a reduced perception of speeds, distances, and gaps. Older drivers also exhibit tentative behaviors in traffic. These behaviors cause the same problems for them that they do for younger drivers, but again, they are caused by reduced mental capacities and functions rather than inexperience (36, 49, 73, 77, 78). Older drivers exhibit a wide range of driving ability. While as a group, they are more likely to have difficulty driving than other users, but some older drivers are confident in their capabilities. Older drivers with lower confidence tend to take shorter trips, travel closer to home, and avoid driving at night. These drivers change their driving patterns later in life as their visuo-motor functions deteriorate (75, 79). This process is referred to as self-regulation. Many elderly drivers self-regulate their driving behaviors – limiting when, where, and how they drive – to compensate for some physical, cognitive, or functional impairment that restricts their driving capabilities or causes them higher accident risk (80). By self-regulating their driving behavior, seniors can retain their independent mobility. This is a critical concern for the aging and retired population, who often have limited transportation options despite that their travel needs do not diminish alongside their physical, mental, and cognitive abilities (81).

Farm Equipment

Literature on safety concerns that users of agricultural equipment face when traveling on roadways is sparse. Federal and state vehicle codes provide regulations and guidance regarding lighting, markings, emblems, and slow moving vehicles. The volume of research on this topic, however, is small. Perhaps this is because agricultural vehicles account for a mere 0.2% of total vehicles involved in traffic crashes. Studies released by the National Highway Traffic Safety Administration have confirmed that collisions involving agricultural equipment follow this trend.

The Committee on Agricultural Safety and Health Research and Extension, part of the U.S. Department of Agriculture, released a report in 2009 that confirmed these facts and compiled a cohesive document regarding the major problems that agricultural equipment encounters on the road. The committee acknowledged that agricultural related collisions, injuries, and fatalities account for less than 1% of total crashes, and this may make them seem relatively insignificant. In their report, *Agricultural Equipment on Public Roads*, the committee argues that these crashes have a disproportionately larger impact on the agricultural industry and those employed by it. The committee identified the key issues agricultural equipment face on the street and what is currently known about those issues (14).

The committee identified several problems in federal and state regulations regarding agricultural equipment on public roads. First, the national guidance provided by the Uniform Vehicle Code is inadequate regarding operating farm equipment on roads, lighting needs for farm equipment, and markings on farm equipment. As such, state regulations establish their own standards. There is no consistency among vehicle code regulations for lighting and markings of agricultural equipment. Oftentimes, these state regulations have failed to keep pace with advances made in lighting and markings. Additionally, regulations are difficult to establish, as advances in technology have resulted in a wide array of farming equipment with varied capabilities and increased speeds. While many older tractors top out at speeds of 25 mph, newer tractors are capable of speeds of up to 45 mph. The committee stressed that lack of consistent regulations are a major concern for these vulnerable users. In fact, another major problem for the safety of agricultural vehicle users is the lack of consistency across states regarding regulations for younger operators. Clear, consistent regulations for speed, lighting, markings, licensing, and operation of farm equipment on roadways is vital for the safety of these special VRUs (14).

The committee also identified several key mechanical-related safety concerns of agricultural equipment for road use. For one, many tractors and similar equipment that people currently use on roads do not meet the road vehicle legislation requirements. Designing roads to meet the safety concerns of such a wide array of equipment is very challenging (14). Tractors' low speeds, limited steering capability, and large braking concerns are the main physical challenges that these vehicles face when traveling on roads. These problems are compounded by the fact that many older tractor models – which to the eyes of the layman, often look very like newer models – see these issues even more pronounced. Other safety related issues included suspension, tires, alignment, hitching components, tractor rollover protection. Lack of regulatory among slow-moving vehicle emblems and speed indicator symbols are also safety concerns (14).

Golf Carts

As with farm equipment, golf carts fall into a small, unique VRU group. 'Golf cart' is actually the colloquial name given to this class of vehicles. Researchers and other officials give this class of vehicles more inclusive labels. Neighborhood electric vehicles (NEVs), low speed vehicles (LSVs), personal transport vehicles (PTVs), and golf carts are all terms which generally refer to small, light electric vehicles that operate at low speeds and produce little to no emissions. Not intended for freeway travel, they carry a limited number of passengers and are used to make short trips within communities (82, 83, 84). The National Highway Traffic Safety Administration (NHTSA) defined LSVs in 49 CFR 571.3. The definition states that "a Low-Speed Vehicle (LSV) is a four-wheeled motor vehicle whose attainable speed in 1 mile is more than 20 miles per hour and not more than 25 miles per hour on a paved level surface and has a gross vehicle weight rating (GVWR) of less than 3000 lbs." (85). As a rule, state DOTs either use NHTSA's

definition of LSVs or use a small variation on it. Florida, for instance, drops the weight requirement from the definition, while California adds further requirements such as special licensing, registration, and insurance for the vehicle. In addition, most states agree that LSVs are not to be operated on any roadway with a speed limit above 35 mph (86, 87).

Similar to farm equipment, accidents involving LSVs make up a relatively tiny portion of total collisions. However, LSVs have steadily gained popularity in recent years as pockets of small communities around the country have begun adopting their use as a fossil-fuel free alternative for making short trips (82, 83, 88, 89, 90). Despite operating within a vehicle, LSV users are also VRUs due to the incredibly limited protection provided by the vehicle and their comparably limited maneuverability. The Consumer Products Safety Commission (CPSC) estimates that golf cart related injuries requiring emergency room treatment in the US increased from approximately 10,000 per year in 2000 to over 17,000 per year in 2007. Of these, about 70% occurred at sports facilities, leaving only a portion of the remaining crashes occurring on public streets. (90, 91, 92, 93). Additionally, about 10% of these crashes involve car rollover. These incidents often result in the most significant injuries. One of the primary causes of rollover crashes is ineffective brakes in LSVs, especially those with brakes only on one axle (91, 92). Even at low speeds, sharp turns in an LSV can result in passenger ejection (90, 92). LSVs can provide mobility to the elderly and disabled in a community, giving them a new freedom to travel. Thus, these vehicles have gained popularity in elderly and retirement communities (82). These users are especially vulnerable. Other safety challenges include left-turn movements, as these require the LSV to interact with the rest of traffic (14). LSVs have difficulty navigating hilly terrain due to limited power and weight (83). Finally, LSVs are typically unable to utilize

multi-use paths, as they are usually not designed to accommodate vehicles of that size, and face great difficulty navigating busy urban centers (88).

Transport-Service Animals

Transport service animals such as horses are another rare VRU group. Their usage is typically limited to rural areas or historical districts in large metropolitan areas. As they have been largely phased out by the automobile, horse use on public roads is uncommon in the U.S. Thus, regulations and literature pertaining to equestrian travel on roadways and their safety concerns is quite limited. Design material for horse-related travel is typically limited to separate horse trails or multi-use paths (94). The Irish Road Safety Authority provides one of the only sources of regulation for equine road travel. Horses and similar transport service animals are uniquely vulnerable vehicles because they have a mind of their own. They may choose not to listen, misunderstand direction, and take sudden actions where the rider loses control over the animal. On roadways, horses are especially vulnerable to being spooked by loud noises from other vehicles or blinded by headlights (95).

II.2 Current Understanding of Factors Affecting VRU Safety

Understanding the needs and unique travel behaviors of each vulnerable user group is only one part of the equation. In order to design, plan, and build a safer roadway environment for VRUs, it is equally vital to understand what factors affect their safety. These factors can be broken into three categories: roadway, behavioral, and temporal factors. Oftentimes these factors vary from one VRU group to another, or vary by location between rural and urban settings. There is also

disagreement over what factors influence the crash safety of VRUs and to what extent that influence reaches. This is natural, as these types of crash factors are expected to vary by location. In the Highway Safety Manual (HSM), for instance, crash factors are modified by location based on local calibration factors (4). In a similar manner to how the HSM works, the body of literature on VRU crash safety can be used to determine the general trends for these crash factors to guide the development of a model which specifies how those factors affect VRU crashes in the state of Alabama. The following section discusses the current understanding of those trends in crash factor safety.

Factors Unique to Rural Areas

One of the biggest challenges to serving and protecting VRUs results from the distinct safety factors that make travelling on a rural highway a dramatically different experience from navigating a sprawling urban thoroughfare. In urban areas, space and right-of-way (ROW) are often some of the most significant constraints limiting the design of the roadway and where each user should travel on it. While many VRUs in the city would benefit from their own dedicated space such as extra-large pedestrian pathways, buffered cycle tracks, and low speeds, other considerations such as travel time, vehicle volume, and most plainly, cost, often limit what sort of countermeasures may be employed. VRUs in small towns and rural country roads face the opposite issue of space, as the lengthy distances that users must cross in rural areas and relatively small portion of VRUs mean that the costs to implement safe, dedicated countermeasures in these areas are prohibitive (96, 97). However, income disparities, high crash rates, and more severe crashes suggest that focusing on improving rural VRU safety should be a priority,

especially in Alabama where such a large portion of the roadway network is in rural environments (33).

In rural areas, crossings at intersections are often not as clearly defined as their urban counterparts and present a high risk to pedestrians, especially when many local towns often have a wide highway that serves as the main street (97). Rural road crossings can be especially dangerous to cross for pedestrians and bicyclists. In cases where there is a high collision rate with crossing VRUs or a high demand to cross in an area isolated from traditional pedestrian signal timers (such as where a popular multi-use or pedestrian off-road path cross a road), a Pedestrian Hybrid Beacon (PHB), sometimes referred to as a High Intensity Activated Crosswalk (HAWK) beacon, may be appropriate to properly improve pedestrian visibility and motor vehicle compliance with mid-block crossings (96). For pedestrians and bicyclists, some of the most common crashes in rural areas occur when these VRUs fail to yield (98). As crossing is the most dangerous act for pedestrians on rural roads, engineers would do well to design intersections so that they do not offset or skew; properly aligned intersections that meet at 90-degree approach angles can minimize these risks. Run-off-road crashes are also more common on rural roadways, so maintaining unrestricted sight distance at intersections and around curves, minimizing roadside obstacles, and using wide paved shoulders can help improve VRU safety on rural roads. Wider shoulders can also substitute for pedestrian or bicycle pathways. If rumble strips are utilized (an effective countermeasure against run-off-road crashes), though, care should be taken to be sure they do not interfere with bicycle routes. Gaps in the rumble strip pattern will allow bicyclists to safety navigate on and off the roadway shoulder (97).

Speeding, driving the wrong way on a highway, and failure to comply with traffic signs and signals are among the highest causes of crashes on rural roads. This is especially true among

elderly drivers (77). Alcohol use and failure to wear a seatbelt are also often cited by researchers as high risk factors for rural roads. Crashes on rural roads often occur at higher speeds, further increasing their severity (99).

Roadway Factors

One of the most common, regular, and important roadway related factors regarding VRU crashes is speed. Many institutions, using a variety of modeling techniques on several crash databases, have all found a positive link between roadway speed limit (or motor vehicle speed at the time of impact) and crash severity. For VRUs in general, crash severity decreases at lower speeds and increases at higher speeds (5, 41, 42, 43, 56, 57). This is of course to be expected, as speed was also linked to the needs and behaviors of each VRU group in some way. However, there may be other factors related to speed limit which are determinant to the level of severity of the crash. A Montreal study of pedestrian and cyclist crashes, for example, found no significant link between speed limit and resulting injury severity (58). The authors proposed that roadway geometry may have more influence on the crash severity.

A second common theme of VRU crash investigation is regarding street patterns. A case study of the City of Calgary used a multinomial logit model to determine which of four selected street patterns was the most likely to produce crashes with severe injuries: grid-iron, warped parallel, loops and lollipops, and mixed. The study found that relative to grid-iron roadway networks (considered standard in this case), the loops and lollipops design increased the likelihood of severe injury, while decreasing the probability of a fatal injury or PDO crash among bicyclists and pedestrians (101). Figure 1 below shows examples of these types of road network patterns taken from that report.

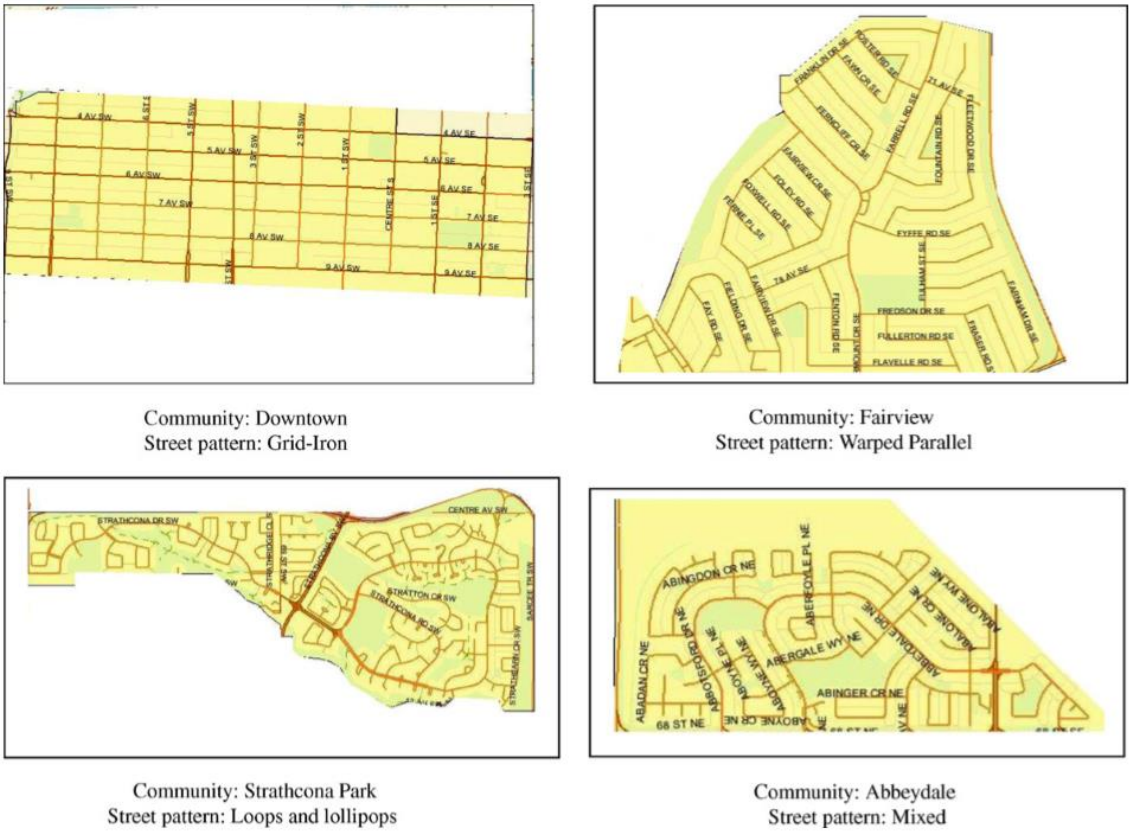

Figure 1: Neighborhood Roadway Networks (101)

A study in Montreal, meanwhile, determined that grid streets increase the risk of severe crash for pedestrians (38). A similar study from the Dutch Sustainable Road Safety Program evaluated five neighborhood street patterns and determined that the 3-way offset and fused grid patterns improved road safety for VRUs by as much as 60% over standard grid and cul-de-sac neighborhoods (101). There was little information available to speculate about why these street grids exhibit these behaviors in these cities. However, it does demonstrate that crash factors vary from one location to another. Thus, it is vital that the transportation engineer conduct a local analysis to determine how crash factors for VRUs vary at their location.

Few studies have investigated the links between aspects of the surrounding development and VRU crashes. One Canadian study, however, found that crash severity for bicyclists and pedestrians was decreased near schools, but increased slightly near parks (58). The researchers concluded that traffic calming measures near school zones were responsible for the decreased crash severity. Additionally, crash related factors varied between urban and rural zones. There is disagreement between researchers over whether VRUs are at higher risk in dense urban zones or wide rural areas. In general, VRUs see more crashes in urban areas than in rural ones (43, 102). However, some studies conclude that VRUs are at higher risk of more severe crashes in urban areas (37, 43) while others identify rural areas as the higher risk (42). This demonstrates that roadway factors may be highly variable depending on the area.

The presence (or lack) of lighting is another important roadway factor in many VRU crash models. There is general agreement among these groups that crashes which occur at night on dark roads, with or without street lamps, tend to be more severe than crashes occurring at other times, regardless of the VRU type (37, 38, 41, 58, 102).

Behavioral Factors

Behavioral factors for VRU crashes include distractions, improper maneuvers and behaviors, and alcohol or drug use. Behavioral factors were significant determinants for crash severity in a variety of VRU groups, especially younger drivers (41). Distractions, especially use of electronic devices, increase crash risk severity for younger drivers as well as for pedestrians and bicyclists – especially younger people (39, 46, 47, 48, 103). Talking on a cell phone, as opposed to texting on it or using it in some other dedicated manner was also found to distract users from the road. For young drivers, the presence of peers may also pose a dangerous distraction.

Improper maneuvers and behaviors were another category of factors which had a large influence on VRU safety. Reckless driving, fatigue, and the lack of a seat belt were among the deadliest factors in young driver crashes (41). Drivers who hit a VRU head-on while driving essentially straight were found by a few studies to result in more severe injuries than other vehicle maneuvers (37, 58). Choosing not to wear a helmet increased the risk of fatal injury among motorcyclists, who were also at high risk from severe injury due to merging traffic and high-access roadways (61, 65, 66). Pedestrians were of course, most likely to be injured while crossing the road, especially if this was done inappropriately (42, 43). The way in which VRUs react to specific maneuvers may require more study.

Finally, VRUs are impacted by alcohol and drug use to a large degree. Alcohol or drug use were involved in a large portion of VRU crashes in studies from Canada, California, and New Zealand (41, 61, 104). More so than many other factors, alcohol use was linked to severe VRU crashes. Increasing awareness and updating enforcement are important countermeasures to decreasing the prevalence of these types of crashes.

Temporal Factors

Temporal factors are often added to a model of VRU crash severity to act as a control. These factors typically had limited effect on determining crash severity and varied from one study to another. Studies have determined that VRUs are at more risk of severe crashes at nighttime (38, 41) during the morning commute (37, 41) or at non-peak hours (61), and at decreased risk during the afternoon and evening hours (41). These answers all generally agree in that crash severity seems to be generally higher during hours with less available sunlight. Some studies also included weather effects, with predictable answers: clear weather was associated with less severe

crashes and crashes were generally more severe in winter in one Canadian study (37). Temporal factors are excluded from many models, though. This is likely due to temporal effects being less transferable to other studies or because they do not generate very useful conclusions for transportation planning and design work.

III. TRENDS IN ALABAMA VRU SAFETY

An extensive statistical analysis was performed on crashes involving vulnerable users in the state of Alabama. Version 10.1 of the Critical Analysis Reporting Environment (CARE) facilitated the investigation of a database provided by ALDOT which consisted of information on crashes recorded over a 3-year study period from 2013-2015. 5 vulnerable user types were identified for analysis: Pedestrians, Bicyclists, Motorcyclists, Younger Drivers, and Older Drivers. A dataset was created for each vulnerable user type and the same statistical analysis was performed on each. The results are presented via histograms which are grouped by common topics into the figures in this section. The crash summaries for each vulnerable user group were analyzed separately. A discussion of the significant trends affecting VRUs as well as those specific to the type of VRU, along with some speculation into the cause of those trends accompanies this extensive figure listing.

This section is divided into five parts. The first part summarizes the Alabama VRU crash dataset. The second part presents an extensive statistical analysis of the VRU crashes. This analysis begins with a discussion of the general trends of VRU crashes in Alabama. In part three, the crashes were analyzed by the type of VRU involved and for each group and variations across VRU types are discussed. In part four, the effects of surrounding land use on which the crash occurred are investigated and the major differences between rural and urban VRU crashes in this state are discussed. Finally, part five discusses a few other primary concerns that were identified during the crash analysis.

III.1 Dataset Development

The crash datasets utilized in this project were developed from crash data over the time period of 2013-2015 provided by ALDOT. Version 10.1 of CARE was utilized to filter the raw crash data to develop a dataset for each of five vulnerable road users that were being considered. Ten different datasets were created for analysis, split by VRU type and urban/rural location (i.e., a Rural Pedestrian crashes dataset, an Urban Pedestrian crashes dataset, a Rural Bicycle crashes dataset, etc.). All crashes involving at least one pedestrian, pedal cycle, or motorcycle were included in the pedestrian, bicycle, or motorcycle datasets, respectively. For the purposes of this project, an elderly driver was defined as a driver of the age of 65 or older and a young driver was defined as a driver between (and including) the ages of 16 and 21. Drivers under the age of 16 were removed from the dataset, as they typically can only hold a learners' permit. Demographic information on persons who were not identified as the causal unit is mostly unavailable in the Alabama crash database. Therefore, the older and younger VRU driver datasets were created by filtering by whether the person at fault for the crash fit the definition of an elderly or younger driver. These datasets were developed by selecting factors which were relevant to evaluating VRU safety, including the crash identifier, surrounding land use, relevant facility type, timing of the crash, demographic information, cause of the crash, relevant events leading up to the crash, conditions at the crash site, and the severity of the crash.

The CARE database is developed from raw crash reports which are taken at the scene of the incident by a reporting police officer. This means that the quality of the data is subject to the officer's subjective interpretation and filing. It is up to the officer to make determinations such as the level of severity of the crash, what incidents caused and led up to the collision, and all of the other crash factors present in the report. To assign crash severity, Alabama uses the standard

KABCO scale. The KABCO crash severity scale assigns one of five severity levels to each crash. From least to most severe, the five severity levels are:

K – Fatal Injury

A – Incapacitating Injury

B – Non-Incapacitating Injury

C – Possible Injury

O – Property Damage Only (PDO)

FHWA provides definitions for each of these severity levels, which officers can use as an aid when attempting to assign a severity level to a real-world collision. Fatal injury crashes are one in which an injury received during the crash results in death within 30 days of the incident. Incapacitating injury crashes cover severe lacerations, broken limbs or extremities, and skull, chest, or abdominal injuries that are suspected to be more serious than bruises or minor lacerations. A non-incapacitating injury crash is one in which any evident injuries occur that would not be classified as incapacitating. Possible injury crashes are ones where an injury is suspected, but not apparent, such as momentary loss of consciousness, limping, nausea, or complaint of injuries which are not evident. A crash is classified as PDO when there is no reason to believe bodily harm occurred (5). However, even these definitions require some subjective decision-making by the officer. The database has other limitations as well, including that officers are only able to report detailed demographic information related to the responsible party and only very limited details such as transportation mode are provided for other parties involved. These limitations of CARE are important to consider, as the data is only as accurate and useful as the author who provided it.

For each factor, the number of possible responses available were reduced where it was logically possible to do so to aid investigation and simplify the results to be more manageable. For instance, the causal unit type was simplified into four categories: motor vehicle, bicycle, motorcycle, and pedestrian. All personal cars, trucks, and other motor road vehicles were included in the motor vehicle category, while the other categories were unchanged. Driver age was split into two categories: young and elderly, as previously defined, with all those in between filling the adult category. Driver age was only used in order to define the older and younger driver datasets. As previously mentioned, demographic information in the CARE database was limited to the driver at-fault for the crash, so the age variable was only used to define the older and younger driver crash datasets. Because of the limitations Speed limits were split into four categories: lower speeds between 0-30 mph, two moderate speed categories of 31-40 mph and 41-50 mph, and high speeds between 51-70 mph (there are no speed limits higher than 70 mph on public roads in the state of Alabama). Roadway facility type was defined by a combination of factors in the original dataset. It was defined such that any crash which occurred at an intersection was defined as an intersection crash, while the remaining crashes were split between those which occurred on main roads and those which occurred on roadways without controlled access. Factors with responses which were too insignificant were grouped into the "other" category and were assigned null values for analysis. Additionally, as there were numerous primary contributing causes, this factor was simplified into four categories: impaired driver, avoidance behavior, driver error, and aggressive driving. In total, the combined VRU crash database includes 117,988 crashes.

III.2 General VRU Trends in Alabama

The clear majority of VRU crashes in Alabama are from older or younger drivers, which make up more than 95% of the database, as seen in Figure 2. This shows that by volume of crashes, older and younger drivers are among the most vulnerable users on the roadway. Their chances of being involved in a collision are higher than for other VRU groups. Remember that due to limitations of the CARE database, the older and younger driver crash datasets consist exclusively of crashes in which they were at fault for the crash. The other VRU datasets do not share this limitation. The bicyclist dataset is especially small, containing only 565 crashes. The smaller crash database size of pedestrians and especially bicyclists makes determining trends to explain VRU behaviors for these groups much more difficult. However, it does not mean that they require any less attention than other VRU groups.

Figure 3 shows that of these total crashes, 21.5% occurred in rural areas and 78.5% occurred in urban areas. Urban areas generally have higher traffic volumes than rural areas, so it makes sense that a higher portion of crashes would occur there. Urban areas tend to see higher concentrations of pedestrian and bicyclist traffic especially. These factors make urban areas a focus for many VRU countermeasures. However, rural areas will require more innovative solutions to account for fewer crashes occurring over a much wider area.

Figure 4 reveals that more than half of crashes occurred on uncontrolled access roadways and of the remainder, slightly more occurred at intersections than at main roads. For the purposes of this study, a main road is classified as a controlled access roadway. That is, a roadway with generally higher speeds and more through traffic with limited driveways and other entrance/exit ramps. Roadways with many access points, driveways, and other entrances/exits are the most challenging road types for VRUs to face. Unrestricted access like this allows for many conflicts

to develop, which are even more dangerous for VRUs. These types of collector or local roads make up a major portion of Alabama roadways, so finding solutions to making travel on these types of roads safer for VRU groups is crucial. Intersections also remain a major conflict area for VRUs where safe countermeasures are difficult to develop.

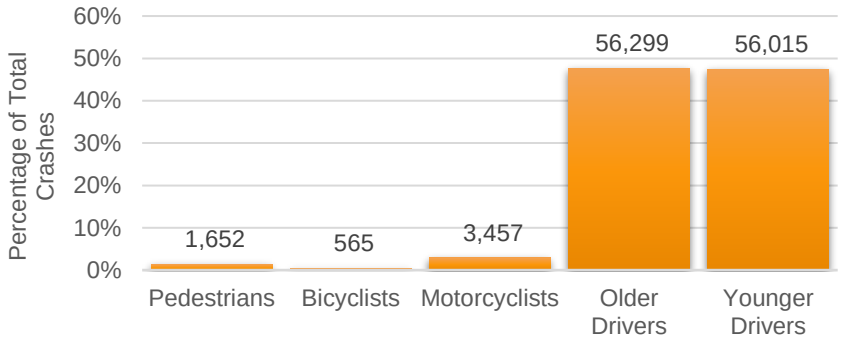

Figure 2: Crashes by VRU Type

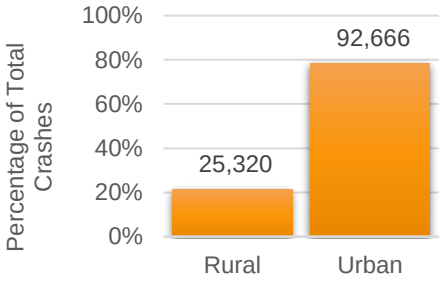

Figure 3: All VRU Crashes by Community Type

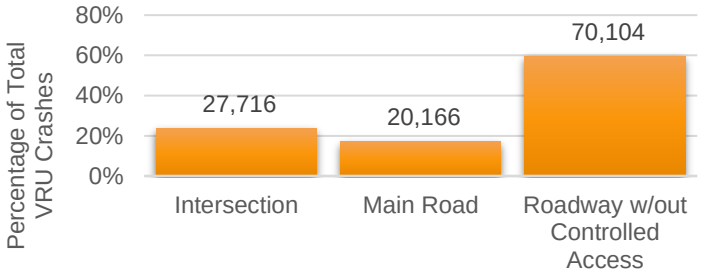

Figure 4: All VRU Crashes by Facility Type

Crashes occurred with more frequency during the spring and winter than during the summer and fall. A hard trend is difficult to determine from seasonal data alone, though, as Figure 5 indicates that the number of VRU crashes varied only slightly by season. Figure 6 shows that significantly more crashes occurred on weekdays than on weekends, however, when considering the 5-2 day split for that category, this crash split would be expected. These two points together seem to indicate that the severity of a VRU crash is independent of the day of the week or the time of year. As for time of day, Figure 7 shows how crash frequency throughout the day mostly follows a bell-shaped curve, with very few crashes occurring in the late evening and early morning hours, then gradually increasing throughout the rest of the day into the afternoon before peaking in the early evening hours. Crashes then decline into the evening at a faster rate. There are some interesting points within this curve, including a relative peak in crashes which occurs between 7-8 AM, during typical morning commute hours. Additionally, the peak crash time with VRUs overall occurs between 3-4 PM, as opposed to the typical peak traffic volume hour of 5-6 PM. This indicates that VRU crashes also generally follow the conventional vehicle crash timing, with peak crash times occurring during the morning and evening rush hours.

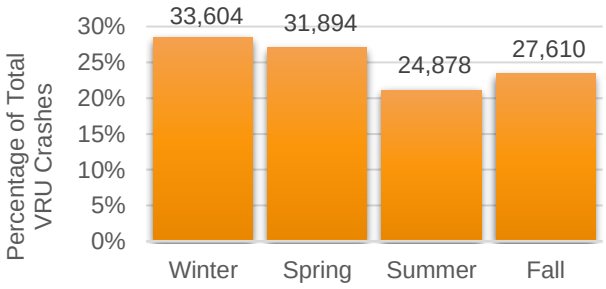

Figure 5: All VRU Crashes by Season

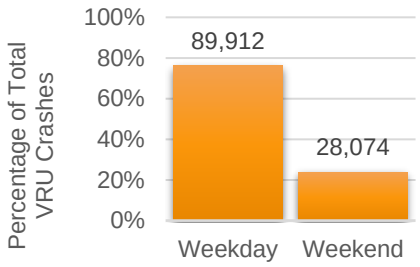

Figure 6: All VRU Crashes by Day of the Week

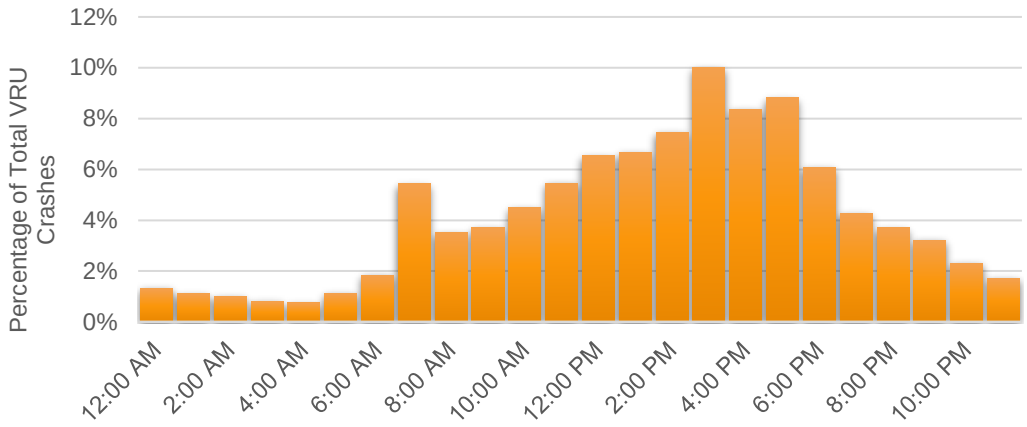

Figure 7: All VRU Crashes by Time of the Day

Looking at Figure 8, most crashes involving VRUs in Alabama occurred in shopping or business developments. A quarter of crashes occur in residential areas, followed closely by open country. The remaining crashes mostly occurred in manufacturing areas, while the crash rate was low in school zones or near playgrounds. VRU crashes in Alabama are generally focused in three different locations: the majority occur in busy urban cores around shopping and business centers. A significant portion also occur close to home in residential neighborhoods and many also occur in open country on rural roads.

In general, most crashes occurred in the daytime hours or near dawn, with adequate lighting, as Figure 9 reveals. Relatively few occurred at night, with most of those occurring on roadways with proper lighting. While many researchers have cited that darkness increases the chance of crash for VRUs, this result indicates that while lighting may have an impact on VRU crash susceptibility, it is not the most important factor, as sunshine has not seemed to prevent many crashes. Weather seems to have a negligible effect, based on the results in Figure 10. Most crashes occurred on clear days, with about half as many on cloudy or foggy/misty days and only a few while it was raining.

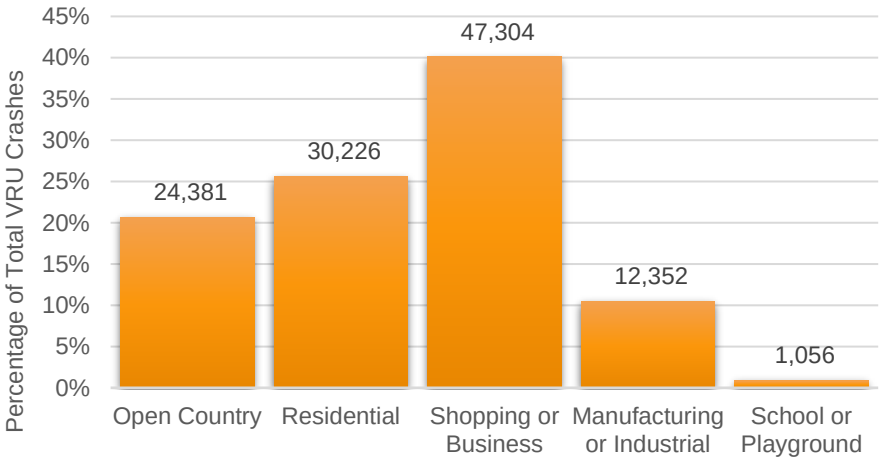

Figure 8: All VRU Crashes by Surrounding Development

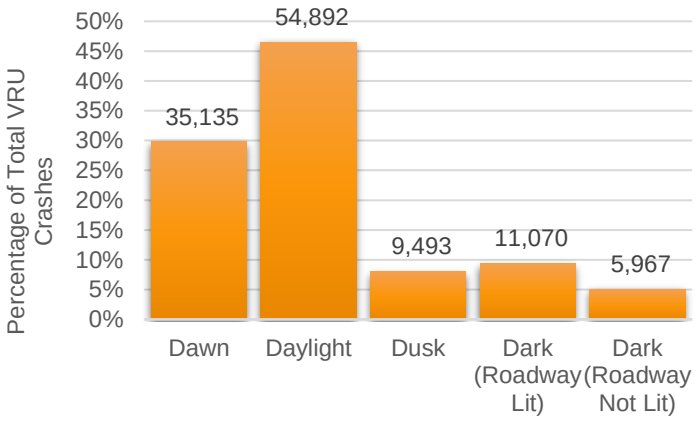

Figure 9: All VRU Crashes by Lighting Conditions

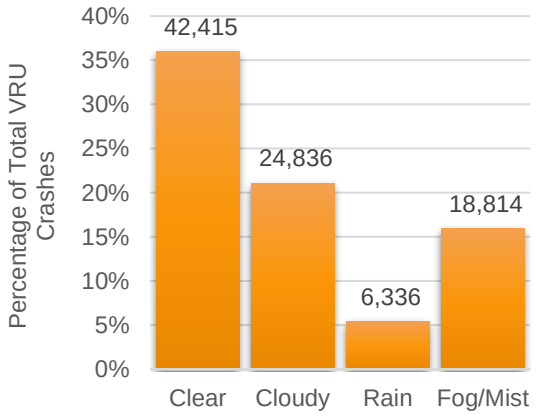

Figure 10: All VRU Crashes by Weather Conditions

Figure 11 shows the VRU crash breakdown by the primary cause. These four categories of primary causes represent categories of similar crash causes taken from the CARE database. The Impaired Driver category includes driving under the influence of drugs or alcohol (DUI), all forms of distracted driving (use of electronic device, passenger, outside distraction, etc.), and pedestrians under the influence. The Avoidance Behavior category includes swerving to avoid a hazard (animal, object, non-motorist, vehicle, etc.), obstructed vision or an unseen hazard, and defective equipment. The Driver Error category includes crashes made due to a variety of

common errors such as an improper turn, crossing the centerline or median of the roadway, an improper passing or lane change, improper backing, running off the road, misjudged stopping distance, driving under the minimum speed, improper parking or stopping, improper crossing, driving on the wrong side of the road, and a failure to yield the right-of-way in any of a number of situations that call for it. Finally, the Aggressive Driving category is comprised of behaviors such as an aggressive operation, running a stop sign or traffic signal, speeding, or following too closely.

Figure 11 show that most VRU crashes were caused by some sort of driver impairment, followed closely by driver error, with the remaining crashes split between avoidance behavior and aggressive driving. Driver impairment was defined as being under the influence of alcohol or drugs, or being distracted – by use of some electronic device or other reason. As advancing technology has allowed people more opportunities for multi-tasking or otherwise entertaining or distracting themselves, it is no wonder that most VRU crashes are caused by these sorts of impairments. Driver errors were defined as any sort of improper movement or action made by the causal unit. It is well known that most crashes are due at least in part to some sort of operator error, so it is natural that such a large portion of crashes would fall into this category. Avoidance behavior crashes were those which occurred when the causal unit swerved to avoid some sort of hazard, did not notice the hazard quickly enough, or defective roadway equipment resulted in the road user acting. Aggressive driving, such as driving too quickly or otherwise disobeying the rules of the road, accounted for the fewest portion of VRU crashes.

Finally, according to Figure 12, the clear majority of VRU crashes resulted in property damage only, or PDO crashes. A much smaller portion resulted in significant injuries and less than 1% resulted in fatal injuries. However, the older and younger driver datasets skew these

statistics, as most PDO crashes come from those groups. While a significantly higher portion of crashes are categorized as PDO only, Figure 12 shows that with 878 fatal crashes and over 6,000 crashes with severe injuries, there is a significant volume of VRU crashes that result in injuries or worse and these crashes are potentially very dangerous.

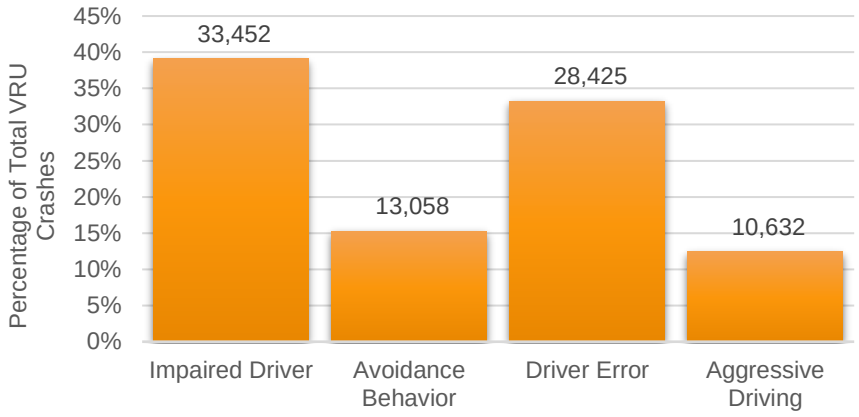

Figure 11: All VRU Crashes by Primary Reason

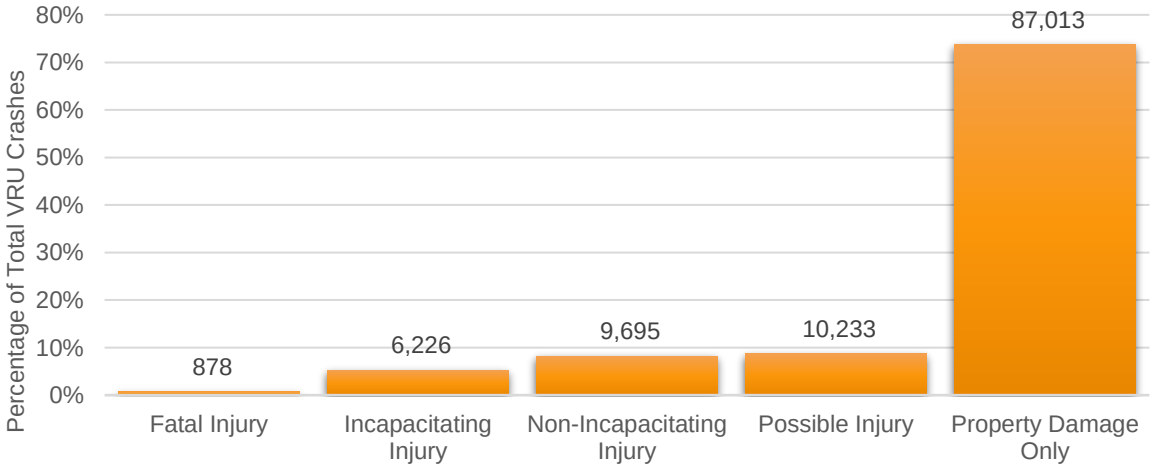

Figure 12: All VRU Crashes by Severity

III.3 Variations in Crash Patterns Across VRU Types

Crash Rates by Manner of Crash

For manner of crash, VRUs differed slightly by group. As shown in Figures 13 and 15 below, pedestrian and motorcycle crashes overwhelmingly involved only a single motor vehicle along with the VRU, followed by angle crashes. Most crashes with these groups involve a collision between a single motor vehicle and VRU. In contrast, angle crashes were the dominant manner of crash when bicyclists were involved, as demonstrated by Figure 14. However, as most crashes involving a pedestrian or bicyclist only involve a single vehicle, the differences in the manner of crash recorded for these users may be a result of how the officer interpreted and recorded the crash at the scene. Bicyclists are at the highest risk of sideswipe crashes with vehicles as they often must travel alongside them on the roadway. Figures 16 and 17 show that older and younger drivers experienced a similar distribution of crash types. About half of crashes involving older or younger drivers were also angle or side impact crashes, with the next largest portion belonging to rear end collisions. Compared with other VRUs, older and younger drivers' maneuverability and visibility is decreased, which explains the higher portion of rear-rend crashes. These crashes are typically at lower speeds and result in fewer and less severe injuries.

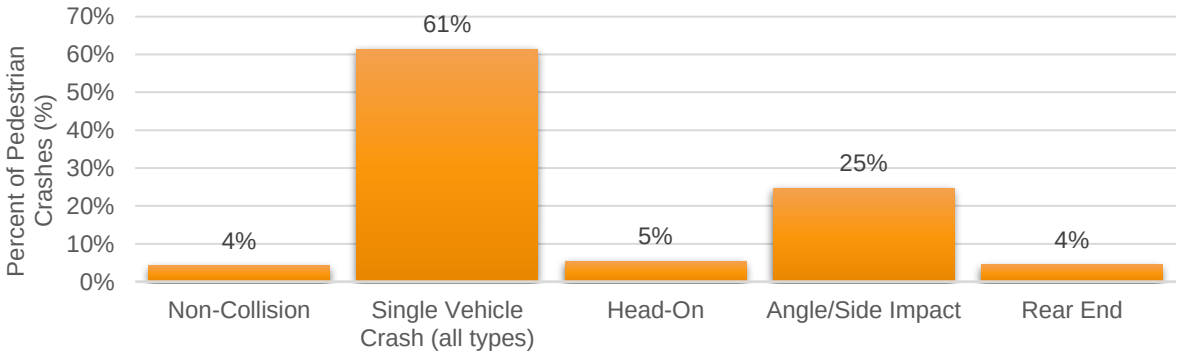

Figure 13: Pedestrian Manner of Crash

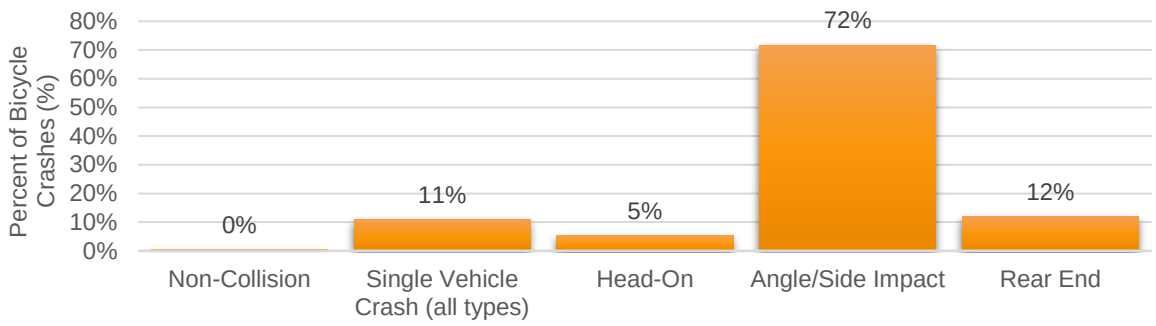

Figure 14: Bicycle Manner of Crash

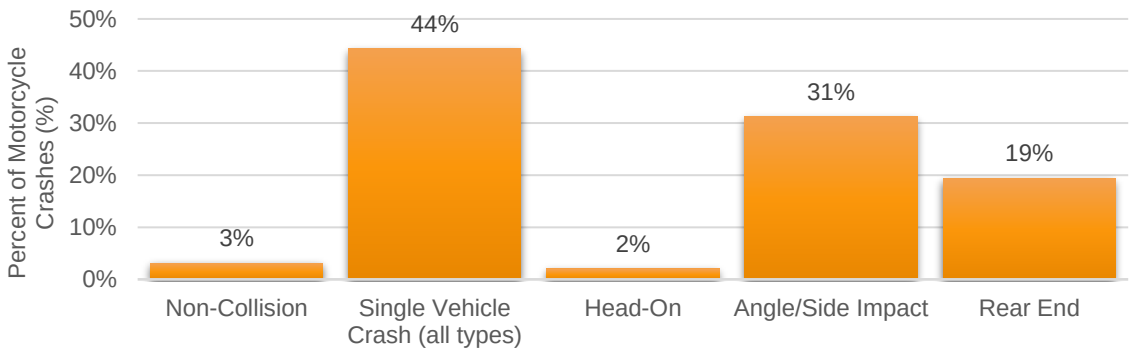

Figure 15: Motorcycle Manner of Crash

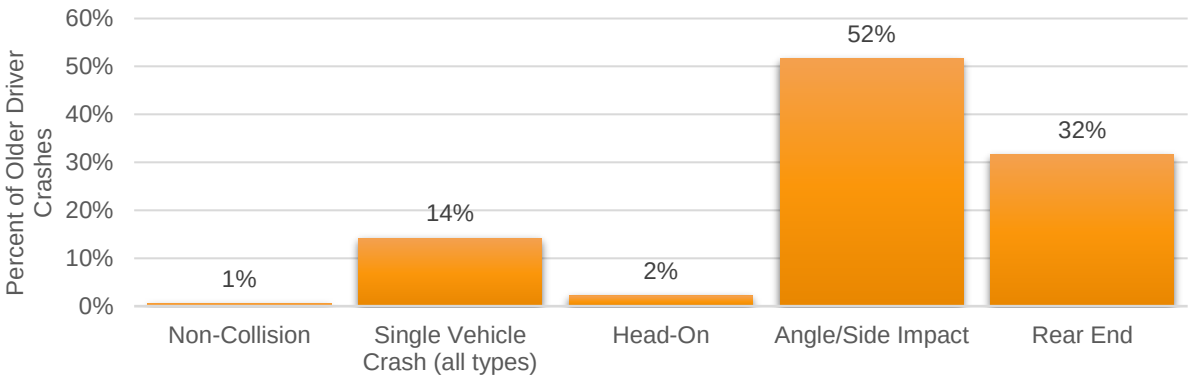

Figure 16: Older Driver Manner of Crash

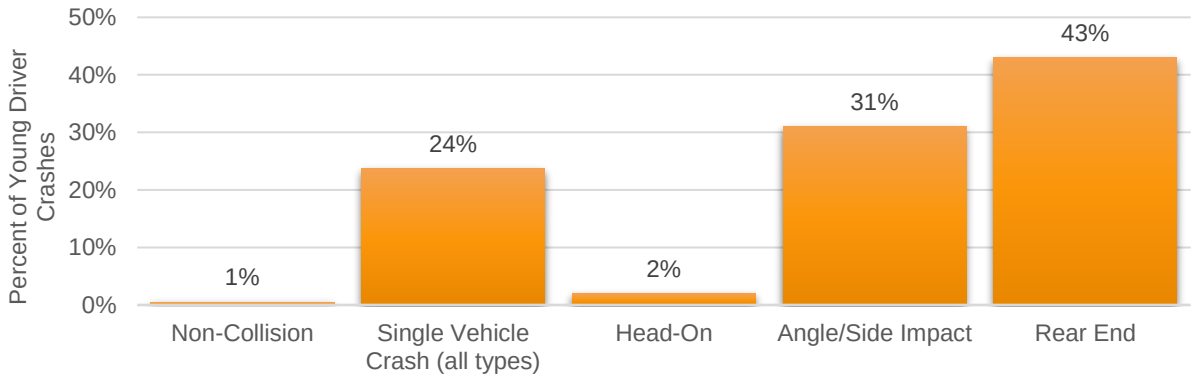

Figure 17: Younger Driver Manner of Crash

Crash Rates by Severity

Figure s 18 through 22 below show the distribution of crash severity for each VRU group. A larger portion of injurious crashes occur among the physically vulnerable groups – bicyclists, pedestrians, and motorcyclists – while the clear majority of crashes among the young and the elderly are PDO crashes. Pedestrians are possibly the most vulnerable group, as 11% of reported crashes with pedestrians result in one or more fatalities. With that, pedestrians in Alabama are involved in a larger portion of crashes resulting in fatalities than any other VRU group. Additionally, 31% of pedestrian crashes resulted in incapacitating injuries – another record high – and a large portion of the remaining crashes still result in injuries, with 34% of crashes categorized as non-incapacitating injurious. Only 4% of pedestrian crashes were PDO crashes, indicating that almost all pedestrian-involved crashes result in injuries. While analysis in the previous section revealed that pedestrian crashes occur much less often than other VRU crashes, this dataset reveals that when these crashes do occur, they are often some of the most dangerous.

A small, but not insignificant portion of bicyclist and motorcyclist crashes result in fatalities. Despite the smaller portion of fatal crashes, cyclists are second only to pedestrians and

in terms of proportion of crashes which result in severe injuries. Like with pedestrian crashes, though there are fewer cyclist crashes among VRUs proportionately, those that do occur are among the most likely to be severe and harmful. Motorcyclists share a similar severity breakdown to bicyclists, indicating that they follow this trend as well.

Very few collisions involving older or younger drivers result in fatalities. Figure *2*21 and Figure *2* 22 demonstrate that older and younger drivers follow a nearly identical pattern of crash severity. Despite the two groups having very different characteristics, in some ways older and younger drivers behave like a group.

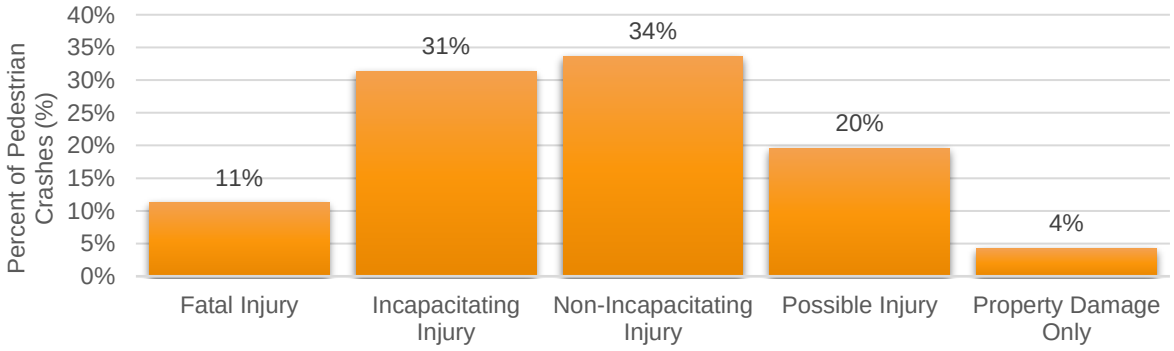

Figure 18: Pedestrian Crash Severity

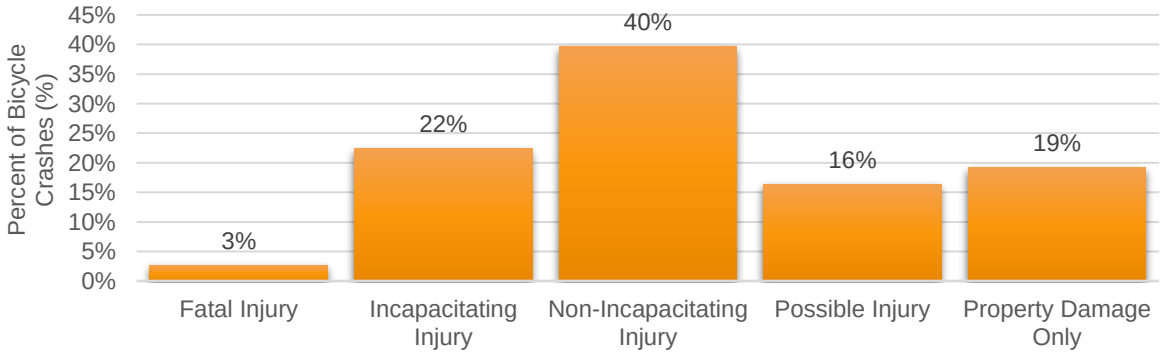

Figure 19: Bicycle Crash Severity

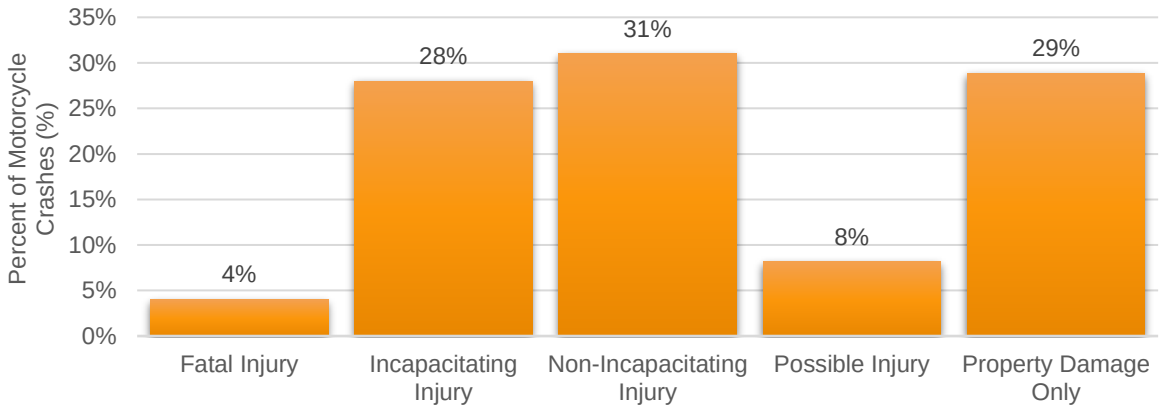

Figure 20: Motorcycle Crash Severity

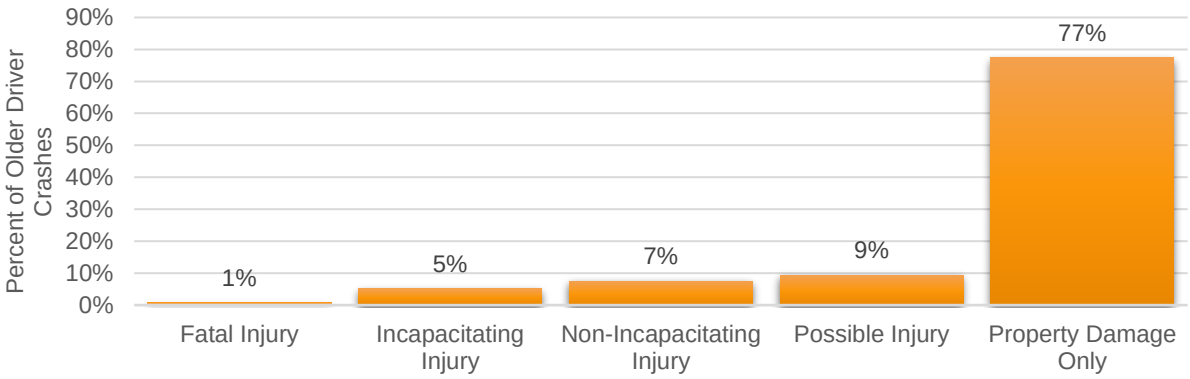

Figure 21: Older Driver Crash Severity

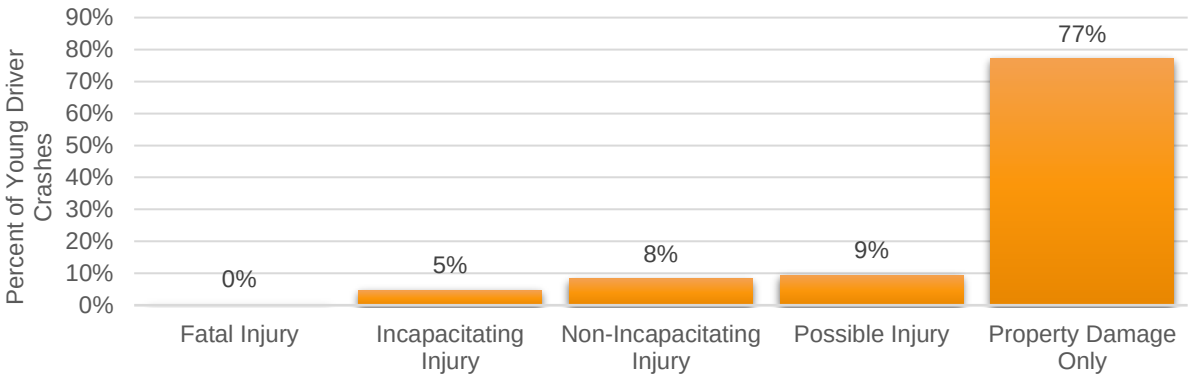

Figure 22: Younger Driver Crash Severity

Crash Rates by Causal Unit

The causal unit at fault in a VRU crash differs significantly between VRU groups. In pedestrian crashes, the causal unit is split nearly evenly between motor vehicles and the VRU, with slightly more motor vehicles at fault (see Figure 23). Among road users who are vulnerable due to lack of physical protection, pedestrians are the only VRU group in which crashes are more likely to be caused by a motor vehicle than by the vulnerable user. However, at 57% of crashes being the fault of a motor vehicle compared to 43% at the fault of the VRU group – pedestrians – even this lead is slight. The crash data indicates that in half or better cases, a crash involving a VRU is the fault of the VRU. The split is even closer between motor vehicles and bicyclists, with slightly more bicyclists at fault. Most motorcycle crashes are caused by the motorcyclist, rather than a motor vehicle. This is demonstrated in Figure 24 and Figure 225, respectively. However, as previously stated, the crash dataset only provided demographic information for the user at fault in the crash. This included age, so Figure 26 and Figure 27 demonstrate that the older and younger driver crash datasets are skewed to only include crashes which they were the cause of.

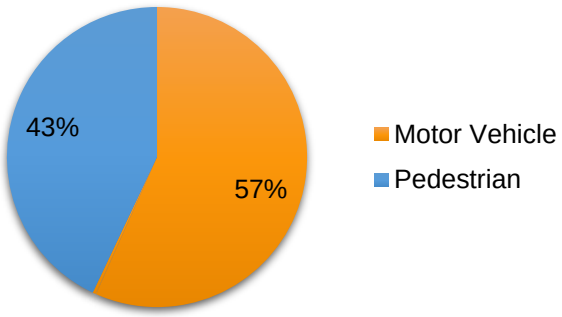

Figure 23: Pedestrian Crash Causal Units

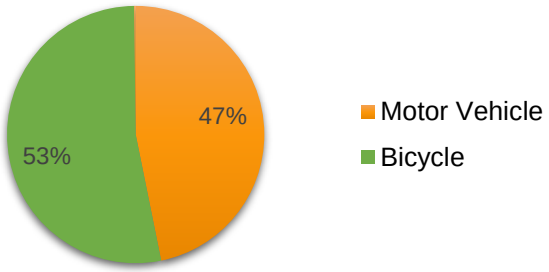

Figure 24: Bicycle Crash Causal Units

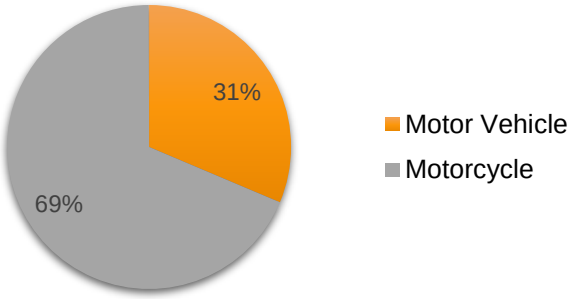

Figure 25: Motorcycle Crash Causal Units

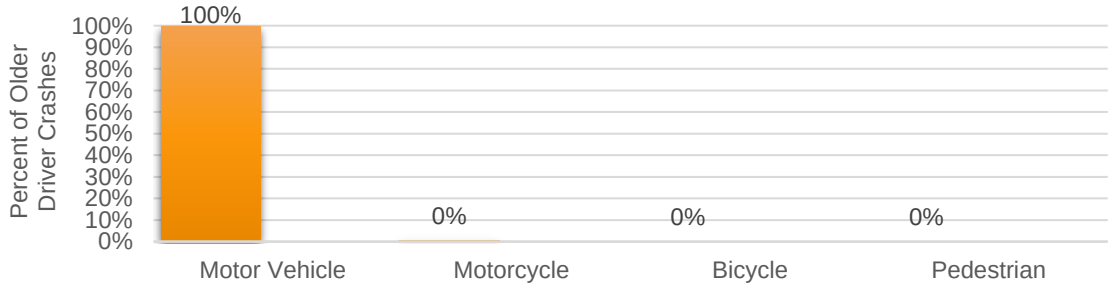

Figure 26: Older Driver Crash Causal Units

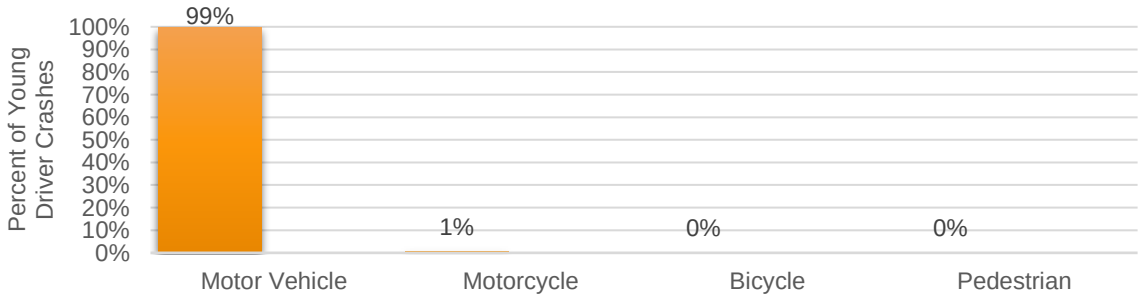

Figure 27: Younger Driver Crash Causal Units

Crash Rates by Primary Reason

Figures 28-32 show the crash rate for each VRU group by the cause of the crash. For all VRU groups, driver error was the most common primary contributing factor to the crash. This was especially true for older drivers. The proportion of remaining causes is split differently among the different VRU groups. Impaired drivers were the least common cause for motorcycle, bicycle, and older driver crashes. Aggressive driving was responsible for the fewest crashes among pedestrians and a relatively small portion among older drivers and bicyclists. However, a relatively high proportion of motorcyclist and younger driver crashes occurred because of aggressive driving.

For pedestrians, bicyclists, and motorcyclists, the most common primary reason for the crash occurring was either a failure to yield the right-of-way or an unseen object, person, or vehicle. Efforts to make right-of-way clear through signposting and markings, education and enforcement, and other countermeasures should be a vital focus to reduce VRU crashes in the state. Failure to properly yield results in most bicycle crashes. Many pedestrian crashes are also caused by improper crossings, so these are another important target area for pedestrians. Motorcycle crashes show much more variance in the primary crash cause than the other physically vulnerable groups, so specialized countermeasures are more difficult to determine for these users. Among older and younger drivers, driver error is the most common reason for a crash to occur. For older drivers, this is likely due to decreased driving ability; for younger drivers, this concern is even more prominent because of their limited driving experience. Younger drivers are also more prone to aggressive behaviors that result in crashes, which is consistent with established literature.

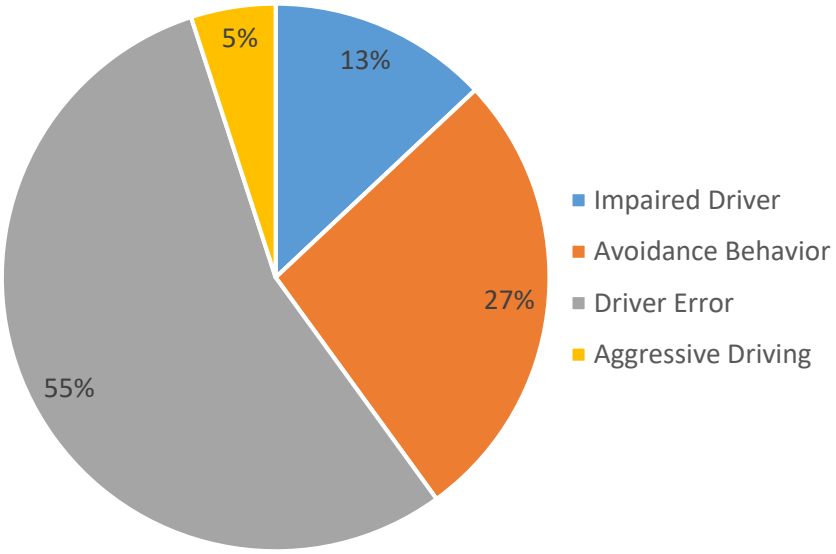

Figure 28: Pedestrian Crash Primary Cause

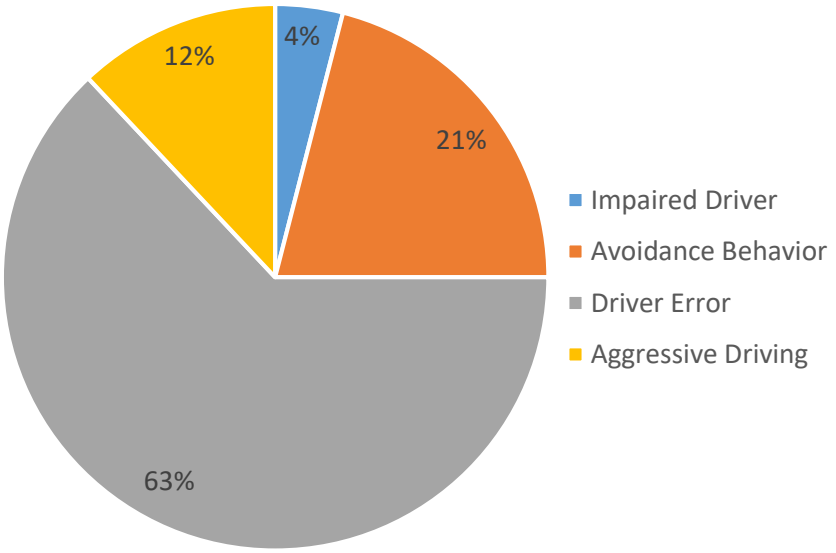

Figure 29: Bicycle Crash Primary Cause

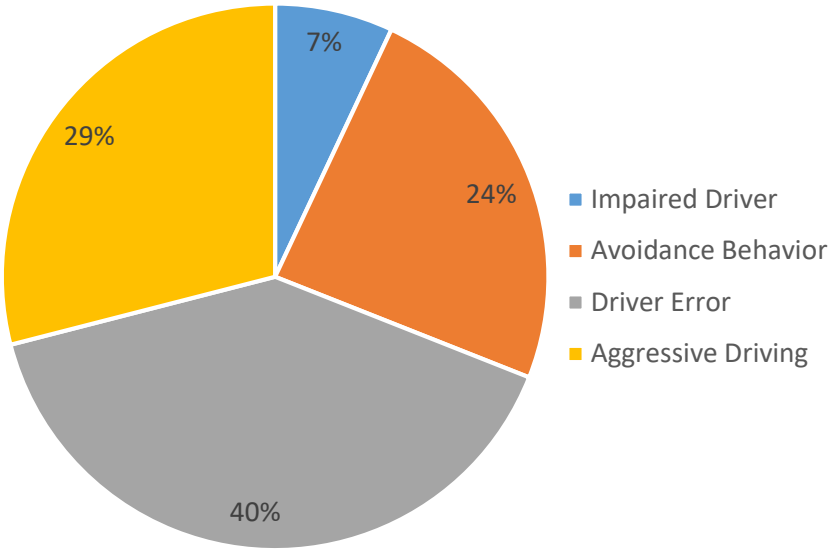

Figure 30: Motorcycle Crash Primary Cause

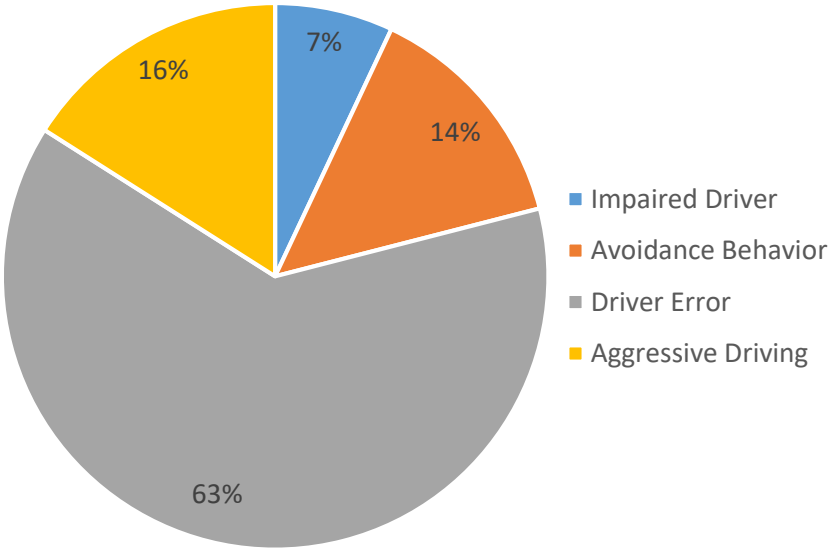

Figure 31: Older Drivers Crash Primary Cause

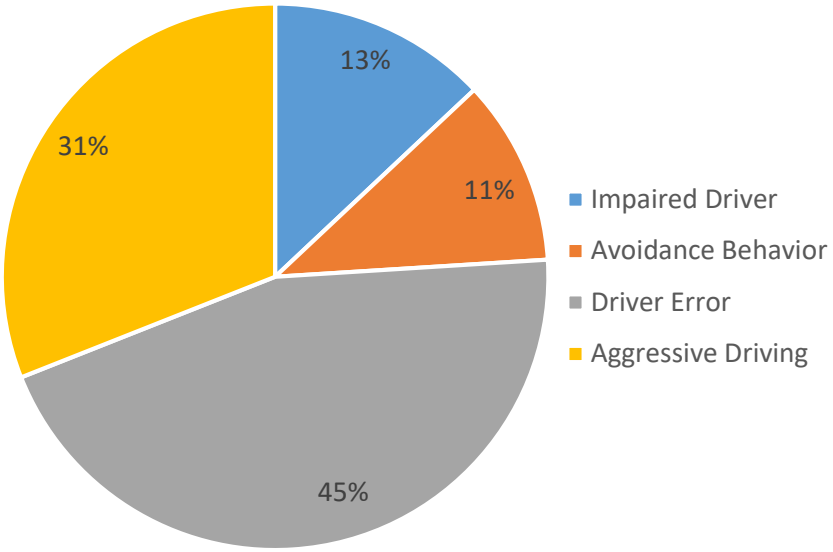

Figure 32: Younger Drivers Crash Primary Cause

III.4 Variations in Crash Patterns Across Urban vs. Rural Settings

Pedestrian Crash Rates Depending on Urban or Rural Setting

Among pedestrians, the clear majority of VRU crashes occurred in urban settings as opposed to rural ones, as the clear majority of pedestrian travel in the state occurs in urban cities. However, Figure 33 demonstrates that the small portion of pedestrian crashes which occur in rural settings are still very much significant, as they are more likely than any other group to result in fatalities or very severe injuries. Urban pedestrian crashes also result in a large proportion of severe injuries, but are much less likely to be fatal. Thus, despite a relatively small portion of crashes occurring with pedestrians in rural areas, these crashes are incredibly significant and much effort should be spent combating them. In addition, Figure 34 demonstrates that pedestrians are slightly

more likely to be at fault for these rural collisions compared to their urban counterparts, where vehicles are primarily at fault.

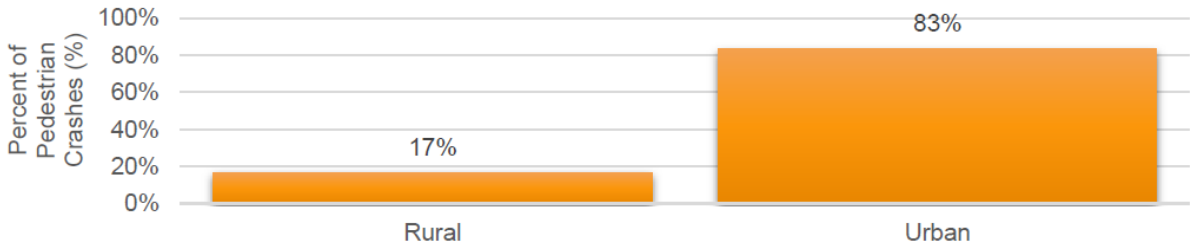

Figure 33: Rural vs Urban Pedestrian Crashes

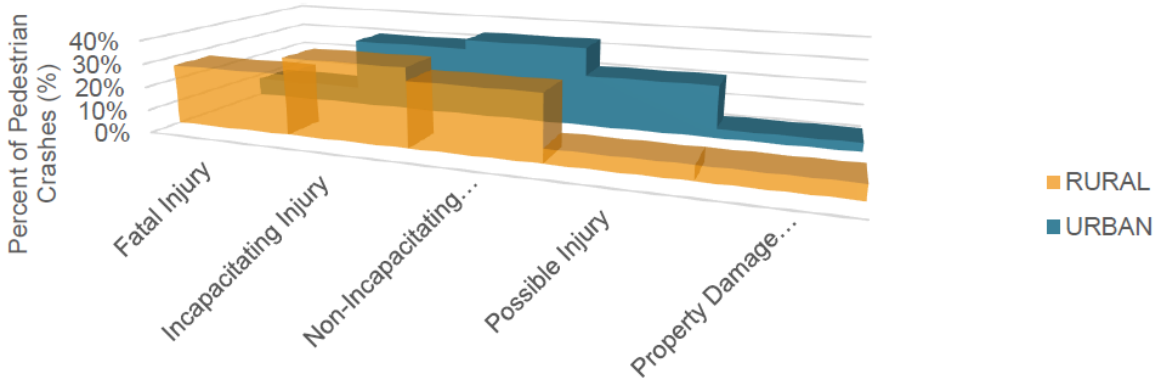

Figure 34: Rural vs Urban Pedestrian Crash Severity

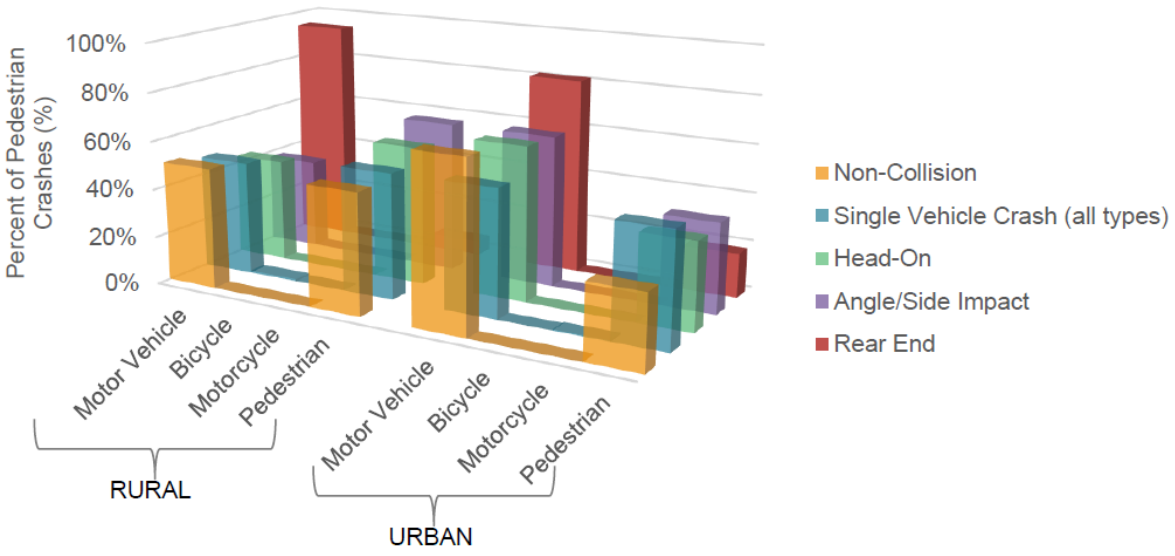

Figure 35: Rural vs Urban Pedestrian Crash Causal Unit

Crash Rates Depending on Posted Speeds

In general, Figures 36-40 demonstrate that crashes involving VRUs are much more likely to occur at lower speeds in urban areas (40 mph or less) and higher speeds in rural areas. The trend is most significant and clear-cut among pedestrians and bicyclists. However, crashes among motorcyclists, older drivers, and younger drivers in urban areas tend to occur equally regardless of speed limit. This suggests that while more crashes may occur at lower speeds in urban areas due to their setting for these users, crashes with motorized VRUs are more likely to occur at higher speeds regardless of the context.

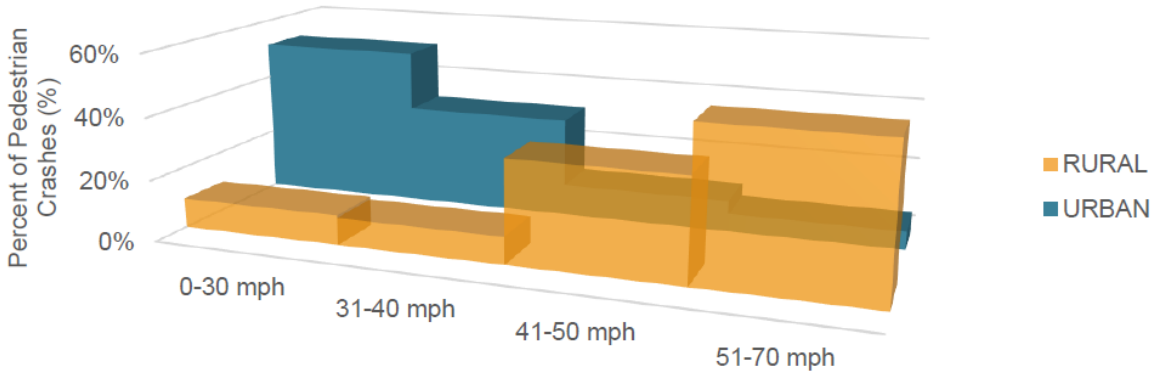

Figure 36: Rural vs Urban Pedestrian Crashes and Posted Speeds

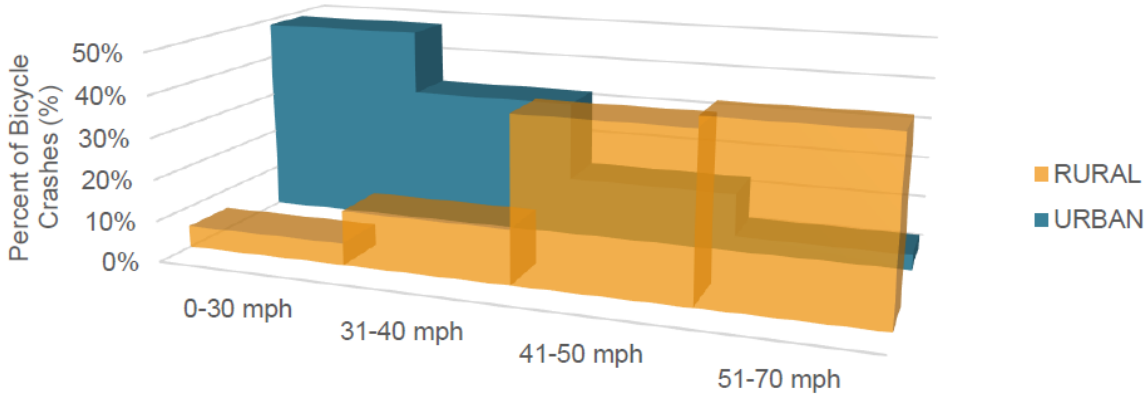

Figure 37: Rural vs Urban Bicycle Crashes and Posted Speeds

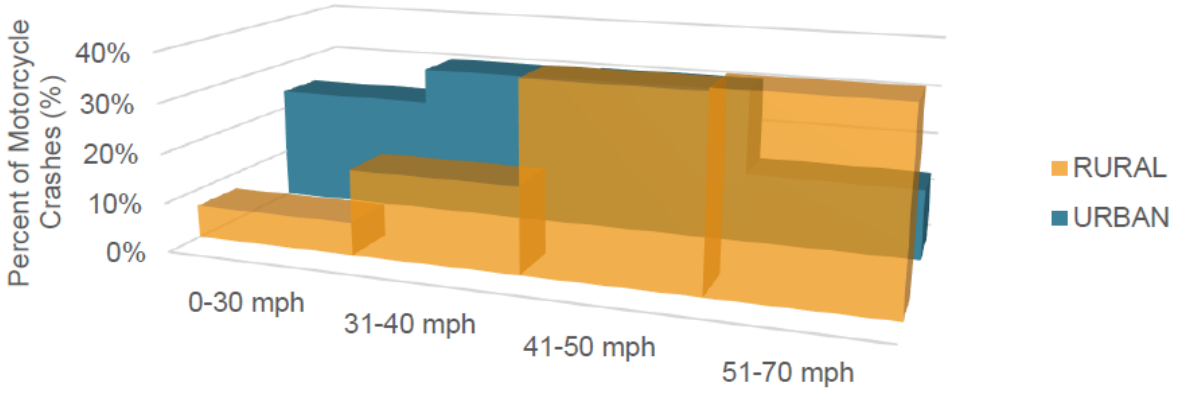

Figure 38: Rural vs Urban Motorcycle Crashes and Posted Speeds

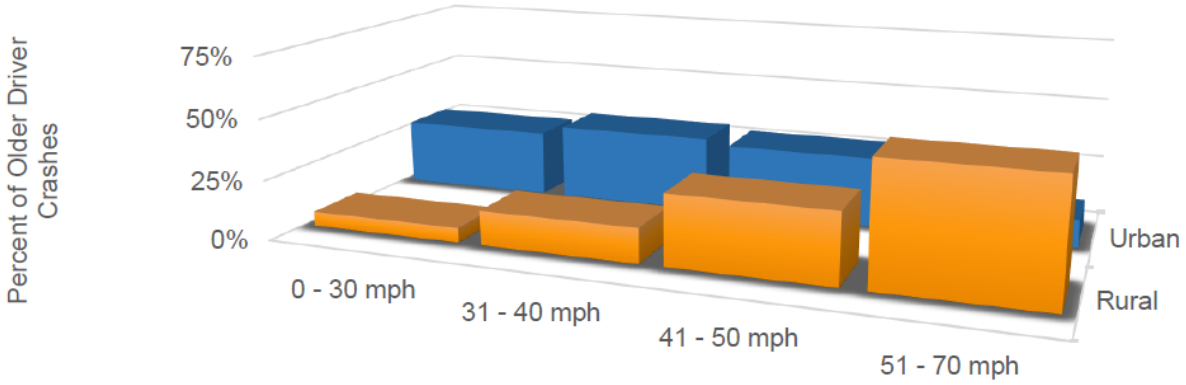

Figure 39: Rural vs Urban Older Driver Crashes and Posted Speeds

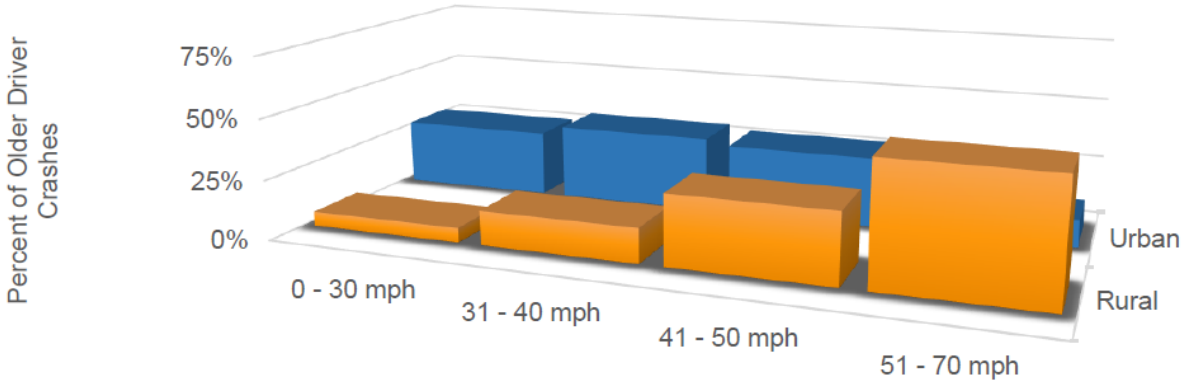

Figure 40: Rural vs Urban Younger Driver Crashes and Posted Speeds

Crash Rates Depending on Facility Types

Figures 41-43 show the number of crashes at each facility type in urban and rural areas for the non-motorized VRUs. Among the non-motorized VRUs, most crashes occurred on uncontrolled access roadways, regardless of whether the road was in an urban or a rural zone. Among pedestrians, intersections were more dangerous locations than main roads in urban areas, but the reverse was true in rural locations. This is likely because of the nature of the roadway system in each environment; pedestrians are most at risk when crossing the road at an intersection, which

occurs much more often in a dense urban network. In rural areas, pedestrians are at risk on main roads, where vehicles travel quickly over long distances. However, bicyclists and motorcyclists are at higher risk at intersections than at main roads in both urban and rural locations. These users are most likely to face conflicts when they must cross with other motor vehicles.

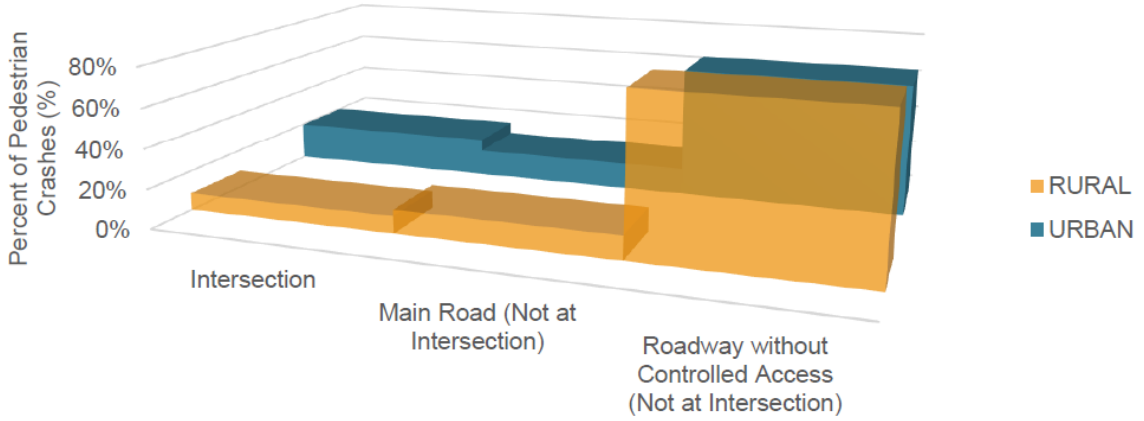

Figure 41: Rural vs Urban Pedestrian Crashes and Facility Type

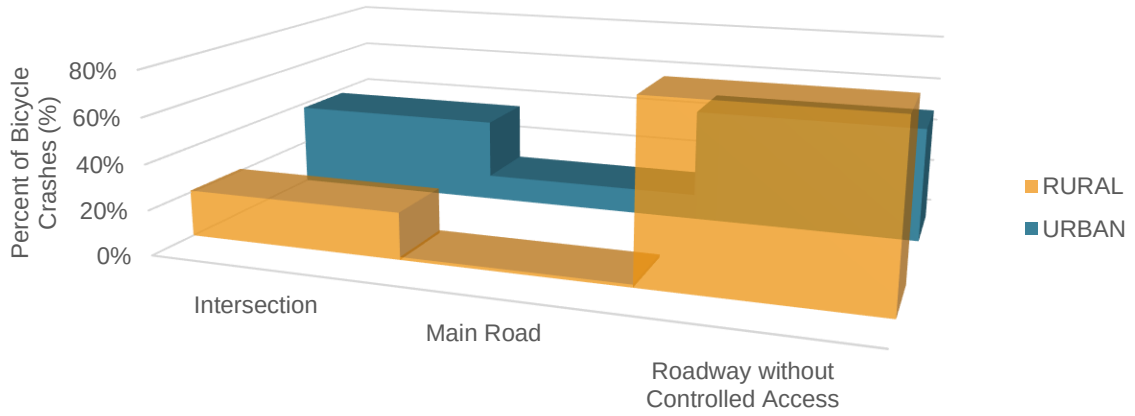

Figure 42: Rural vs Urban Bicycle Crashes and Facility Type

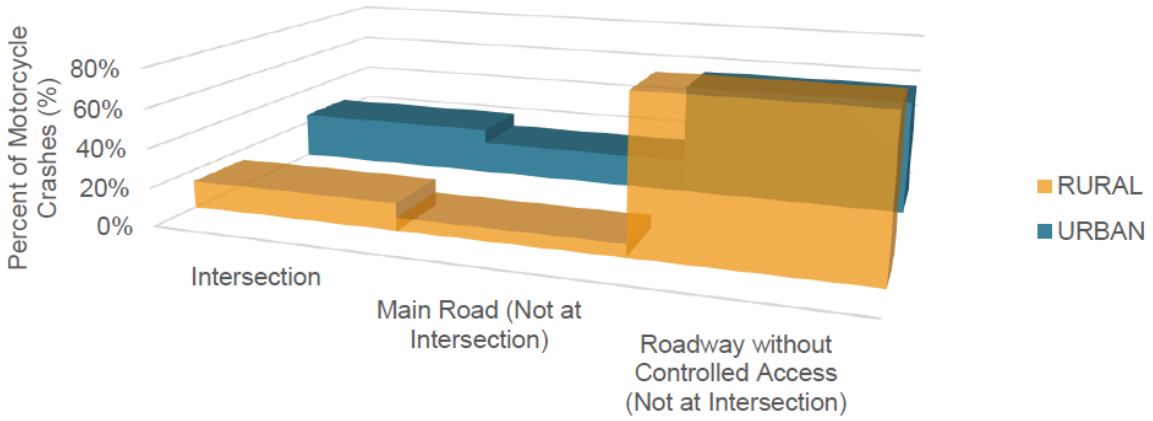

Figure 423: Rural vs Urban Motorcycle Crashes and Facility Type

Crash Rates Depending on Surrounding Development

For all VRUs, crashes in rural areas most often occur in the open country, as this is where most rural road mileage is dedicated. To varying degrees, the remaining 20-25% of rural VRU crashes are split among residential developments (~10-20%) and shopping/business districts (~5-15%). Figures 44-48 show that in rural developments, VRUs behave generally as a group. The pattern of these crashes indicates that most VRU crashes in rural regions occur on long open country highways.

There are more significant variances in urban developments. In general, most VRU crashes in urban areas are split between residential developments and shopping/business districts. These areas typically see the most VRU traffic, so designing safe neighborhoods and smart roadways in cities in the future will be important for reducing casualties among the most vulnerable travelers. In general, VRU crashes in Alabama were split between those two zones. For pedestrians, the split was about 40% residential to about 50% shopping/business. A small fraction occurred near schools or playgrounds. Bicyclists were the only group where most urban

VRU collisions occurred in neighborhoods, but as Figure 45 shows, there were almost as many shopping/business collisions. About 5-10% of urban bicyclist crashes occurred near schools or playgrounds. This is alarming, as these users could be younger children, who are especially vulnerable. Finally, motorcyclists, older drivers, and younger drivers have similar crash behaviors by facility type in urban areas. Most are concentrated in shopping or business zones where traffic volumes are higher, roadways have more access, and conflicts are abundant. A small portion of crashes occur in open country areas where speed limits are often higher.

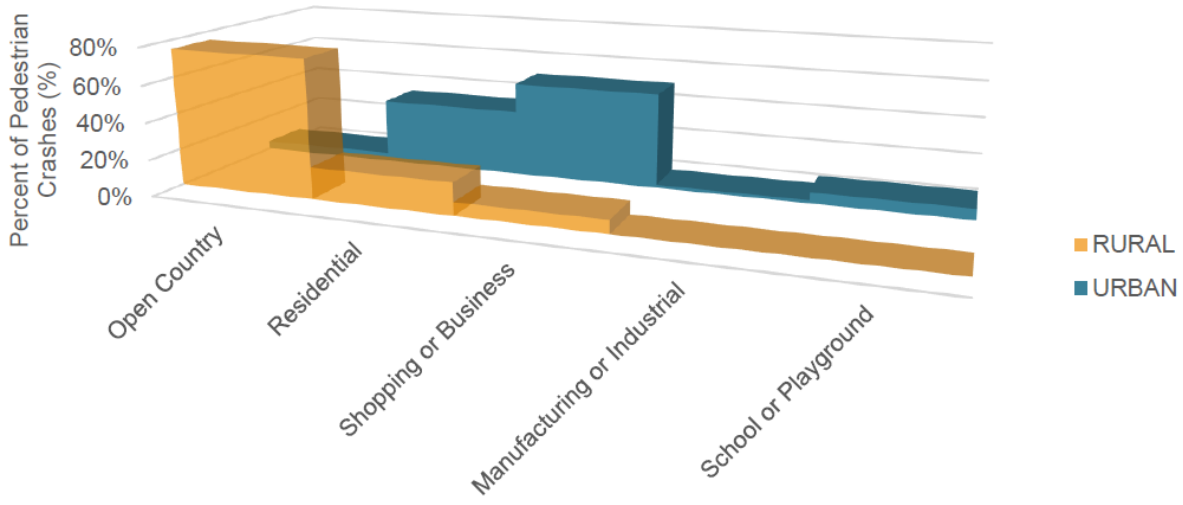

Figure 44: Rural vs Urban Pedestrian Crashes and Surrounding Development

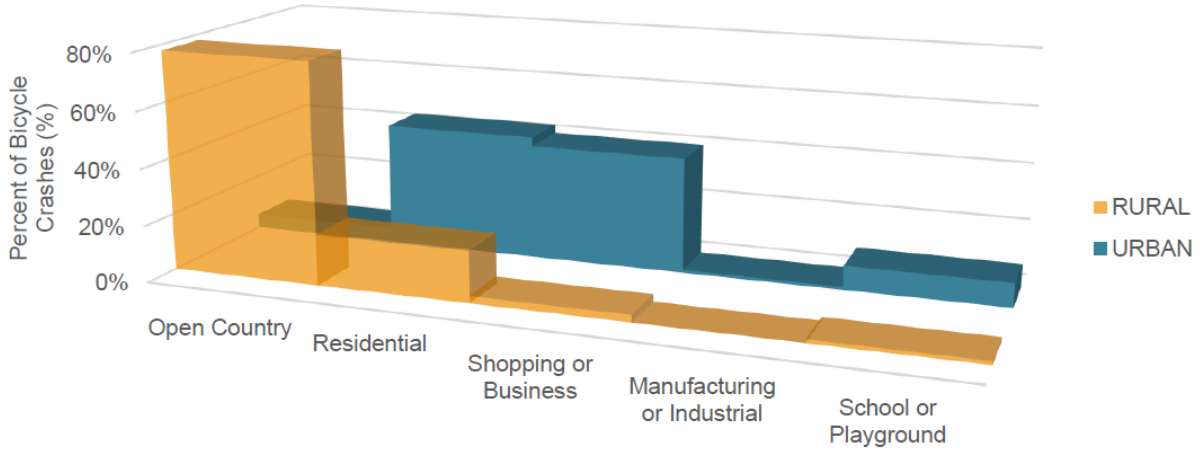

Figure 45: Rural vs Urban Bicycle Crashes and Surrounding Development

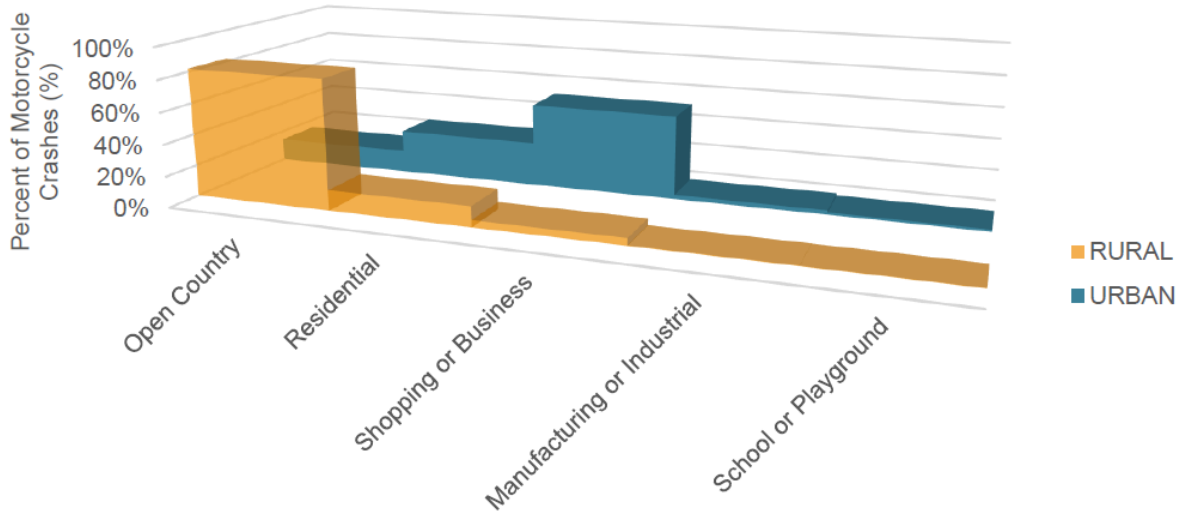

Figure 46: Rural vs Urban Motorcycle Crashes and Surrounding Development

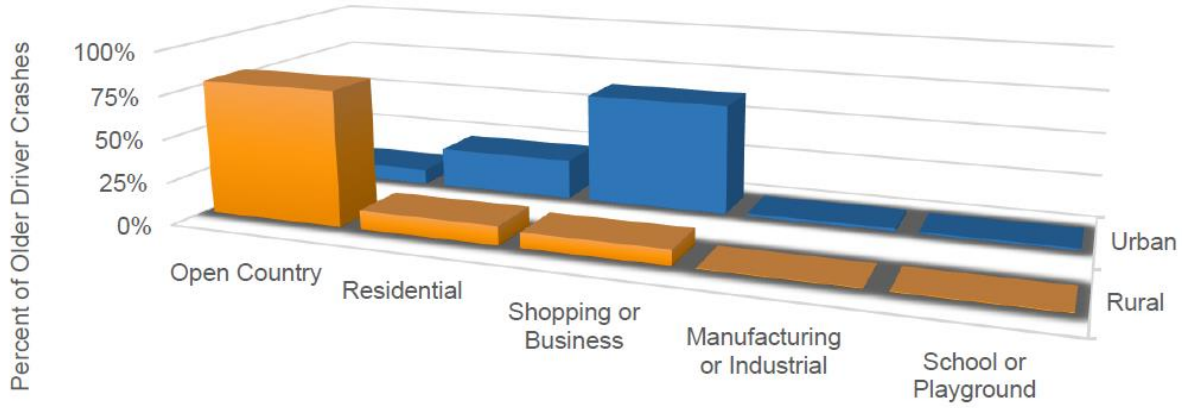

Figure 47: Rural vs Urban Older Driver Crashes and Surrounding Development

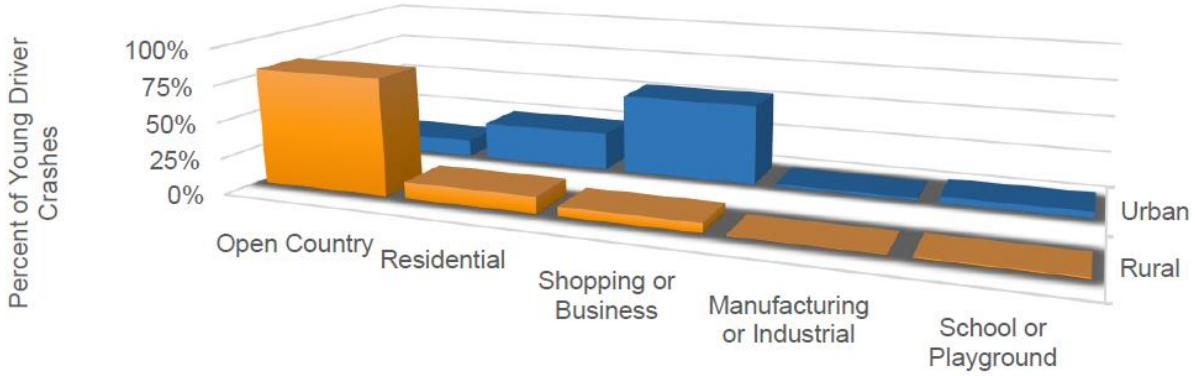

Figure 48: Rural vs Urban Younger Driver Crashes and Surrounding Development

Crash Rates Depending on Lighting Conditions

Figures 49-53 examine the lighting conditions during the crash for each VRU group in rural and urban areas. These figures show that in general, the lighting conditions for rural crashes were about the same regardless of group and that a similar pattern holds for urban crashes. Most (~60-70%) of crashes in urban areas occurred during daylight hours and most the remaining (typically ~10-20%) occurred at night but with good roadway lighting conditions. A small portion of urban VRU crashes occurred at night without proper lighting, but the only group that breaks this trend

is pedestrians. Only about 50% of crashes involving pedestrians in urban areas occurred in daylight hours, with most of the remaining occurring at night with good lighting, but about 5-10% occurring on roadways without proper lighting. This indicates that good lighting is an essential safety component for pedestrians and that more so than any other VRU group, pedestrians are more likely to be involved in a collision while traveling at night.

For rural VRU crashes, most occurred in the daylight (about 60-70%) while most of the remaining portion occurred at night under improper lighting conditions (about 20-30%). A larger portion of VRU crashes occur at night in rural areas than in urban ones. And for the most part, these crashes occur in areas without roadway lighting. This is a very tough challenge to solve for rural travel, as lighting every mile of roadway is a totally impractical solution. As before, pedestrian behavior breaks the general VRU trend with lighting. Unlike any other VRU group, more pedestrian crashes in rural areas happen at night than during the day. As with other VRU crashes, the clear majority of these occur under improper or no lighting. Pedestrians in rural areas are especially vulnerable if they travel at night, where they are both difficult to spot and unexpected for motor vehicles who are typically travelling at high speeds. Extra care must be spent to engineer solutions to allow pedestrians to travel more safely at night on rural roadways.

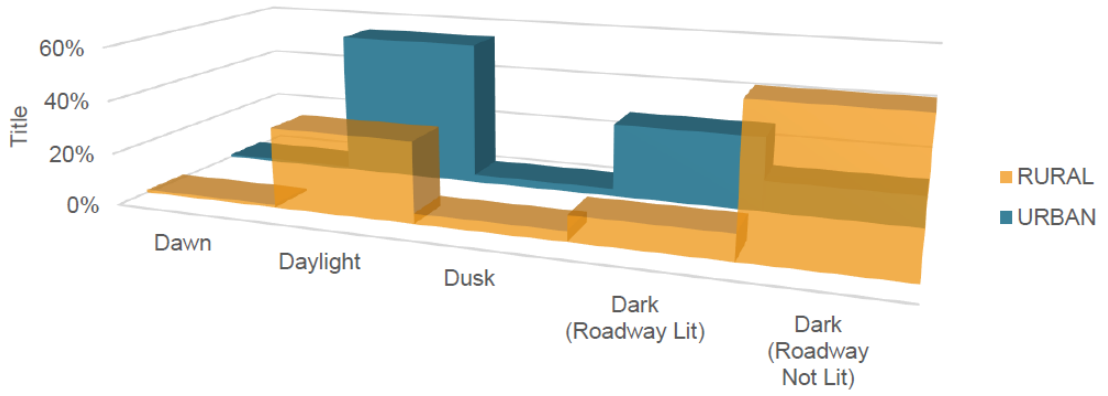

Figure 49: Rural vs Urban Pedestrian Crashes and Lighting Conditions

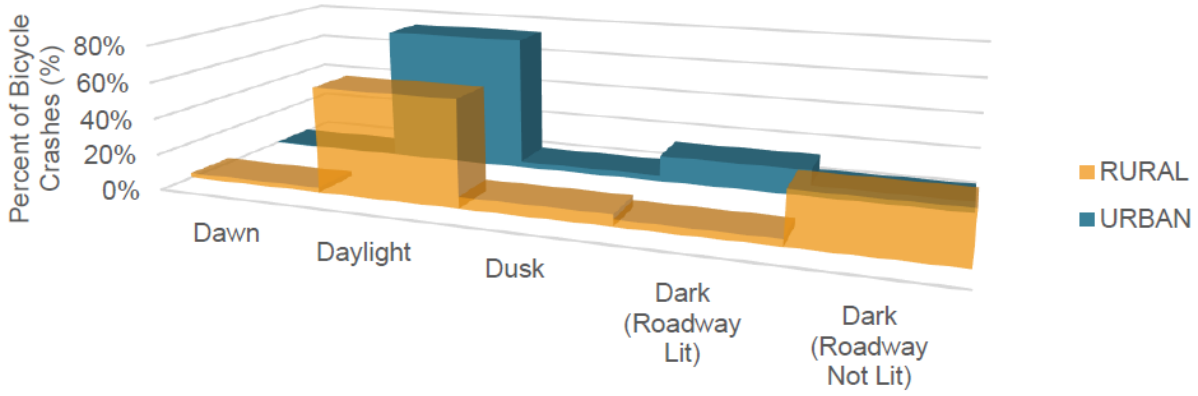

Figure 50: Rural vs Urban Bicycle Crashes and Lighting Conditions

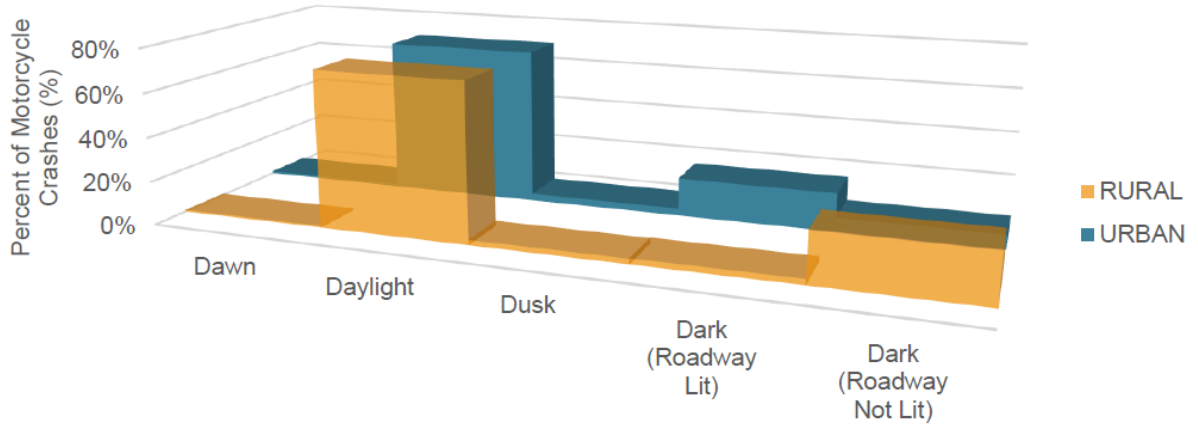

Figure 51: Rural vs Urban Motorcycle Crashes and Lighting Conditions

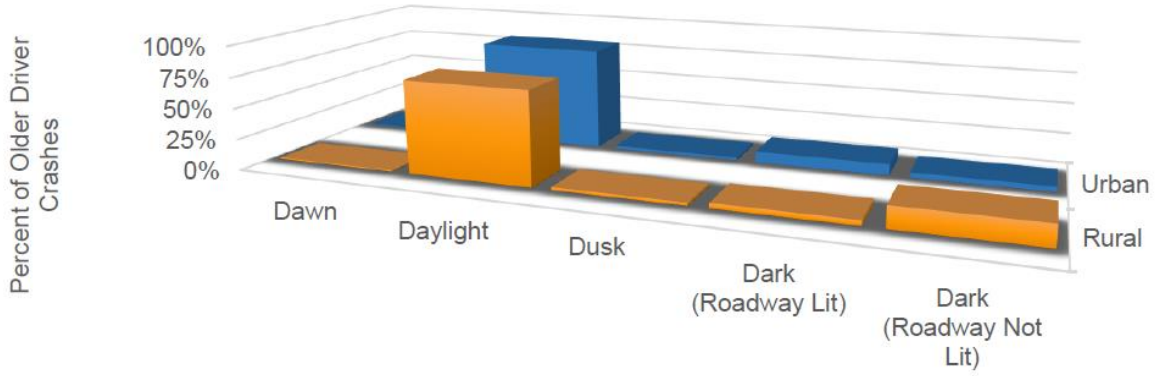

Figure 52: Rural vs Urban Older Driver Crashes and Lighting Conditions

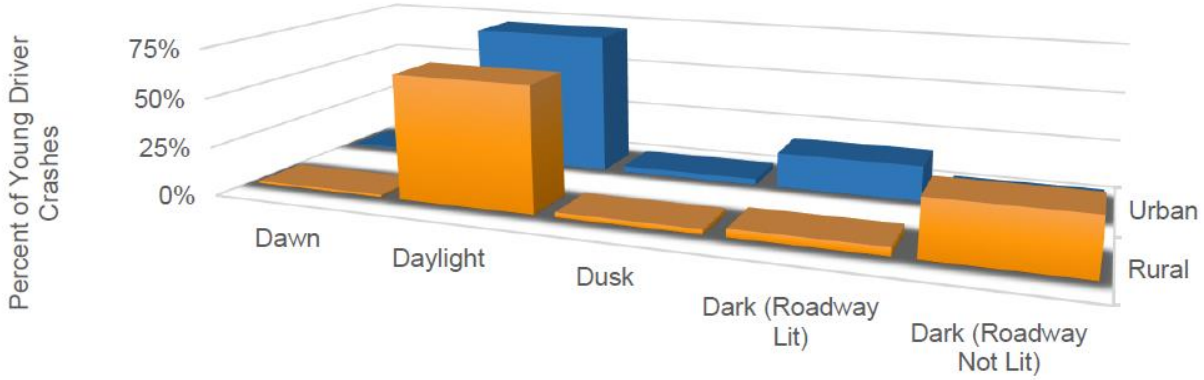

Figure 53: Rural vs Urban Younger Driver Crashes and Lighting Conditions

Crash Rates Depending on Non-Motorized Maneuvers

Pedestrians and bicyclists face different challenges in urban and rural areas, which is reflected in Figures 54 and 55 below, which show what the VRU was doing the moment before the crash occurred. Regardless of mode or surrounding development, in 99% of cases, the VRU was either entering/crossing the roadway or walking/running/cycling alongside the roadway just before the collision. How they are portioned is what changes. In urban areas, both pedestrians and bicyclists are entering or crossing the roadway when the crash occurred. There is about a 60-40 split

between crossing and traveling alongside the roadway. In urban areas, both pedestrians and bicyclists are at their most vulnerable when they cross into the roadway, as this leaves them incredibly vulnerable to potential conflicts with motor vehicles.

In rural areas, pedestrians and bicyclists' behaviors differ. Most pedestrian crashes in rural areas occur when the pedestrian is travelling alongside the roadway. Motorized road users traveling at high speeds on rural roads combined with poor visibility or human errors can likely explain this result. For bicyclists in rural areas, though, collisions are split evenly between cyclists traveling alongside the roadway and crossing it. As road crossings occur less often in general in rural areas, this indicates that this is a particularly challenging area for bicyclists. Countermeasures like a PHB signal that stop traffic to allow crossings for VRUs may be appropriate in some of these situations.

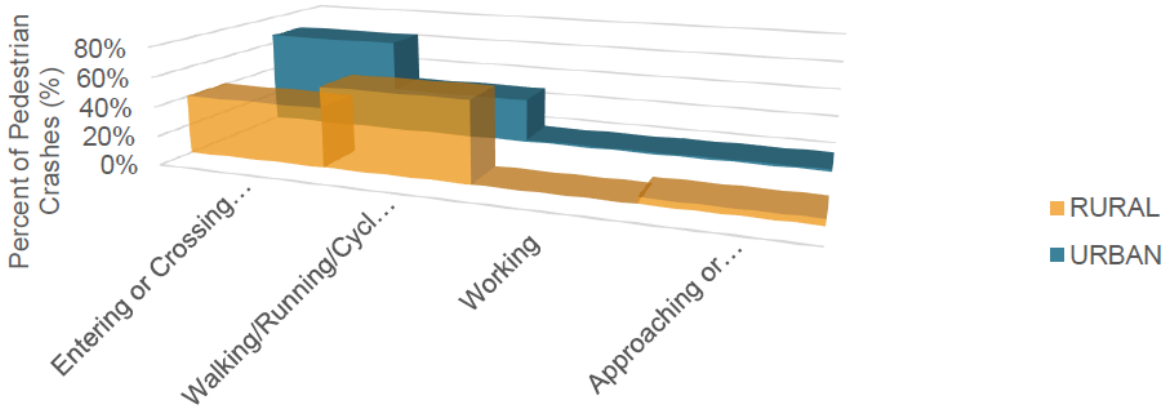

Figure 54: Rural vs Urban Pedestrian Crashes and Maneuvers

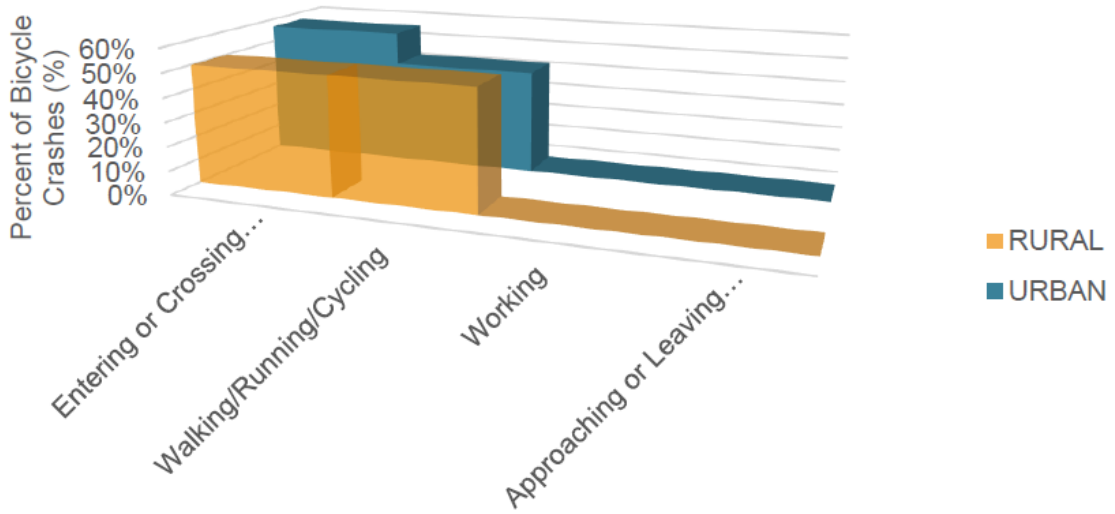

Figure 55: Rural vs Urban Bicycle Crashes and Maneuvers

Crash Rates Depending on Primary Reason

In general, VRU crash rates do not vary much by primary reason based on their surrounding development. Older and younger drivers provide two notable exceptions in Figures 56 and 57 below. Older drivers are slightly less likely to crash due to driver error or aggressive driving in rural developments than in urban developments, and are slightly more likely to crash due to avoidance behaviors or impairments in rural areas than in urban areas. This shows a tendency towards collisions due to distraction, improper sight conditions, or some unexpected impedance in rural areas among older drivers. Among younger drivers, driver error is also much less common in rural areas than in urban ones and younger drivers are also more likely to crash due to some impairment or distraction in rural areas than in urban ones. However, unlike older drivers, younger drivers are also slightly more likely to exhibit aggressive driving behaviors such as speeding in rural areas. Designing roadways to discourage these behaviors should be an important focus to reduce younger driver crashes.

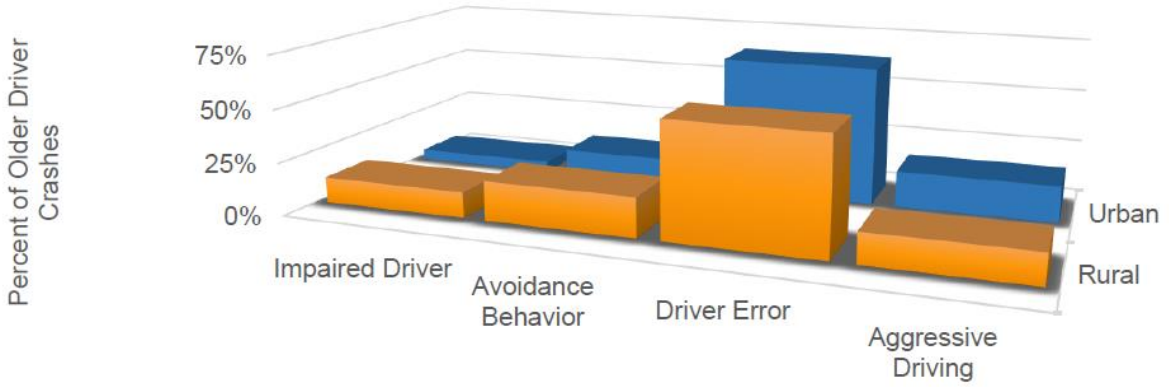

Figure 56: Rural vs Urban Older Driver Crashes and Primary Reason

Figure 57: Rural vs Urban Younger Driver Crashes and Primary Reason

III.5 Specific Concerns

The Role of Timing in Pedestrian Crashes

More crashes with VRUs tended to occur in the winter and spring, with fewer in the summer and fall. The weekday to weekend split of crashes was about the same for VRU groups, with crashes occurring about equally on each day of the week. Regardless of VRU type, crashes tended to occur over the course of the day in a manner very like the trend from Figure 7 in the previous section.

Figure 58 shows the how pedestrian crashes occurred over the year. The other VRU groups showed a seasonal split very like that in the figure. The weekday-weekend crash split for pedestrians is demonstrated by Figure 69, which serves as a representation for the other VRU groups as well. Finally, Figure 60 shows the distribution of pedestrian crashes over a day. The same general trends, peaks, and valleys in daily crash timing hold across all VRU groups. See the discussion of Figures 5-7 for how VRU crashes varied by timing in general, as there was little variation across the type of VRU.

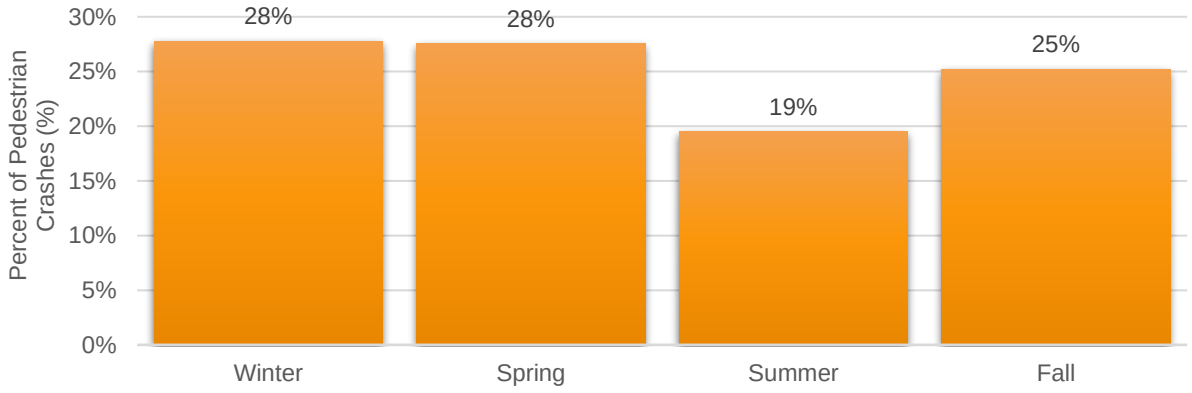

Figure 58: Pedestrian Crashes by Season

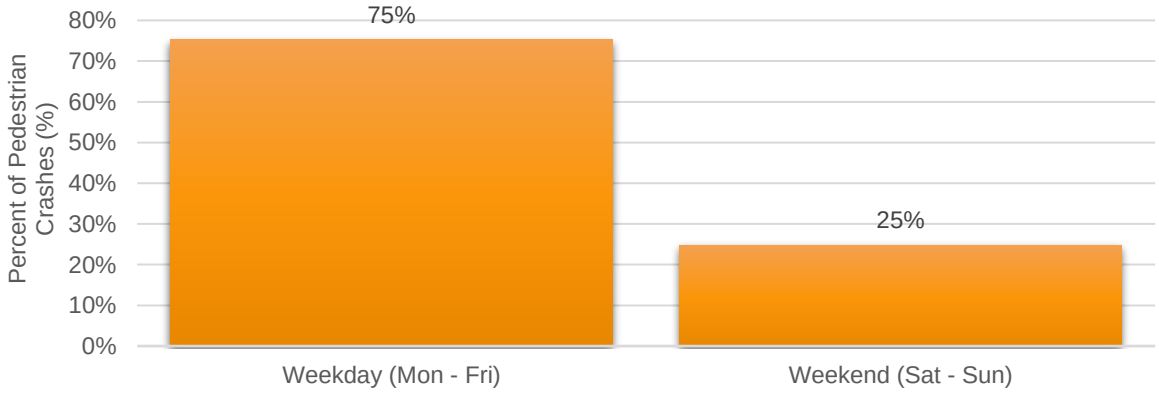

Figure 59: Pedestrian Crashes by Day of the Week

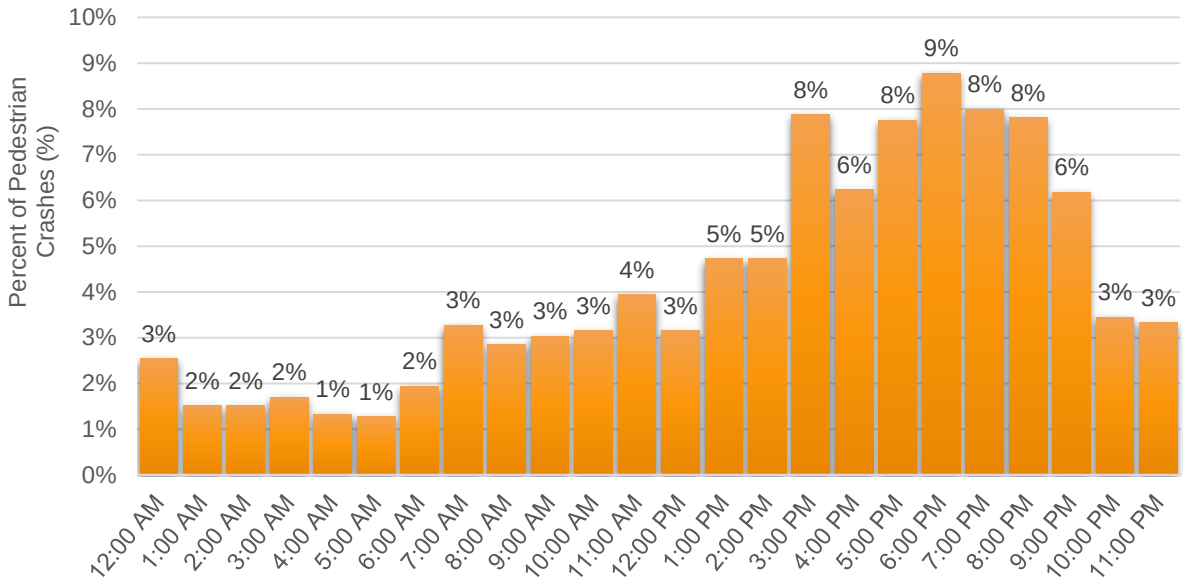

Figure 60: Pedestrian Crashes by Time of the Day

The Role of Speed in Bicycle and Younger Driver Crashes

Most bicyclist and pedestrian crashes occur at lower speeds, while for other VRU types, crashes tend to occur at moderate to higher speeds. Figures 61 and 62 serve as representative examples of the distribution of crashes based on roadway speed limit for bicyclists and younger drivers, respectively. Most VRU crashes occurred at roadways without controlled access, and crashes were more likely to occur at intersections among older and younger drivers than other VRU groups. The clear majority of VRU crashes also occurred in urban areas as opposed to rural ones. For pedestrians and older and younger drivers, most crashes occurred in shopping or business districts and many the remaining crashes were split between open country and residential areas. Bicyclist crashes, meanwhile, occurred most often in residential areas, followed by shopping or business and then open country. Motorcyclist crashes were the only group most likely to occur in open country areas.

For all VRUs, rural crashes were much more likely to occur at moderate to high speeds, while urban crashes were most likely to occur at low to moderate speeds. Pedestrian crashes serve as an example of this trend in Figure 63. Crashes at intersections were more likely to occur at lower speeds, while crashes on main roads tended to occur at very high speeds. Figure 646 uses pedestrian crashes again as an example. No other trends differed significantly with facility type or land use.

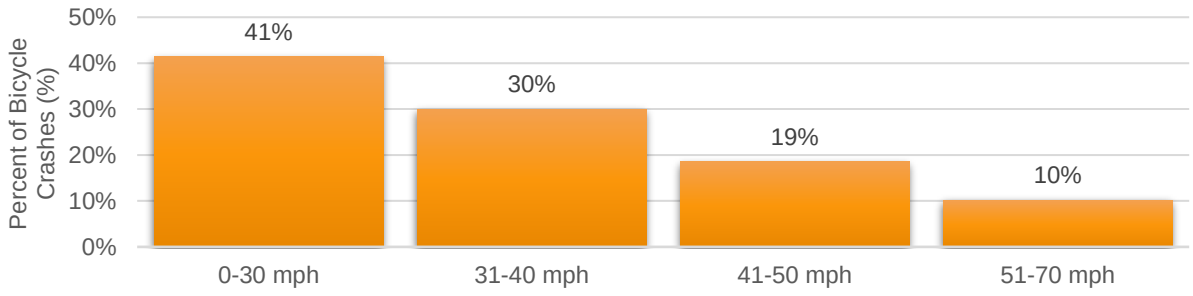

Figure 613: Bicycle Crashes by Speed Limit

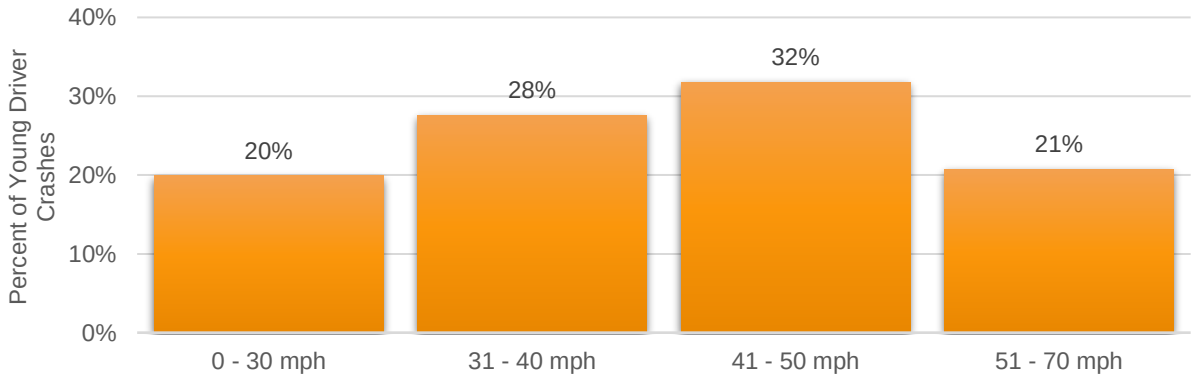

Figure 624: Younger Driver Crashes by Speed Limit

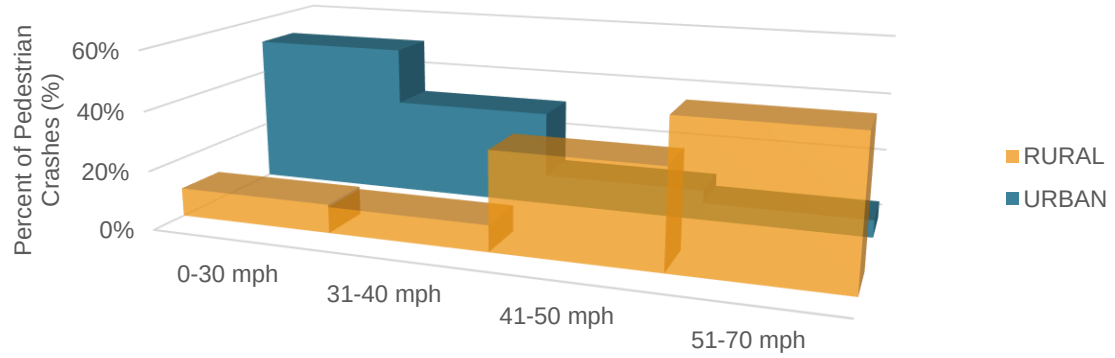

Figure 635: Rural-Urban Pedestrian Crashes by Roadway Speed Limit

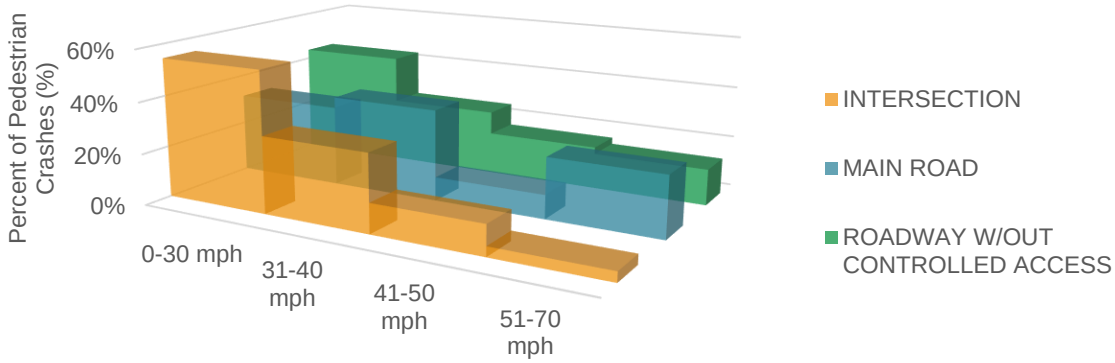

Figure 646: Surrounding Development Pedestrian Crashes by Roadway Speed Limit

IV. MODELING FACTORS AFFECTING VRU CRASHES

IV.1 Modifying the Vulnerable Road User Dataset for Modelling

Section III.1 details how the VRU dataset was developed from crash data from 2013-2015 in the state of Alabama for each of five vulnerable user groups: pedestrians, bicyclists, motorcyclists, older drivers, and younger drivers. To prepare this dataset for modeling, the only remaining step was to create dummy variables for each of the categorical variables. For instance, crash severity was split into five different variables, one for each possible severity outcome – fatal, incapacitating, etc. Of the final datasets, the pedestrian database contains 1,652 crashes, the bicyclist database contains 565 crashes, the motorcyclist database contains 3,457 crashes, the older driver database contains 56,299 crashes, and the younger driver database contains 56,015 crashes.

IV.2 Developing the Ordered Probit Model

An ordered probit model was utilized to estimate the effect that roadway environment characteristics, user behavioral choices, and various other crash-related factors had on VRU safety. An ordered probit model is an ordinal choice model, which means that the response variable being estimated has a natural order. As the goal of this model is to obtain a measurable impact on the safety of VRUs, the severity of each crash on the standard KABCO scale was chosen to serve as the dependent response variable. The KABCO crash severity scale assigns one of five severity levels to each crash. From least to most severe, the five severity levels are:

O = Property Damage Only (PDO), C = Possible Injury, B = Non-Incapacitating Injury, D = Incapacitating Injury, and A = Fatal Injury. An ordinal model was chosen because these five categories are related by a natural order (in this case, of increasing crash severity). An ordered probit model estimates threshold parameters to generate probabilities that the data will match each discrete outcome. Using maximum likelihood estimation, the ordered probit model determines the outcome for each case. The underlying relationship is characterized in Equation 1.

$$y^* = x\beta + \epsilon \qquad \text{(Equation 1)}$$

where y^* is the exact but unobserved dependent variable, x is the vector of independent variables, β is the vector of regression coefficients, and ϵ is the vector of error terms. However, y^* is assumed to be a latent variable and cannot be directly observed. Instead, the categories of the response are observed as in Equation 2.

$$y = \begin{cases} 0 & if\ y^* \leq 0 \\ 1 & if\ 0 < y^* \leq \gamma_1 \\ 2 & if\ \gamma_1 < y^* \leq \gamma_2 \\ \vdots & \\ N & if\ \gamma_{N-1} < y^* \end{cases} \qquad \text{(Equation 2)}$$

where y represents the categories of observations, γ represents the cutoff points or threshold parameters, and N is the number of discrete categories or outcomes. The ordered probit model uses the observations on y to fit the parameter vector β. In this case, there are five discrete categories (one for each crash severity level) and four threshold cutoffs. For each crash, the ordered probit model generates a probability that the event will result in each of the crash severity levels. The crash is then assigned the severity level that it has the highest probability of a match.

The initial set of independent variables which were considered for inclusion in the ordered probit model are displayed below in Table 1. A separate model for each of the five primary VRU groups present in Alabama: Pedestrians, Bicyclists, Motorcyclists, Younger Drivers, and Older Drivers. Each model was developed from the set of independent variables in Table 1.

The crash severity level is the dependent variable in each of the models. Each crash or case has a known severity level that was assigned by a reporting officer at the time of the incident. The models attempt to use the roadway, behavioral, and temporal characteristics listed in Table 1 as input variables in Equation 1 to correctly predict the recorded crash severity level for each crash. Equation 1 can also be used to predict the severity of hypothetical or future crashes by using new values for the predictors. The models use Maximum Likelihood Estimation (MLE) to determine threshold cutoff points ($\gamma_1, \gamma_2, \ldots, \gamma_n$) for the independent variable (i.e., the model assigns relative values for when the severity of a crash changes from O to C, from C to B, and so on, on the KABCO scale) and to determine coefficients for each of the predictor variables. MLE is a method of estimating the model parameters to find parameter values which maximize the likelihood of accurately predicting the known observations, given the parameters.

The relative accuracy of these models was measured using chi-square values. The chi-square is a measurement of goodness of fit. It is a dimensionless quantity produced by the Chi-Square Test, which tests the null hypothesis that the variables are independent. The chi-square value is a measurement of well the observed distribution of data fits with the distribution that would be expected if the variables are independent.

Table 1: Crash-Related Characteristics Considered for Modeling

Roadway Characteristics	**Temporal Characteristics**	**Behavioral Characteristics**	
Roadway Facility…	*Season…*	*Responsible Driver Age Range…*	*Associated Resp. Party Maneuver…*
…Main Road	…Spring	…Younger Driver	…Forward Movement
…Intersection	…Summer	…Adult Driver	…Turning Left
…Roadway w/o Controlled Access	…Fall	…Older Driver	…Turning Right
	…Winter	…Non-Motorized VRU	…Making U-Turn
Roadway Speed Limit…	*Time of Week…*		…Overtaking/ Changing Lanes
…30 mph or Less	…Weekday	*Party Responsible for Crash…*	
…31 - 40 mph	…Weekend	…Personal Vehicle	…Entering or Leaving Main Road
…41 - 50 mph	*Time of Day…*	…Bicycle	…Backing Up
…51 - 70 mph	…12 AM to 1 AM	…Motorcycle	…Slowing/ Stopping
	⋮	…Pedestrian	…Stopped or Parked
Surrounding Development…	…12 PM to 1 PM		*Associated Resp. VRU Party Man…*
…Open Space	…1 PM to 2 PM	*Manner of Crash…*	…Entering or Cross--ing Roadway
…Residential	⋮	…Non-Collision	…Walking/ Running/ Cycling
…Shopping or Business	…11 PM to 12 PM	…Single Vehicle Crash w/ Object	…Working
…Manufacturing or Industrial	*Weather…*	…Head-On Collision	…Approaching or Leaving Vehicle
…School or Playground	…Clear	…Angle/ Side Impact	
	…Cloudy	…Rear End Collision	
Lighting Conditions…	…Rain		
…Daylight	…Fog/ Mist	*Primary Contributing Factor…*	
…Dawn		…Impaired User	
…Dusk		…Avoidance Behavior	
…Dark and Roadway Lit		…User Error	
…Dark and Roadway Not Lit		…Aggressive Driving	

IV.3 Estimation Results

An ordered probit model was conducted on each of the ten vulnerable user crash datasets from CARE for 2013-2015 in Alabama. The goal of these models was to determine how various characteristics affected the severity of crashes with vulnerable users. Five crash severity levels were considered, with the lowest level of crash resulting in Property Damage Only, followed by Possible Injury, Non-Incapacitating Injury, Incapacitating Injury, and finally Fatal Injury at the highest level of crash severity. The same process was used to run a model for each of the five vulnerable user types for which there was sufficient crash data: pedestrians, bicyclists, motorcyclists, younger drivers, and older drivers. Separate models were considered for crashes occurring in urban and rural communities, resulting in ten datasets, each with a distinct but related model. The results are presented in Table 2 and Table 3 on the following pages, with Table 2 combining the model results from the five urban VRU models and Table 3 combining the results from the five rural VRU models.

In Tables 2 and 3, the Severity Thresholds represent the cutoff points between crash severity levels. Figure 65 below shows how these thresholds are used by the model with Equation 2 to generate categories for each level of crash severity.

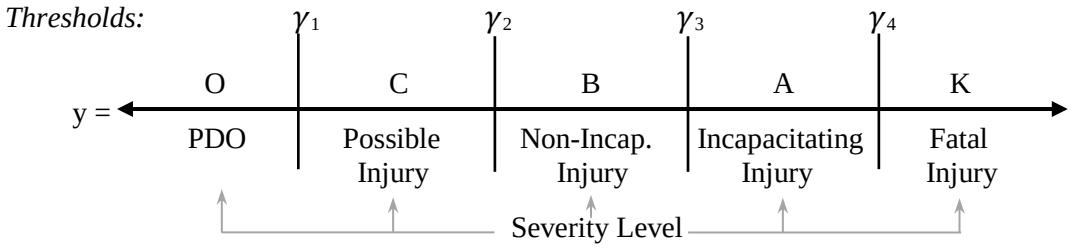

Figure 65: Severity Thresholds

Each characteristic provided in Tables 2 and 3 represents an independent variable x_i in Equation 1. The coefficients of those characteristics represent the β coefficient for that independent variable x_i. Variables which were insignificant at a 95% p-value confidence level (α=0.05) in a given model were removed from that model. These are noted in Tables 2 and 3 by a dashed line (-), and are given a coefficient of 0 when input in the model. This occurs in variables that do not significantly affect the severity of a crash compared to a base. For instance, in Table 2, Intersection and Roadway w/o Controlled Access have a dashed line for urban pedestrian crashes. These are Roadway Facility characteristics, with Main Road serving as the base to compare the other facility types to. This means that according to the model, if all other factors are held equal, crashes involving pedestrians in urban communities in Alabama at intersections are likely to be neither more nor less severe than those occurring on main roads. The same can be read from the dash for Roadway w/o Controlled Access. In other words, the results of the model indicate that urban pedestrian crash severity in Alabama is independent of the roadway facility type. Instead, other factors in the model control the severity level.

Characteristics which tended to increase the crash severity level or produce more severely injurious crashes were assigned a positive value. Characteristics which tended to decrease the crash severity level were assigned a negative value. One way to think of this is to imagine a characteristic which produced more severe crashes as pushing the y-value on the number line in Figure 65 further to the right, increasing the injury level of the crash. A characteristic which produced less severe crashes would push the y-value on the number line further to the left, decreasing the injury level of the crash. The absolute value of the coefficient provides a relative measure of how much influence that factor has on determining the severity of the crash. To use Pedestrians in Table 2 as an example again, high roadway speed limits of 51-70 mph have a

positive coefficient, indicating that crashes which occur on roadways with higher speeds tend to result in more severe injuries. Shopping or Business Developments have a negative coefficient, indicating that crashes with pedestrians which occurred in these districts were less severe than those which occurred in open space developments.

For each estimation, the chi squared values show that the models presented are statistically different than a constants-only specification, at any level of significance. Following the tables, the remainder of this section provides an in-depth analysis and discussion of the results of the VRU Crash Severity models.

Table 2: Factors Affecting VRU Crashes in Urban Communities

	PEDESTRIANS		BICYCLISTS		MOTORCYCLISTS		YOUNGER DRIVERS		OLDER DRIVERS	
	Coeff.	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Severity Thresholds										
... γ1	-3.34	-18.550	-1.12	-7.537	-0.20	-1.174	1.74	21.519	1.73	34.680
... γ2	-1.09	-8.926	-0.15	-1.133	0.30	1.721	2.68	32.732	2.61	50.154
... γ3	0.49	4.143	1.76	10.858	1.81	10.256	3.97	46.741	3.73	66.536
... γ4	2.59	17.486	4.52	11.827	4.20	19.882	6.74	48.114	6.11	66.413
Roadway Characteristics										
Roadway Facility (Base: Main Road)										
... Intersection	-	-	-	-	-	-	0.26	6.366	0.36	12.857
... Roadway w/o Controlled Access	-	-	-	-	0.26	3.146	0.13	3.667	-	-
Roadway Speed Limit (Base: 30mph or Less)										
... 31 - 40 mph	-	-	-	-	-	-	0.27	7.556	0.07	2.000
... 41 - 50 mph	-	-	-	-	0.24	2.554	0.44	12.306	0.31	8.722
... 51- 70 mph	0.89	2.706	-	-	0.59	4.861	0.58	13.395	0.46	9.766
Surrounding Development (Base: Open Space)										
... Residential	-	-	0.37	2.132	-	-	-	-	-0.30	-6.340
... Shopping or Business	-0.22	-2.037	-	-	-0.27	-3.214	-0.16	-5.821	-0.23	-5.429
... Manufacturing or Industrial	-	-	-	-	-	-	-	-	-0.24	-2.531
... School or Playground	-0.58	-2.560	-	-	-	-	-0.30	-3.934	-0.50	-4.464
Lighting Conditions (Base: Daylight)										
... Dawn	-	-	3.24	2.291	-	-	-	-	-	-
... Dusk	-	-	-	-	-	-	-	-	-	-
... Dark and Roadway Lit	0.47	3.941	-	-	-	-	0.08	2.394	-	-
... Dark and Roadway Not Lit	0.62	3.735	1.16	3.285	-	-	0.22	4.075	-	-
Behavioral Characteristics										
Responsible for Crash (Base: Personal Vehicle)										
... Bicycle	-	-	-	-	-	-	-	-	2.69	21.726
... Motorcycle	-	-	-	-	-	-	2.54	16.953	1.68	8.546
... Pedestrian	0.69	5.807	-	-	-	-	-	-	3.58	39.744
Manner of Crash (Base: Non-Collision)										
... Single Vehicle Crash with Object	-	-	-	-	0.57	4.021	0.51	7.155	0.66	14.932
... Head-On Collision	-	-	-	-	1.12	3.535	1.11	11.716	0.85	12.171
... Angle/Side Impact	-0.45	-3.055	-	-	0.45	3.141	0.36	5.200	-	-
... Rear End Collision	-	-	-	-	-0.57	-3.712	-0.34	-4.870	-	-
Primary Contributing Factor (Base: Impaired User)										
... Avoidance Behavior	-0.41	-2.866	-	-	-0.40	-3.624	-0.43	-8.580	-	-
... User Error	-0.39	-3.152	-	-	-	-	-0.08	-2.655	0.13	4.226
... Aggressive Driving	-	-	-	-	-	-	-	-	0.33	8.865
Associated Resp. Party Maneuver (Base: Forward Movement)										
... Turning Left	-	-	-	-	-	-	-	-	0.22	5.400
... Turning Right	-	-	-	-	-0.61	-3.382	-0.74	-11.136	-0.70	-9.681
... Making U-Turn	-	-	-	-	-	-	-0.39	-2.175	-	-
... Overtaking/ Changing Lanes	-	-	-	-	-0.35	-2.071	-1.14	-15.861	-1.13	-15.311
... Entering or Leaving Main Road	-	-	-	-	-	-	-0.36	-5.070	-	-
... Backing Up	-	-	-	-	-2.78	-4.698	-2.32	-13.153	-1.65	-14.759
... Slowing/ Stopping	-	-	-	-	-	-	-0.33	-6.385	-0.34	-4.608
... Stopped or Parked	-	-	-	-	-1.39	-2.507	-0.70	-3.697	-0.47	-3.219
Temporal Characteristics										
Season (Base: Winter)										
...Spring	-	-	-	-	0.50	4.057	0.16	4.588	0.13	3.912
...Summer	-	-	-	-	0.50	4.000	0.15	4.162	0.13	3.622
...Fall	-	-	0.45	2.297	0.46	3.654	0.10	2.722	0.11	3.200
Timing (Base: Weekday)										
...Weekend	-	-	-	-	-	-	0.08	2.633	-	-
Sample Size (n)	1277		456		2137		40830		44294	
Log-Likelihood	-431.552		-269.136		-1387.677		-12325.277		-7976.727	
Chi-Square	112.224		82.167		267.599		2532.743		4146.889	

Table 3: Factors Affecting VRU Crashes in Rural/ Suburban Communities

	PEDESTRIANS		BICYCLISTS		MOTORCYCLISTS		YOUNGER DRIVERS		OLDER DRIVERS	
	Coeff.	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**	**Coeff.**	**t-stat**
Severity Thresholds										
... γ1	-3.16	-10.035	-0.55	-1.387	-0.45	-2.103	1.91	14.022	2.31	17.254
... γ2	-2.34	-9.019	-0.37	-0.959	-0.22	-1.024	2.23	16.382	2.60	19.259
... γ3	-0.60	-2.922	1.12	2.765	1.04	4.847	3.26	23.609	3.49	25.438
... γ4	1.02	4.802	4.03	6.167	3.73	15.048	5.91	36.475	5.40	34.583
Roadway Characteristics										
Roadway Facility (Base: Main Road)										
... Intersection	-	-	-	-	-	-	0.77	8.895	0.76	8.085
... Roadway w/o Controlled Access	-	-	-	-	-	-	0.61	8.686	0.39	5.026
Roadway Speed Limit (Base: 30mph or Less)										
... 31 - 40 mph	-	-	-	-	0.47	1.982	0.24	2.756	0.37	3.417
... 41 - 50 mph	-	-	-	-	0.57	2.642	0.35	4.268	0.62	6.564
... 51- 70 mph	-	-	-	-	0.72	3.314	0.43	5.107	0.71	7.685
Surrounding Development (Base: Open Space)										
... Residential	-0.72	-2.454	-	-	-	-	-0.16	-2.438	-	-
... Shopping or Business	-	-	3.59	2.325	-	-	-0.28	-3.135	-	-
... Manufacturing or Industrial	-	-	-	-	-	-	-	-	-	-
... School or Playground	-	-	-	-	-	-	-	-	-	-
Lighting Conditions (Base: Daylight)										
... Dawn	-	-	-	-	-	-	-	-	-1.01	-3.445
... Dusk	-	-	-	-	0.91	2.580	-	-	-	-
... Dark and Roadway Lit	-	-	-	-	-	-	-	-	-0.43	-3.242
... Dark and Roadway Not Lit	0.70	3.101	-	-	0.47	3.656	0.10	2.476	-0.48	-8.000
Behavioral Characteristics										
Responsible for Crash (Base: Personal Vehicle)										
... Bicycle	-	-	-	-	-	-	-	-	3.04	10.040
... Motorcycle	-	-	-	-	-	-	1.97	9.816	1.74	8.571
... Pedestrian	-	-	-	-	-	-	-	-	3.84	21.204
Manner of Crash (Base: Non-Collision)										
... Single Vehicle Crash with Object	-	-	-	-	0.36	3.148	0.56	6.065	0.59	5.673
... Head-On Collision	-	-	-	-	1.46	3.649	1.49	9.280	1.39	7.685
... Angle/Side Impact	-1.37	-4.490	-	-	-	-	0.39	3.748	0.30	2.868
... Rear End Collision	-1.22	-2.392	1.21	2.345	-	-	-0.37	-3.703	0.47	4.052
Primary Contributing Factor (Base: Impaired User)										
... Avoidance Behavior	-0.62	-2.202	1.55	2.464	-0.64	-4.893	-0.80	-13.115	-0.29	-3.585
... User Error	-	-	0.99	2.027	-	-	-0.19	-3.081	-	-
... Aggressive Driving	-	-	-	-	-	-	-0.11	-2.340	-0.16	-2.329
Associated Resp. Party Maneuver (Base: Forward Movement)										
... Turning Left	-	-	-	-	-	-	-	-	-	-
... Turning Right	-	-	-	-	-	-	-0.55	-3.833	-0.85	-4.399
... Making U-Turn	-	-	-	-	-	-	-	-	-	-
... Overtaking/ Changing Lanes	-	-	-	-	-	-	-0.36	-3.078	-1.03	-7.544
... Entering or Leaving Main Road	-	-	-	-	-	-	-0.69	-4.235	-	-
... Backing Up	-2.14	-2.556	-	-	-	-	-1.48	-4.771	-2.08	-5.326
... Slowing/ Stopping	-	-	-	-	-1.47	-3.967	-0.72	-5.698	-0.69	-3.505
... Stopped or Parked	2.12	2.944	-	-	-	-	-	-	-	-
Temporal Characteristics										
Season (Base: Winter)										
...Spring	-	-	-	-	-	-	0.13	2.510	-	-
...Summer	-	-	-	-	-	-	0.15	2.849	-	-
...Fall	-	-	-	-	-	-	0.17	3.269	-	-
Timing (Base: Weekday)										
...Weekend	-	-	-	-	-	-	0.09	2.350	-	-
Sample Size (n)	275		77		1231		13971		9497	
Log-Likelihood	-97.204		-28.421		-269.136		-5787.437		-1896.134	
Chi-Square	50.208		18.134		82.167		1083.852		1017.874	

Urban Communities Model Estimation Results

In general, the urban models had more statistically significant variables remain than the rural models. As Table 2 shows, few characteristics are significant in determining the crash severity for pedestrians, and even fewer are available to make that prediction for bicyclists. This suggests that it is more difficult to determine the crash severity for these VRUs, especially bicyclists. The chi-square values for these VRUs are lower than those for motorcyclists and younger or older drivers as well. However, these models were also developed from substantially smaller datasets than the other VRUs, with a sample size of 456 crashes and 1277 crashes involving bicyclists and pedestrians in urban areas, respectively. Younger and older drivers by far had the largest sample sizes and the best fit. Crashes involving these VRUs are more common or at least more commonly reviewed and the resulting larger datasets could possibly be contributing to the volume of characteristics which remained significant in the older and younger drivers' models.

The following section will discuss the trends present in Table 2 for all VRU groups as well as how these characteristics impact individual VRUs. For each category of characteristics, such as *Roadway Facility*, the crash severity is compared to a base, such as *Main Road*.

Urban Roadway Characteristics

In urban areas, crash severity for bicyclists and pedestrians is not significantly impacted by the roadway facility type. For the other vulnerable user groups, though, crashes occurring at intersections or on roadways without controlled access tend to be more severe than those occurring on main roads. Motorcyclists have particularly severe crashes on roadways without controlled access, while older drivers have more severe crashes at intersections. Younger drivers have more severe crashes on both facility types compared to the main road, with intersections

being the more dangerous of the two. Roads without controlled access often present many driveways that serve as conflict points, so motorcyclists who are more difficult to spot than a motor vehicle may be in particular danger on these roads. Younger drivers who have less experience with these locations are more likely to make a mistake. The complications and abundance of sensory information required to process at an intersection may be more difficult for younger drivers with less experience and older drivers with slower reaction times to maneuver safely.

In general, as the speed limit on the roadway increases, so too does the chance for more injurious crashes involving vulnerable users. Speed limits higher than 50 mph are especially dangerous for VRUs. Pedestrian crash severity is only impacted by this highest speed category, while for bicyclists, speed is not a significant factor. This does not indicate that cyclists are not negatively impacted by higher speed limits during a crash, but rather, even at low speeds, any crash involving a bicyclist can result in severe injuries.

For most crashes with a vulnerable user in urban areas, crashes tend to be more severe on roadways in open space compared to other surrounding developments. The only exception to this is bicyclists. Crashes with cyclists occurring in residential zones are typically more severe than other bicycle crashes, while crash severity is not significantly impacted by other zones. One possible reason for this could be that most bicycle travel in Alabama primarily occurs in residential areas, especially by younger users. Similarly, motorcyclists have less severe crashes in shopping or business districts but other surrounding development does not impact severity. Pedestrians are also safer (in terms of crash risk severity) in shopping districts than in residential, manufacturing, or open space zones. Lower speeds, better facilities, and increased driver awareness are all factors in these business districts that likely contribute to the decreased crash

severity for pedestrians and motorcyclists. Crashes involving pedestrians and older or younger drivers are the least severe near schools or playgrounds, followed by shopping or business districts. Users traveling in these areas often drive more slowly and with more caution due to the expectation of increased vulnerable user traffic. More so than other VRUs, older drivers tend to have more severe crashes in open space areas than in any other surrounding development. They have a relatively lower crash risk in neighborhoods, especially compared to other groups.

Lighting conditions during the crash are only significant in specific circumstances. Crashes involving pedestrians, bicyclists, and younger drivers are affected by lighting. Lighting is an important issue for the latter group for whom poor lighting conditions can be a challenge due to their inexperience. For bikes and pedestrians, proper lighting is vital for their safety, especially in regards to being seen by motor users. Crashes for these users are typically the most severe on dark roads with inadequate lighting. Additionally, crashes also tend to be more severe on dark roads which do have adequate lighting for pedestrians and younger drivers. For pedestrians and cyclists, this increase in severity can likely be attributed to these VRUs being much more difficult to spot at night. For younger drivers, this can again likely be attributed to a lack of experience driving in the dark. Interestingly, crashes with cyclists at dawn are more severe than during other times of the day, indicating that they may be at their most vulnerable during their morning commute.

Urban Behavioral Characteristics

When considering how the responsible party for the crash affects the crash severity, the causal unit in most crashes involving vulnerable users is insignificant compared to motor vehicles, the base. For VRU types other than older or younger drivers, there are typically only two possible

parties responsible for the crash: a motor vehicle or the respective VRU. Therefore, the severity of bicycle and motorcycle crashes is not dependent on whether the responsible party was the VRU or a motor vehicle. However, pedestrian crashes are more severe when the pedestrian is the responsible party. These crashes are likely the result of pedestrians crossing the road without the proper right-of-way or not at a crosswalk. Such unexpected action leaves little time for a motor vehicle to respond and slow down. Younger drivers have the most severe crashes when a motorcycle is the responsible party, while older drivers have more severe crashes when the responsible party is any vulnerable user type, but especially if that party is a pedestrian. Thus, in urban areas, vulnerable users are often at the highest risk due to their own actions, rather than those of drivers.

When considering the manner of the crash, most crashes for VRUs are more severe than the base crash type of non-collision. Pedestrians and cyclists are the largest exceptions once again, as the crash type does not significantly impact cyclist crash severity and only one category is significant for pedestrians; angle/side impact crashes with pedestrians are less severe than other crash types. This is likely because this type of crash involves the least direct impact with a pedestrian. For the other vulnerable users, head-on collisions are predictably the most dangerous crash type, followed by a single vehicle crash. Rear-end collisions for the other VRU types result in less injurious crashes. These types of crashes often occur at slower speeds and allow for more protection for most users involved in the crash.

For primary contributing factor which resulted in the crash, the base factor was user impairment – i.e., DUI, distracted driving, etc. Crash severity is again indeterminate for bicycles in urban settings in this category of characteristics. For all but older drivers, crashes as a result of avoidance behaviors are the least severe, with user error also resulting in less severe crashes. For

these VRUs, crashes are more dangerous when the causal unit is impaired by distractions such as using some mobile cellular device or other electronics while driving, or while under the influence of drugs or alcohol. Older drivers exhibit different behaviors; aggressive driving is responsible for their most severe crashes and unlike other VRU types, user error results in more severe crashes when older drivers are involved. Driving presents new challenges with age and the model suggests that this leads to mistakes with more severe consequences for older drivers.

Because of the way crash statistics are recorded in the CARE database, data in the associated responsible party maneuver category was only recorded if the responsible party was a motor vehicle. While these maneuvers were insignificant in determining crash severity for bikes and pedestrians, they were consistent across the remaining three VRU groups. Compared to a base maneuver of forward movement (essentially straight), most other maneuvers made by the causal vehicle resulted in less severe crashes. Crashes because of a vehicle backing up were the least severe overall, followed by crashes from a stopped or parked vehicle in motorcycle crashes and crashes resulting from overtaking or changing lanes for older or younger drivers. For each of the three groups, right turn crashes were also typically less severe. These crashes are typically made at lower speeds and have fewer conflicts than left turns. The results of the model indicate that VRUs are at as least as much risk when making a left turn prior to a crash as when driving straight. However, for older drivers, left turns result in the most severe crashes overall. This indicates that vulnerable users are especially at risk at intersections from left turns and that this challenge is greatest for older users. It may be that these crashes are only significant for older drivers because they may incorrectly predict the speed of oncoming traffic or fail to notice the vulnerable user because of the “busy-ness” of intersections.

Urban Temporal Characteristics

Vulnerable users in urban communities appear to be more likely to have more severe crashes during the spring, summer, and fall than the winter, with a slight emphasis on crashes in the spring and summer over the fall. Crash severity for pedestrians is not significantly impacted by the season, while crashes with bicyclists are only significantly more dangerous during the fall. This could be due to school returning to session during the fall, so more students in both primary education and at colleges are likely to be using their bikes to commute.

Whether the crash occurred on a weekday or on a weekend typically does not contribute to the severity of the crash. The only exception is younger drivers, who are slightly more likely to have a more severe crash on weekends than during the week. Young drivers are more likely to be driving for social purposes to see their peers on weekends. If these young peers are in the car, they may be a distraction from driving that results in more severe crashes.

Rural/Suburban Communities Model Estimation Results

In general, the rural models for crashes involving VRUs had lower log-likelihood and chi-square values than their urban counterparts, indicating that they did not fit the data quite as well. Additionally, the sample size for each VRU is much smaller in the rural dataset than in the urban dataset, as the bulk of crashes involving vulnerable users occurred in urban areas. This is especially true of the bicyclist and pedestrian datasets, which have a mere 77 and 275 entries respectively. The reader should keep in mind that the smaller sample size impacts the model prediction by making it more difficult to identify general trends. In general, there are fewer significant characteristics in the rural models than in the urban models. Many characteristics which were significant in determining crash severity for vulnerable users in urban communities

are again significant in rural communities. However, there are also many cases in which characteristics which were insignificant in the urban models which are significant in the rural models, and vice-versa. As with the urban models, the older and younger drivers have the highest sample size, best fit, and the most volume of significant predictors. The following section will discuss the trends present in Table 4.3.2 for all VRU groups, how those trends vary for individual VRUs, and how those trends differ from those in Table 1, discussed in the previous section.

Rural/Suburban Roadway Characteristics

In rural communities, the only VRUs which vary significantly across roadway facility type as compared to the base main road are younger and older drivers. As with the urban models, crash severity tends to increase the most for these VRUs at intersections, followed by roadways without controlled access. For the other VRU types, crash severity is determined by variables other than the facility type.

Speed limit has the same general effect in the rural model as it did in the urban one: as speed increases, so too does the severity of crashes with VRUs. However, bicyclist and pedestrian crashes in rural areas are not significantly impacted by speed. This indicates that in rural communities, a crash at any speed could result in serious injury for these VRUs.

The surrounding development near the crash site is much less important for crashes in rural communities than for urban communities, with only a few developments altering the crash severity for select VRUs. The only trend that exists here is that because these crashes are happening in rural areas, a large portion of them are taken up by the base development type:

open space. For pedestrians, crashes occurring in residential areas are less severe, likely due to lower speeds in these areas and users being more used to seeing cyclists around neighborhoods. Younger drivers also make less severe crashes in residential areas and slightly less severe crashes in shopping or business areas compared to the base. Bicyclists, however, tend to have much more injurious and serious crashes in shopping or business districts. These districts often have high volumes of traffic, are important destination sites for all modes of travel, and typically have more conflict points than other developments.

Lighting has a similar effect on crash severity for VRUs in rural areas that it did in urban areas, though the interactions between lighting and older drivers are unique. Bicyclist crash severity in rural areas is not significantly impacted by the lighting, but for pedestrians, motorcyclists, and younger drivers, more severe crashes tend to occur on dark roadways without adequate lighting. This is likely due to decreased visibility on these roads. For reasons unknown to the author, motorcyclists are most likely to have injurious crashes at dusk. As for older drivers, compared to the base of crashes during the daytime, crashes at any other time of the day are less likely to be severe. This indicates that older drivers in rural areas probably drive far more often during the normal daytime hours rather than at night; it probably does not indicate that older drivers are less likely to have a serious crash if they drive in the dark on rural roads.

Rural/ Suburban Behavioral Characteristics

When considering how the responsible party for the crash effects the crash severity, the rural models behave very similarly to the urban models. Thus, the causal unit in most crashes involving vulnerable users is insignificant compared to motor vehicles, the base. Only younger and older drivers have significant cases where the causal unit is other than a motor vehicle, and

they follow the same exact trends as their urban counterparts, with crashes caused by pedestrians being the most severe for older drivers and crashes caused by motorcycles being the most severe for younger drivers.

The manner of the crash is the most determinant predictor group for determining the severity of a crash involving VRUs in rural or suburban developments. The trends here differ somewhat from their urban analogues. Compared to a base crash type of non-collision, most other crash types are more severe for VRUs. Head-on collisions are again the most severe crash type, followed for most VRUs by a single vehicle crash. Angle/side impact crashes are also more severe than the base for younger and older drivers. However, while rear-end collisions are less severe for younger drivers, they are slightly more severe than angle crashes for older drivers. This may indicate that older drivers are more likely to hit another VRU from behind than other drivers. Bicyclists are also vulnerable to severe crashes in rural developments because of a rear end collision. Pedestrians have less severe crashes in rural areas when the crash is an angle crash or rear end collision, as these crashes with pedestrians are typically less of a direct impact.

The primary contributing factor has very different results in the rural models compared to the urban models. In the urban model, bicyclist crash severity was not impacted by this category of predictors and older drivers exhibited different behavior from the other VRUs by having crashes which were more severe than those due to the base contributing factor, impaired user. In the rural model, however, older drivers follow the same trends as the other VRUs (excluding bicyclists), as all contributing factors result in less severe crashes than the base. The least severe crashes result from avoidance behaviors again, with user error and aggressive driving also resulting in somewhat less severe crashes. This indicates that crashes because of driver impairment (e.g., using electronic device, DUI) typically result in the most severe injuries for

most VRUs. However, bicyclists break this trend. Crashes because of avoidance behaviors are the most severe for bicyclists. These crashes likely occur when a motor vehicle does not see a bicyclist before performing a maneuver that conflicts with them, or the bicyclist attempts to swerve to avoid a hazard and ends up colliding with a vehicle. User error also contributes significantly to bicycle crash severity in rural areas. These factors indicate that the most dangerous crashes for cyclists in rural areas occur simply due to user mistakes and a lack of understanding of how to share the road.

For the associated responsible party movement, similar trends to those which were present for older and younger drivers in urban environments apply in rural environments as well, with each possible category resulting in less severe crashes than the base of forward movement. Motorcyclists, however, obtain much more limited results from the rural model than the urban one. Only one category is significant for them, as there was not enough variety in movement options to determine how the others differed from the base. Once again, backing up, slowing/stopping, overtaking/changing lanes, and making right turns result in the least severe crashes. However, the model indicates that while most variables are not significantly different from the base in this category, crashes that occurred when the responsible party was stopped or parked are more severe than any other movement. This may indicate that the pedestrian was hit while standing in the road. This result is the most confusing and difficult to interpret out of all the models.

Rural/ Suburban Temporal Characteristics

In rural developments, seasons only significantly impact the crash severity of younger drivers. As with the urban model, crashes occurring in seasons other than winter tend to be slightly more severe for these VRUs. This may be due to decreased pedestrian traffic during the winter.

As with urban developments, the only group impacted by whether a crash occurs on a weekday or a weekend are again younger drivers. As with the urban model, crashes on weekends tend to be more severe.

IV.4 Summary Takeaways

General Takeaways

- The urban models fit better than their suburban counterparts and provided a higher quantity of significant response variables. It is more difficult to accurately predict crash severity for vulnerable road users in rural areas than urban areas.
- Determining specific factors and behaviors that result in a greater risk of injurious crashes is more difficult for pedestrians and bicyclists than other VRUs. This is especially true for bicyclists.
- The younger and older driver crash datasets resulted in the most determinate models with more predictors than other VRU groups. Younger and older driver crashes were also far more numerous than any other VRU group.
- Despite often being treated as a group, pedestrians and bicyclists react differently to many risk factors.

- Younger and older drivers often behave like a group, with some key differences appearing in user behaviors.
- As motorized VRUs, motorcyclists, younger drivers, and older drivers also often share similar behaviors according to the models.
- Intersections, left turns, high speeds, poor lighting, head-on collisions, and VRU responsibility for causing the incident consistently produce the most severe crashes for VRUs, regardless of type.
- Surrounding development, lighting, primary contributing factor, and associated responsible party maneuver had the most significant differences when comparing urban and rural crashes.

Roadway Characteristics

  - Bicyclist and pedestrian crash severity is not significantly impacted by roadway facility type.
  - Younger and older drivers are more likely to have severe crashes at intersections than anywhere else on the road. They also have more severe crashes on roadways without controlled access than on main roads.
  - For motorized VRUs, roads with higher speed limits pose increasingly greater risk of deadly crash.
  - For bicyclists, roadway speed is not a determinant of crash severity. They are at risk of severe crashes regardless of the travel speed prior to the crash.
  - In general, VRUs are at greater risk of severe crashes when traveling at night on roads with inadequate lighting.

Behavioral Characteristics

- Younger drivers seem to have trouble interacting with motorcycles. They tend to have more severe crashes when the crash involves a motorcycle and the motorcyclist was ruled at fault for the incident.
- When an older driver is involved in a crash, the severity of that crash tends to be greater when a non-motorized vulnerable road user is the responsible party. This risk is highest when the responsible party is a pedestrian.
- For crashes involving bicyclist(s) and motorcycle(s), crash severity is not dependent on the responsible party.
- Regarding the manner of the crash, head-on crashes tend to result in the most severe injuries for motorized VRUs. Single-vehicle and angle/side-impact collisions are also typically more severe than non-collisions or rear-end crashes for motorized VRUs, though there are a few exceptions.
- Single-vehicle and head-on crashes do produce statistically significant differences in crash severity from crashes ruled a non-collision for pedestrians. However, angle/sideswipe crashes tend to be the least severe for pedestrians, perhaps because this type of crash involves less of a direct impact with the pedestrian than other crash types.
- For all VRUs except bicyclists, cases where the primary contributing factor to the crash were the result of user impairment typically resulted in more severe crashes than those where the primary factor was an avoidance behavior, aggressive driving, or user error. Cases of user impairment include DUI and distracted driving.

- For all VRUs except bicyclists, cases where the primary contributing factor to the crash were the result of avoidance behavior typically resulted in less severe crashes than for other causes.
- According to the model, the results for the maneuver made by the responsible party prior to the crash are mostly consistent across motorized VRUs. A vehicle backing up, stopped or parked, overtaking or changing lanes, or turning right tend to result in crashes of a lower severity. Crashes occurring at a left turn or when the user is simply driving straight produce the most severe crashes.
- The maneuvers made in the moments prior to crash have no significant impact on determining the severity of a crash involving a bicyclist.

Temporal Characteristics

- With the exception of younger drivers, the day of the week had no impact on VRU crash severity. Younger drivers are slightly more likely to be in a severe crash on weekends than on weekdays. This could be because younger drivers may be more active travelers on the weekends, especially with their peers, who tend to increase their crash risk as well.

Characteristics Unique to Urban Communities

Roadway Characteristics

- Motorcyclists tend to have more severe crashes on roadways without controlled access than on main roads or at intersections. These types of roadways have more access points, increasing the number of potential conflicts for the VRU to face.

- Pedestrians are especially vulnerable on urban roads with very high speeds (greater than 50 mph), compared to roads with lower speeds. This impact can only be seen in the highest speed categories.
- In general, crashes involving VRUs in urban areas are more likely to be severe in open space areas compared with other surrounding developments (residential, shopping or business, manufacturing or industrial, school or playground).
- Crashes with VRUs in urban areas near school zones or playgrounds tend to result in fewer injuries for pedestrians and older and younger drivers. Lower speeds and greater awareness of VRUs in these areas may contribute to this result.
- Urban shopping/business districts produce some of the least severe crashes for pedestrians and motorcyclists compared to most other surrounding developments. Better facilities and increased awareness of these VRUs by motor users in the area likely help to make travel safer for these users in these busy downtown areas.
- In neighborhoods, older drivers experience a lower crash risk, while bicyclists are at their highest risk of severe injury. For the former, this is likely due to experience and neighborhoods being a less demanding driving environment. For the latter, this result is likely connected to neighborhoods being the most frequently traveled area for bicyclists, especially younger bicyclists.
- Lighting only affects crash severity in urban areas in specific cases, and only significantly impacts pedestrians, bicyclists, and younger drivers. Lighting is a common issue for bikes and peds, who require adequate lighting to be seen by fast-moving motor vehicles. Lighting, or lack thereof, can also be a hazard for younger drivers who have less experience driving at night with limited visibility.

- In urban areas, bikes, peds, and younger drivers are at increased risk of higher crash severity when traveling in the dark. This risk increases when they are traveling in the dark on a roadway without adequate lighting. Strangely, bicyclists are at the highest risk of a severe crash when traveling at dawn, indicating that these users may be at their highest risk of crash when traveling during morning rush hour.

Behavioral Characteristics

- Behavioral characteristics did not significantly impact crash severity for bicyclists in urban areas.
- In urban developments, pedestrians tend to have more severe crashes when they are at fault for the incident.
- Rear-end collisions produced different results in urban and rural areas. In urban areas, rear-end collisions resulted in less severe crashes for motorcyclists and younger drivers.
- In urban areas, pedestrians and younger drivers tended to have less severe crashes as a result of user error than when the crash had other causes such as user impairment.
- For older drivers, however, user error tended to result in some of the more severe crashes and aggressive driving maneuvers (such as failing to properly yield, overtaking, etc.) resulted in the most severe crashes compared to user impairment and avoidance behaviors.
- While left turns and driving straight produce the most severe crashes for motorized VRUs, other maneuvers are equally challenging to older drivers

and motorcyclists in urbanized areas. These include entering or leaving a main road and making a U-turn.

Temporal Characteristics

- Pedestrian crash severity is unaffected by season.
- Bicyclist crashes tend to be the most severe in the fall.
- Motorized VRUs have more severe crashes in other seasons compared to winter.

Characteristics Unique to Rural/Suburban Communities

Roadway Characteristics

- Motorcyclist crash severity is independent of roadway facility type in rural areas.
- Speed is not a statistically significant determinant of pedestrian crash severity in rural areas.
- The most common type of surrounding development on rural roads are open space areas. Crash severity only changes compared to open space in limited cases.
- In rural areas, pedestrians and younger drivers have much less severe crashes in residential zones compared to other surrounding developments.
- In rural areas, bicyclists have their most severe crashes in shopping or business areas. Alabama road users in rural areas likely do not expect to see a bicyclist on the road and may not be actively looking for them. As such, bicyclist crash risk is increased in these higher-trafficked shopping districts.
- In rural areas, younger drivers tend to have less severe crashes in shopping or business districts.

- Bicycle crash severity is not significantly impacted by lighting conditions in rural areas. Pedestrians, motorcyclists, and younger drivers, however, have more severe crashes at night on unlit roads than at any other time of the day. A lack of lighting is even more significant to rural VRU crashes than urban ones.
- Older drivers exhibit different behavior regarding lighting in rural areas; they are at their greatest risk of severe crashes during the regular daylight hours. All other lighting conditions (dawn, dusk, night with or without proper lighting) result in less severe crashes for older drivers. Rather than saying that older drivers are safer to drive at night in rural zones, these results more likely indicate that older drivers in rural areas do most of their traveling during the day, and are thus more likely to be involved in a serious crash during that time.

Behavioral Characteristics

- Regarding the impact of the responsible party, older and younger driver crash severity in rural areas is very similar to the results from urban areas. Unlike in urban areas, however, pedestrian crash severity in rural areas is not affected by who was at fault for the incident.
- Rear-end collisions produced different results in urban and rural areas. In rural areas, rear-end collisions resulted in less severe crashes for pedestrians and younger drivers than other collision types, but more severe crashes for older drivers and bicyclists.
- Regarding the primary contributing factor to causing the crash, rural crashes differ from urban crashes in a few key areas. Aggressive driving tended to result in fewer severe crashes among older and younger drivers. While older driver

crashes resulting from user error tended to be about as severe as those resulting from user impairment, younger driver crashes due to some user error tended to be less severe.

- The primary contributing factor also provided one of the few areas where the model was able to identify distinct traits in rural bicycle crashes. Compared to crashes resulting from user impairment or aggressive driving, crashes resulting from avoidance behaviors and user errors were the most severe for bicyclists.
- Regarding the maneuver made before collision by the party responsible for the crash, pedestrians were at the least risk of severe crash as a result of the responsible party backing up, but were at their highest risk when the responsible party was stopped or parked. This result is difficult to interpret alone.
- Still regarding maneuvers made, unlike in urban areas, motorcyclists in rural areas were only significantly impacted when the responsible party was slowing or stopping, which resulted in less severe crashes than any other maneuvers including driving straight, making left or right turns, etc.

Temporal Characteristics

- As in urban areas, younger drivers tended to have more severe crashes in other seasons compared to winter. However, no other VRU group's crash severity was significantly affected by the season in rural areas.

V. GUIDANCE ON SELECTING VRU COUNTERMEASURES

V.1 State of the Practice for Federal/ State/ City VRU Guidance

To gain a better understanding of the best practices regarding designing for vulnerable road users, Complete Streets and Vulnerable Road User design guides were gathered from as many organizations as the researcher could find. The final list of design guides included resources from 9 states, 28 city transportation authorities and MPOs, and 15 national organizations.

While many cities and states have created Complete Streets plans or implemented policies to focus more resources on vulnerable road users, the extent of these plans and policies can vary widely. Many of these policies are defined in broad strokes, outlining a need or a plan to refocus design efforts to make travel safe, pleasant, and efficient for everyone, with a special focus on the most vulnerable users. Oftentimes, though, concrete plans and any type of specific guidance was missing from these policies. While many agencies across the US have adopted this new style of road design, few have devoted resources to creating a design guide. As such, the list of design sources was lower than originally anticipated.

The quality and range of information and recommendations available varied widely from one design guide to the next. Some guides, such as Boston's Complete Streets design guide, provided extensive design specifications along with design drawings, detailed options, and advice on when certain countermeasures should be considered (114). Other guides, like Maryland's presented design philosophies and examples of good practices, but very few specifications or empirical data with which to compare them against other design guides (164). The type of recommendations presented, the manner in which they were presented, and the detail in which they were presented all varied by design guide. The numerous difficulties in determining agreement between design guides revealed that there is a large amount of variation

in how to approach this topic. Many design guides seem to omit specifications or provide a broad range to allow for a context-sensitive-solutions type of design process, possibly giving the engineer more freedom to find the best solution to a given problem and avoid a "one-size fits all" situation.

Design specifications for relevant roadway characteristics from these different guidelines were compared with several key national guidelines. Specifically, guidebooks from the Active Transportation Alliance (ATA), Federal Highway Administration (FHWA), Institute of Transportation Engineers (ITE), and the National Association of City Transportation Officials (NACTO) were used to set the standards to compare design specifications from state and local organizations. However, the lack of consistency in which recommendations are presented by varying guides troubled the choice of settling on whether two design guides agreed as a binary yes or no choice. Regardless of whether the design guide was a national, state, or city source, most design guides focused almost exclusively on pedestrians and bicyclists and how to design for those VRUs. A few city design guides included some information regarding designing for older drivers and some other VRUs had a specific guide focused on them, but in the case of many of those VRUs, specific infrastructure design guidance often does not differ from design standards already established to protect other road users.

While the goal was to compare specifics within each design manual to determine how strong of a consensus among the states and the cities there was with various national standards, the researcher came to discover that this question could not be adequately answered by a percentage compliance rate. A better way to answer this question then was to focus on where there was more consensus among design guides: when, where, and what type of infrastructure countermeasures should be applied. The tables resulting from this analysis are discussed in

Section 5.2. Meanwhile, Section 5.3 discusses how the various design guides present these improvements and provide examples of some of the varying design specifications.

V.2 Countermeasures to Consider for Different VRUs

Table 4 below serves as an example to discuss how all the figures in this section. The table shows at what conditions various countermeasures are appropriate to consider to increase the safety of pedestrians in urban environments. These countermeasures were chosen for the consensus in appearance across the currently available design literature. Land Use, Roadway Access Type, Speed, Traffic Volume, and Vulnerable Road User Volume were used to define broad, relatable design scenarios that can be applied to a variety of local contexts. The land use types were Urban, Suburban, and Rural. Roadway Access was divided into three categories of Minor Access roads, Limited Access Roads, and High Access Roads. These Access categories are related to Arterials, Collectors, and Local Roads, respectively. They reflect the difference in roadway facility type in the models, but are more versatile than the difference between a Main Road with limited access and Roadways w/o Controlled Access with a great deal of access. 40 mph was defined as the speed limit cutoff point, and Roadway Traffic Volume was split roughly between High and Low vehicle volumes. Similarly, two categories of Vulnerable Road User Volume were presented at Moderate and High volumes. These categories were defined based on key characteristics from the models in Tables 2 and 3, namely roadway access type, speed, and whether the crash occurred in an urban or rural area.

These categories are used to define a variety of situations, from a high speed highway in a small rural county with a relatively low amount of traffic, but a high proportion of motorcyclists to a densely packed downtown drag at midnight with a lot of traffic and a lot of

(potentially less cognizant) pedestrians. These situations and more are presented in the many figures throughout this section.

In the table, a check mark means that the consensus among researchers and guidebooks is that countermeasure may be appropriately applied and is recommended under those circumstances. If a check mark is not present, it does not mean that that countermeasure cannot be used for the given roadway conditions, but that it is not specifically recommended by a consensus. Though many road design improvements can benefit all users, these tables present countermeasures specific to each individual VRU. Each section presents a table and relevant discussion on the main takeaways.

Considerations in Urban Areas

Urban environments are characterized by dense populations, extensive multi-modal transportation networks, and high volumes of all vehicle types, especially motor vehicles. These characteristics make navigating urban environments particularly dangerous for vulnerable road users who face constant risk and unknowns. The percentage of the U.S. population rose from 79.0% in 2000 to 80.7% in 2010 according to the U.S. Census (162). Finding countermeasures to make urban environments a safer travel experience for VRUs is vital as urban populations continue to grow.

Pedestrians

As Table 4 shows, in Urban environments, oftentimes shared use paths that mingle with the roadway network are inappropriate for pedestrians. While they can be used, space constraints are

often very problematic, so they are not specifically recommended in cities for pedestrian use. Sidewalks are inappropriate to use alongside high-speed roads, as they are dangerous for pedestrians. Raised crosswalks, while safe for VRUs, are not recommended on high speed roads or on roads where there is not sufficient VRU demand. Pedestrian refuge medians should be used wherever they are needed, but are not recommended on high access roadways. Midblock crosswalks should be placed wherever there is sufficient demand, except when it is too dangerous to cross, such as on high speed, high volume roadways. In those cases, a PHB signal may be recommended. Chicanes and speed humps are only recommended for low speeds and low vehicle volumes. Otherwise, countermeasures such as curb bulbouts may be used. Roundabouts should only be built at lower speed intersections, and pedestrians can always benefit from better lighting and increased access to bus stops.

Table 4:Geometric Countermeasures for Promoting Pedestrians in Urban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Sidewalks	SU Path Adjacent	SU Path Buffer	Raised Crosswalks	Standard Striped Crosswalks	Zebra Striped Crosswalks	Pedestrian Refuge Median	Midblock Crosswalk	HAWK	Chicane	Speed Humps	Curb Bulbouts	Bollards	Lighting	Bus Stops	Roundabouts	Traditional Intersections
Urban	Minor Access	40 mph or more	High	Mod.	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
				High	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
	Limited Access			Mod.	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
				High	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
			Low	Mod.	-	-	-	-	✓	✓	✓	✓	-	-	-	✓	✓	✓	✓	-	✓
				High	-	-	-	-	✓	✓	✓	✓	-	-	-	✓	✓	✓	✓	-	✓
		35 mph or less	High	Mod.	✓	-	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	✓	✓	✓
				High	✓	-	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	✓	✓	✓
			Low	Mod.	✓	-	-	-	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓
				High	✓	-	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓
	High Access			Mod.	✓	-	-	-	✓	-	-	✓	-	✓	✓	-	✓	✓	✓	✓	✓
				High	✓	-	-	✓	✓	-	-	✓	-	✓	✓	-	✓	✓	✓	✓	✓

Bicyclists

As Table 5 shows, bicycle safety in urban environments is tricky to achieve. This is because most agencies are hard-pressed to recommend significant countermeasures for bicycles on higher volume roadways or roadways with high speeds. Some of the main takeaways from Table 5 include: Simple Share the Road signs are appropriate on roads with low traffic volumes to alert traffic that bicyclists may be on the road. Wide shoulders are typically inappropriate to use in urban environments, which typically use curb and gutter. To increase safety along a route where there are higher cyclist numbers but not enough ROW to add a full bike lane, Sharrows can be installed on low speed roads with low traffic volumes. If bike lanes can be installed though, they need to be along low speed roads unless they are buffered from traffic. Their use is slightly discouraged on high access roadways due to the vast number of potential conflicts the cyclist may face on this type of road. Speed humps should be completely avoided if bicyclists may use a route, as they present a much greater hazard to bicyclists than to motor vehicles.

Table 5: Geometric Countermeasures for Promoting Bicyclists in Urban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Share the Road Sign	Wide Shoulder	Sharrow	Bike Lane	CycleTracks	Contraflow Bike Lane	SU Path Adjacent	SU Path Buffer	Chicane	Speed Humps
Urban	Minor Access	40 mph or more	High	Mod.	-	-	-	-	-	-	-	-	-	-
				High	-	-	-	-	✓	-	-	-	-	-
	Limited Access		Low	Mod.	-	-	-	-	-	-	-	-	-	-
				High	-	-	-	-	✓	-	-	-	-	-
				Mod.	✓	-	-	-	-	-	-	-	-	-
				High	✓	-	-	-	-	-	-	-	-	-
		35 mph or less	High	Mod.	-	-	-	✓	-	-	-	-	-	-
				High	-	-	-	✓	-	-	-	-	-	-
			Low	Mod.	✓	-	✓	✓	-	✓	-	-	✓	-
				High	✓	-	✓	✓	-	✓	-	-	✓	-
	High Access			Mod.	✓	-	✓	-	-	✓	-	-	✓	-
				High	✓	-	✓	-	-	✓	-	-	✓	-

Table 6 presents options appropriate to help bicyclists at intersections, as these areas are particularly dangerous for cyclists and challenging to design for. Roundabouts can be used at low speed intersections, but should remain only 1-lane to be safer for bicyclists and other VRUs. Additionally, it should be clear to the cyclist and to motor vehicles via signage and markings how the bicyclist should move through the roundabout, so all users know what to expect. The cyclist can either enter the roundabout and act as a motor vehicle or the rider can get off the bike and walk the roundabout as a pedestrian. Traditional intersections with no special bicycle lane or markings are not safe in urban environments when there is a large portion of cyclists making left turns at that intersection. They should be replaced with something like a combined bike/turn lane to accommodate a high right-turning volume among bicyclists or a bike box, which is typically only recommended for lower traffic volumes and lower speeds.

Table 6: Geometric Countermeasures for Promoting Bicyclists at Urban & Suburban Intersections

Land Use	Speed	Traffic Volume	Right-Turn Vehicle Traffic	Left-Turn Cyclist Traffic	Single-Lane Roundabout	Traditional Intersection	Combined Bike Lane / Turn Lane	Bike Box Intersection
Urban & Suburban	40 mph or more	High	High	High	-	-	-	-
				Low	-	✓	-	-
			Low	High	-	-	-	-
				Low	-	✓	-	-
		Low	High	High	-	-	-	-
				Low	-	✓	-	-
			Low	High	-	-	-	-
				Low	-	✓	-	-
	35 mph or less	High	High	High	✓	-	✓	-
				Low	✓	✓	✓	-
			Low	High	✓	-	-	-
				Low	✓	✓	-	-
		Low	High	High	✓	-	✓	✓
				Low	✓	✓	✓	✓
			Low	High	✓	-	-	✓
				Low	✓	✓	-	✓

Motorcyclists & Scooter Users

In general, especially within the US, guidance on specific infrastructure countermeasures that make travel safer for VRUs such as motorcyclists, younger and older drivers, equestrians, or golf carts is unavailable. In some cases, national standards may provide some context, or conclusions drawn from research and case studies serve to provide specific counterexamples.

Motorcycle travel is nowhere near as popular in the US as it is in some other countries like in Southeast Asia, so specific motorcycle infrastructure improvements are rare. Most

roadway improvements focus on other VRUs or on automobiles. Where there are extremely high volumes of motorcycle travel on high speed highways, a dedicated motorcycle lane may be appropriate. However, this is unlikely to occur within the US or Alabama. Table 7 provides recommendations for countermeasures for motorcyclists in urban areas. In urban environments with enough demand, creating an HOV lane or allowing motorcyclists to also use bus lanes can be a relatively easy improvement that can ease congestion. Smooth, well-taken care of pavement with well-maintained markings is critical to keeping motorcyclists safe whenever it is possible, though this is especially true in urban areas. Advanced warning signs are recommended on roads with more motorcycle traffic, even on turns where the posted speed limit is appropriate for curve, but especially at higher speeds. Guard rails and a safety pavement edge are typically inappropriate countermeasures in urban environments.

Table 7: Geometric Countermeasures for Promoting Motorcyclists in Urban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Motorcycle Lane	Shared Motorcycle/Bus Lane	Smoothed Pavement & Markings	Break-off Guard Rails	Advanced Turn Warning Sign	Safety Edge Shoulders
Urban	Minor Access	40 mph or more	High	Mod.	-	✓	✓	-	✓	-
				High	-	✓	✓	-	✓	-
	Limited Access			Mod.	-	✓	✓	-	✓	-
				High	✓	✓	✓	-	✓	-
			Low	Mod.	-	✓	✓	-	✓	-
				High	-	✓	✓	-	✓	-
		35 mph or less	High	Mod.	-	✓	✓	-	-	-
				High	-	✓	✓	-	✓	-
			Low	Mod.	-	✓	✓	-	-	-
				High	-	✓	✓	-	-	-
	High Access			Mod.	-	-	✓	-	-	-
				High	-	-	✓	-	-	-

Younger & Older Drivers

In general, while older and younger drivers are the topic of much research, few guidebooks publish road design standards targeted specifically at these groups. This list of countermeasures was gathered from several research studies and publications. Table 8 below provides an aid for this discussion on infrastructure countermeasures for older and younger drivers in urban locations. Difficulty interpreting signage is a common driving mistake among older drivers, who may have reduced vision and cognitive abilities, and among younger drivers, who have less driving experience and are more likely to make a mistake or misinterpret information. Two-way-left-turn-lanes are discouraged for the safety of this VRU group, while a clear ROW, wider turn radii, and guard rails and rumble strips are typically solutions reserved for suburban or rural roads. Intersections should meet at as close to 90-degree angles as possible for the aid of older drivers and if the volumes demand a left-turn signal, they should be installed wherever possible, as protected-only lefts are the safest for these VRUs. Whatever the type of signal used, it is vital to remain consistent with that philosophy throughout an area, as inconsistent signals can be confusing to older or less experienced drivers. Roundabouts are discouraged when there are a high proportion of older drivers on a road, as they are often inexperienced with roundabouts due to their scarce use in the US.

Table 8: Geometric Countermeasures for Promoting Older and Younger Drivers in Urban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Retroreflective Signage w/ Large Lettering	ROW clear of fixed objects	Widen radius of curvature	Guard rails / Rumble strips	TWLTL?	90-degree intersection	Protected Left-Turn Signal	Roundabout
Urban	Minor Access	40 mph or more	High	Mod.	✓	-	-	-	-	✓	✓	-
				High	✓	-	-	-	-	✓	✓	-
	Limited Access		Low	Mod.	✓	-	-	-	-	✓	✓	✓
				High	✓	-	-	-	-	✓	✓	-
		35 mph or less	High	Mod.	✓	-	-	-	-	✓	✓	✓
				High	✓	-	-	-	-	✓	✓	-
			Low	Mod.	✓	-	-	-	-	✓	-	✓
				High	✓	-	-	-	-	✓	✓	-
	High Access			Mod.	✓	-	✓	-	-	✓	-	✓
				High	✓	-	✓	-	-	✓	✓	-

Farm Equipment, Golf Carts & Transport Service Animals

While there are various national and state standards for operating farm equipment on public roads, and some states and small communities have rules for operating golf carts on roadways or riding on transport service animals such as by horseback, proportionately, these make up a tiny portion of trips in the US. As such, while there is some research investigating the major issues these VRUs face, some guidance on how to plan a golf cart community, and advice on how to safely ride a horse on public roadways, there is no intellectual consensus regarding specific infrastructure solutions for these unique VRUs. For more information regarding the challenges these users face, see Chapter 2.

Considerations in Suburban Areas

Pedestrians

In terms of appropriate infrastructure improvements for pedestrians, comparing Table 4 with Table 9 shows that in general, many of the same solutions apply conceptually, despite requiring different approaches and context sensitive solutions. The main difference to point out are that shared-use paths are more easily recommended in suburban environments compared to urban environments. A shared-use path can be built adjacent to the roadway if speed and access are limited. A shared-use path is preferable with a buffer when the ROW is available, and can be used along higher speed roads if traffic volumes are not too high.

Table 9: Geometric Countermeasures for Promoting Pedestrians in Suburban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Sidewalks	SU Path Adjacent	SU Path Buffer	Raised Crosswalks	Standard Striped Crosswalks	Zebra Striped Crosswalks	Pedestrian Refuge Median	Midblock Crosswalk	HAWK	Chicane	Speed Humps	Curb Bulbouts	Bollards	Lighting	Bus Stops	Roundabouts	Traditional Intersections
Suburban	Minor Access	40 mph or more	High	Mod.	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
				High	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
	Limited Access			Mod.	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
				High	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	✓	-	✓
			Low	Mod.	-	-	✓	-	✓	✓	✓	-	-	-	-	✓	✓	✓	✓	-	✓
				High	-	-	✓	-	✓	✓	✓	-	-	-	-	✓	✓	✓	✓	-	✓
		35 mph or less	High	Mod.	✓	-	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	✓	✓	✓
				High	✓	-	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	✓	✓	✓
			Low	Mod.	✓	✓	✓	-	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓
				High	✓	✓	✓	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	✓	✓	✓
	High Access			Mod.	✓	-	✓	-	✓	-	-	✓	-	✓	✓	-	✓	✓	✓	✓	✓
				High	✓	-	✓	✓	✓	-	-	✓	-	✓	✓	-	✓	✓	✓	✓	✓

Bicyclists

Comparing Table 5 to 10 reveals a very similar situation to pedestrians, as many recommendations for urban environments apply to suburban environments as well. The main significant change between Tables 5 and 10 is that Table 10 indicates that there is a greater consensus for applying shared-use paths in suburban environments than in urban environments under a variety of different conditions.

Table 10: Geometric Countermeasures for Promoting Bicyclists in Suburban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Share the Road Sign	Wide Shoulder	Sharrow	Bike Lane	CycleTracks	Contraflow Bike Lane	SU Path Adjacent	SU Path Buffer	Chicane	Speed Humps
Suburban	Minor Access	40 mph or more	High	Mod.	-	-	-	-	-	-	-	-	-	-
				High	-	-	-	-	✓	-	-	-	-	-
	Limited Access		Low	Mod.	-	-	-	-	-	-	-	-	-	-
				High	-	-	-	-	-	-	-	-	-	-
				Mod.	✓	-	-	-	-	-	-	✓	-	-
				High	✓	-	-	-	✓	-	-	✓	-	-
		35 mph or less	High	Mod.	-	-	-	✓	-	-	-	-	-	-
				High	-	-	-	✓	-	-	-	-	-	-
			Low	Mod.	✓	-	✓	✓	-	✓	✓	✓	✓	-
				High	✓	-	✓	✓	-	✓	✓	✓	✓	-
	High Access			Mod.	✓	-	✓	-	-	✓	-	✓	✓	-
				High	✓	-	✓	-	-	✓	-	✓	✓	-

Motorcyclists & Scooter Users

In suburban environments, there are fewer opportunities to allow motorcycles to travel in bus lanes or other similar systems. While smoothed pavement and markings are important everywhere for motorcyclists, there are typically fewer resources to handle this effort outside of heavily populated urban areas. On higher speed roads, safety edges at the shoulders of the road (reshaping the outer edge of pavement to have a 30 degree decline), or similar improvements such as gentler shoulder slope and a wider clear zone can help motorcyclists that accidently leave the travel way maneuver back onto the road safely.

Table 11: Geometric Countermeasures for Promoting Motorcyclists in Suburban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Motorcycle Lane	Shared Motorcycle/Bus Lane	Smoothed Pavement & Markings	Break-off Guard Rails	Advanced Turn Warning Sign	Safety Edge Shoulders
Suburban	Minor Access	40 mph or more	High	Mod.	-	✓	-	-	✓	✓
				High	-	✓	-	-	✓	✓
	Limited Access		Low	Mod.	-	✓	-	-	✓	✓
				High	-	✓	-	-	✓	✓
				Mod.	-	-	-	-	✓	✓
				High	-	-	-	-	✓	✓
		35 mph or less	High	Mod.	-	-	-	-	-	-
				High	-	-	-	-	-	-
			Low	Mod.	-	-	-	-	-	-
				High	-	-	-	-	-	-
	High Access			Mod.	-	-	-	-	-	-
				High	-	-	-	-	-	-

Younger & Older Drivers

Many suburban solutions for older and younger drivers can be applied similarly to urban solutions. Where possible, especially on higher speed roads, the ROW should be cleared of fixed objects to reduce crash risk. Additionally, increasing the radius of curvature on a road can help older drivers. Intersections in curves which experience a higher crash rate among these VRUs should be investigated to see if this solution is viable.

Table 12: Geometric Countermeasures for Promoting Older and Younger Drivers in Suburban Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Retroreflective Signage w/ Large Lettering	ROW clear of fixed objects	Widen radius of curvature	Guard rails / Rumble strips	TWLTL?	90-degree intersection	Protected Left-Turn Signal	Roundabout
Suburban	Minor Access	40 mph or more	High	Mod.	✓	✓	✓	-	-	✓	-	-
				High	✓	✓	✓	-	-	✓	-	-
	Limited Access			Mod.	✓	✓	✓	-	-	✓	✓	✓
				High	✓	✓	✓	-	-	✓	✓	-
			Low	Mod.	✓	-	✓	-	-	✓	✓	✓
				High	✓	-	✓	-	-	✓	✓	-
		35 mph or less	High	Mod.	✓	-	✓	-	-	✓	✓	✓
				High	✓	-	✓	-	-	✓	✓	-
			Low	Mod.	✓	-	✓	-	-	✓	-	✓
				High	✓	-	✓	-	-	✓	-	-
	High Access			Mod.	✓	-	✓	-	-	✓	✓	✓
				High	✓	-	✓	-	-	✓	✓	-

Farm Equipment, Golf Carts & Transport Service Animals

There is no consensus on specific improvements that can be targeted at improving the safety of these unique VRU groups. For more information regarding the challenges these users face, see Section II.

Considerations in Rural Areas

Pedestrians

The same kind of solutions apply to pedestrians regardless of land use context. The only significant change is that bus stops are impractical countermeasures for pedestrian safety in rural areas because of the long distances and relatively lower transit ridership rates.

Table 13: Geometric Countermeasures for Promoting Pedestrians in Rural Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Sidewalks	SU Path Adjacent	SU Path Buffer	Raised Crosswalks	Standard Striped Crosswalks	Zebra Striped Crosswalks	Pedestrian Refuge Median	Midblock Crosswalk	HAWK	Chicane	Speed Humps	Curb Bulbouts	Bollards	Lighting	Bus Stops	Roundabouts	Traditional Intersections
Rural	Minor Access	40 mph or more	High	Mod.	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	-	-	✓
				High	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	-	-	✓
	Limited Access			Mod.	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	-	-	✓
				High	-	-	-	-	✓	✓	✓	-	✓	-	-	✓	✓	✓	-	-	✓
			Low	Mod.	-	-	✓	-	✓	✓	✓	✓	-	-	-	✓	✓	✓	-	-	✓
				High	-	-	✓	-	✓	✓	✓	✓	-	-	-	✓	✓	✓	-	-	✓
		35 mph or less	High	Mod.	✓	-	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	-	✓	✓
				High	✓	-	-	✓	✓	✓	✓	✓	-	-	-	✓	✓	✓	-	✓	✓
			Low	Mod.	✓	✓	✓	-	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓
				High	✓	✓	✓	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓
	High Access			Mod.	✓	-	✓	-	✓	-	-	✓	-	✓	✓	-	✓	✓	-	✓	✓
				High	✓	-	✓	✓	✓	-	-	✓	-	✓	✓	-	✓	✓	-	✓	✓

Bicyclists

In rural areas, dedicated bike lanes are typically an impractical and unnecessary solution to bicycle travel. Oftentimes, except on busier high access roadways, an extended paved shoulder provides the necessary safety buffer from traffic that cyclists need and gives these users a space on the road. The other improvements are similar to those found in Tables 5 and 10.

Table 14: Geometric Countermeasures for Promoting Bicyclists in Rural Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Share the Road Sign	Wide Shoulder	Sharrow	Bike Lane	CycleTracks	Contraflow Bike Lane	SU Path Adjacent	SU Path Buffer	Chicane	Speed Humps
Rural	Minor Access	40 mph or more	High	Mod.	-	✓	-	-	-	-	-	-	-	-
				High	-	✓	-	-	-	-	-	-	-	-
	Limited Access			Mod.	-	✓	-	-	-	-	-	-	-	-
				High	-	✓	-	-	-	-	-	-	-	-
			Low	Mod.	✓	✓	-	-	-	-	-	✓	-	-
				High	✓	✓	-	-	-	-	-	✓	-	-
		35 mph or less	High	Mod.	-	✓	-	-	-	-	-	-	-	-
				High	-	✓	-	-	-	-	-	-	-	-
			Low	Mod.	✓	✓	✓	-	-	-	✓	✓	✓	-
				High	✓	✓	✓	-	-	-	✓	✓	✓	-
	High Access			Mod.	✓	-	✓	-	-	-	-	✓	✓	-
				High	✓	-	✓	-	-	-	-	✓	✓	-

In rural areas, Table 15 states that specific bicycle intersection improvements are impractical and probably should not be applied. These types of improvements cannot realistically be applied in rural areas, where the distances that the cyclists must travel are so great and they would only potentially benefit a very small number of riders. Traditional intersections will suffice in most cases. Roundabouts may be considered on lower speed roads if there is enough traffic demand and safety improvements are needed.

Table 15: Geometric Countermeasures for Promoting Bicyclists at Rural Intersections

Land Use	Speed	Traffic Volume	Right-Turn Vehicle Traffic	Left-Turn Cyclist Traffic	Single-Lane Roundabout	Traditional Intersection	Combined Bike Lane / Turn Lane	Bike Box Intersection
Rural	40 mph or more	High	High	High	-	✓	-	-
				Low	-	✓	-	-
			Low	High	-	✓	-	-
				Low	-	✓	-	-
		Low	High	High	-	✓	-	-
				Low	-	✓	-	-
			Low	High	-	✓	-	-
				Low	-	✓	-	-
	35 mph or less	High	High	High	✓	✓	-	-
				Low	✓	✓	-	-
			Low	High	✓	✓	-	-
				Low	✓	✓	-	-
		Low	High	High	-	✓	-	-
				Low	-	✓	-	-
			Low	High	-	✓	-	-
				Low	-	✓	-	-

Motorcyclists & Scooter Users

Motorcyclists in rural areas face very different challenges and require a different set of solutions. Specially designed break-off guard rails with ends designed to break away from the ground and bend upon collision lessen the impact on the user. These or other technologically sound guard rail solutions should be considered on high speed roads, targeting where there are high numbers of off-road motorbike crashes. Research has yet to come to a consensus on the type of guard rail that is best for motorcyclists, so this should be investigated. Smooth pavement and markings are especially important on higher speed roads for motorcyclists traveling in rural areas because of the tendency of some motorcyclists to speed in rural areas, as discussed in previous sections.

Table 16: Geometric Countermeasures for Promoting Motorcyclists in Rural Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Motorcycle Lane	Shared Motorcycle/Bus Lane	Smoothed Pavement & Markings	Break-off Guard Rails	Advanced Turn Warning Sign	Safety Edge Shoulders
Rural	Minor Access	40 mph or more	High	Mod.	-	-	✓	✓	✓	✓
				High	-	-	✓	✓	✓	✓
	Limited Access		Low	Mod.	-	-	✓	✓	✓	✓
				High	-	-	✓	✓	✓	✓
		35 mph or less	High	Mod.	-	-	-	-	-	✓
				High	-	-	-	✓	-	✓
			Low	Mod.	-	-	-	-	-	✓
				High	-	-	-	✓	-	✓
	High Access			Mod.	-	-	-	-	-	✓
				High	-	-	-	-	-	✓

Younger & Older Drivers

Where the space is available and the situation allows, ROW should be cleared on higher speed rural roads or rural roads with a high portion of older or younger drivers. Guard rails and rumble strips are also good solutions on higher speed roadways to prevent an off-road accident. Protected left-turns are typically inappropriate or impractical at traffic signals in rural areas, except on some higher access roads where services and venues are gathered.

Table 17: Geometric Countermeasures for Promoting Older and Younger Drivers in Rural Environments

Land Use	Roadway	Speed	Traffic Volume	VU Volume	Retroreflective Signage w/ Large Lettering	ROW clear of fixed objects	Widen radius of curvature	Guard rails / Rumble strips	TWLTL?	90-degree intersection	Protected Left-Turn Signal	Roundabout
Rural	Minor Access	40 mph or more	High	Mod.	✓	✓	✓	✓	-	✓	-	-
				High	✓	✓	✓	✓	-	✓	-	-
	Limited Access			Mod.	✓	✓	✓	✓	-	✓	-	-
				High	✓	✓	✓	✓	-	✓	-	-
			Low	Mod.	✓	-	✓	✓	-	✓	-	-
				High	✓	✓	✓	✓	-	✓	-	-
		35 mph or less	High	Mod.	✓	-	✓	-	-	✓	-	-
				High	✓	✓	✓	-	-	✓	-	-
			Low	Mod.	✓	-	✓	-	-	✓	✓	-
				High	✓	-	✓	-	-	✓	✓	-
	High Access			Mod.	✓	-	✓	-	-	✓	✓	-
				High	✓	-	✓	-	-	✓	✓	-

Farm Equipment, Golf Carts & Transport Service Animals

There is no consensus on specific improvements that can be targeted at improving the safety of these unique VRU groups. For more information regarding the challenges these users face, see Section II.

VI. DETAILS ON INFRASTRUCTURE IMPROVEMENTS

In this section, each infrastructure improvement is described in detail. This includes what each treatment includes, which VRUs benefit from the treatment, important implementation considerations, best environments for implementation and design considerations. While many states use AASHTO's "Green Book" to set their ultimate design guide standards, the goal of this report was to highlight safety information that specifically targets VRUs. Therefore, this section primarily focuses on design recommendations specifically targeting VRU safety, which may go beyond those general safety requirements. Engineers and planners may use this information to best introduce a VRU countermeasure in their location.

VI.1 VRU Improvement Opportunities on Sidewalks & Pathways

Standard Sidewalks

Figure 66: Standard Sidewalk Example (5)

What is this treatment?

Sidewalks are the standard method for creating pedestrian pathways.

Which VRUs benefit from this treatment?

Sidewalks are used by pedestrians of all ages and capabilities. Depending on the laws of the area, other non-motorized users such as bicyclists and skateboarders may or may not be allowed to use them as well.

What are the important VRU considerations related to this treatment?

To comply with ADA standards, sidewalks must be at least 5 feet wide to allow pedestrians of all abilities to pass side-by-side (36). However, the specific recommended width varies widely across national, state, and city guidebooks due to the wide variety of functions a sidewalk can serve depending on its location and its context.

When should this treatment be implemented?

Sidewalks are not recommended to be implemented alongside high speed roadways, where the risk of severe or fatal injuries in a crash are very high for pedestrians. When the roadway speed limit allows for it, sidewalks should be placed along every corridor. In rural areas, an extended paved shoulder can be substituted for a sidewalk (16).

What are the recommended design characteristics of this treatment?

ITE recommends a minimum sidewalk width of 6 feet for urban areas and 8 feet for residential neighborhoods, but also note that sidewalk width should vary with the context of the zone, the land use, and other factors. (16) ATA recommends that sidewalks be designed using the Sidewalk Zone System – Curb, Furniture, Pedestrian, and Frontage Zones – as an easy way to always meet ADA requirements and create pleasing, comfortable, and safe pedestrian environments. For urban sidewalks, ATA recommends that sidewalks have a 1 - 2-foot curb zone, 5 - 6-foot furniture zone, an 8 – 10-foot pedestrian zone, and a 1 – 2-foot frontage zone, while for residential complete streets, ATA recommends a 1 – 2-foot curb zone and a 5 – 6-foot pedestrian zone (15).

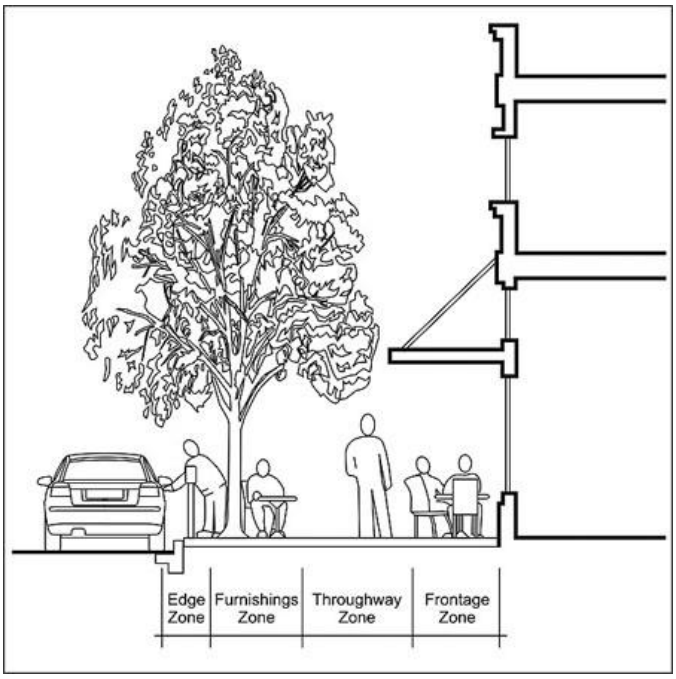

Figure 67: ITE Sidewalk Zone System (16)

Some state guides at least agree with ITE's standards as a minimum, but there is little agreement over recommended widths. Most states set recommendations for residential sidewalks between 5 and 6 feet. However, in urban areas, some states recommend sidewalk widths of 5 – 6 feet (Georgia) and 5 – 8 feet (Texas) on the low end, up to 6 – 12 feet (North Carolina, Massachusetts) and 6 – 14 feet (Virginia). States on the higher end of the spectrum recommend wider sidewalks to account for high pedestrian volumes and areas without a buffer from the road. Additionally, Massachusetts recognizes that in areas such as a CBD, sidewalk widths of up to 20 feet may be desired. Virginia's complete street guide is the only state guide to utilize the Sidewalk Zone System, but no standards are provided (31, 106-111).

Like the states, most cities set minimum sidewalk widths that agree with ITE's standards, but actual recommendations vary wildly, as do the range of the recommendations. However,

unlike the state guides, many cities with complete streets guides utilize the Sidewalk Zone System. Wider sidewalks are recommended in areas with high pedestrian traffic. Sidewalk widths vary from 5 foot minimum recommendations in Philadelphia, Polk County, San Diego, and others, to cities with a range of recommended sidewalk widths that vary based on the area and context. Some examples include Basalt, Colorodo, with minimum sidewalk widths that range from 5 – 12 feet; Boston, with preferred sidewalk widths that range from 11.5 – 20.5 feet; and Chicago, with sidewalks ranging from 5 to 27 feet wide (112-117).

There is little agreement over buffer space between sidewalk paths and roadways. ITE recommends a 6 – 8 feet wide planting strip or tree well wherever possible to create a safe buffer space between pedestrians and other road users (16). FHWA recommends that the buffer space be the width of one bike lane, though other guides do not seem to approach the topic this way (16, 19). However, the recommended size of this buffer space varies widely among guides and from street to street. Connecticut and Massachusetts recommend a minimum 3 feet wide buffer space, while Georgia recommends a 6 feet buffer zone (109, 110, 118). Recommended widths among cities vary from 3 feet minimums in Knoxville and Louisville to 8 feet minimum on higher volume roads in Monterey Bay and even wider in some cities (119-121). These buffer widths also apply to other pedestrian routes like shared-use paths.

Shared Use Path Adjacent

Figure 68: Standard Shared-Use Path Adjacent Example (124)

What is this treatment?

A shared-use path serves a multitude of (typically non-motorized) road users. These shared spaces give VRUs a separate, dedicated travel-way within the transportation network. When ROW is scarce, a shared-use path may be built adjacent to a roadway (15).

Which VRUs benefit from this treatment?

While they are typically designed to support pedestrians and cyclists, some may also support small motorized carts, horses, or other users (15).

What are the important VRU considerations related to this treatment?

A shared-use path is designed for use by vulnerable, slower moving road users. Automobiles and other motorized vehicles should be prohibited from using a shared-use path. A

shared-use path which is built adjacent to the roadway provides less protection to these users from motor traffic, so this trade-off must be weighed whenever a shared-use path is considered (19).

When should this treatment be implemented?

A shared-use path should be considered in areas where pedestrian and/or bicyclist volume is high while vehicle traffic speed limits are low. A shared-use path should not be placed adjacent to a high-speed roadway without the use of some protective barrier. Additionally, they are not recommended to be used unprotected along corridors with high traffic volumes – though this should be determined on a case-by-case basis. They should be avoided along high-access corridors when possible due to the increased potential for conflict with motor vehicles. In urban areas where higher traffic volumes and high access may be unavoidable, a shared-use path should be implemented with careful consideration of potential conflict areas and safety concerns (109).

What are the recommended design characteristics of this treatment?

The design of a shared-use path is flexible enough to allow engineers and designers to change them to best suit the needs and desires of their area. This is typically reflected in the policies and design manuals of the state or locality in question. However, FHWA does provide some standards for design. The path material should be selected based on the users it is being made for: bicyclists and skaters fare much better on paths made of asphalt or concrete, while pedestrians can also navigate on crushed aggregate or impacted soil (19). When they are a major consideration, equestrians and other service animal riders fare best on impacted soil trails (19, 95).

A shared-use path is commonly designed for travel in two opposing directions in a single treadway. Oftentimes, the two directions of travel are separated only by pavement markings. Other designs are possible, such as a divided shared-use path for each direction of travel or a physical barrier separating the two travel flows. The minimum width for a typical 2-lane path is 10 feet, though 12-14 feet is recommended to accommodate substantial use by all mode types. In areas where proximity to the roadway is a great safety concern, such as along higher speed or higher volume corridors, a physical barrier such as bollards may be used to separate motor vehicle traffic on the road from the VRUs on the shared-use path (109). However, this comes with a trade-off, as bollards can also be a fixed-object hazard, so designers must weigh this against the needs of the VRUs. North Carolina and Massachusetts recommend multi-use path widths of 10 – 12 feet and 8 – 14 feet, respectively. North Carolina recommends that multi-use paths be installed along parkways or rural roads. Massachusetts recommends that reduced widths only be used under constraints and wider paths be utilized when possible to accommodate a variety of users (106, 109).

Shared Use Path with Buffer

Figure 679: Standard Shared-Use Path with Buffer Example (124)

What is this treatment?

A shared-use path serves a multitude of (typically non-motorized) road users. These shared spaces give VRUs a separate, dedicated travel-way within the transportation network. Where ROW is of less concern, a shared-use path is recommended to be built with a buffer from the roadway to provide better protection to the VRUs on the path (16, 19).

Which VRUs benefit from this treatment?

While are typically designed to support pedestrians and cyclists, though some may also support small motorized carts, horses, or other users. However, these latter situations are a special case and are typically only allowed to operate on a shared-use path when that permission is expressly granted – either through proper signage or specific local ordinance (47, 95, 122, 123).

What are the important VRU considerations related to this treatment?

A shared-use path is designed for use by vulnerable, slower moving road users. Automobiles and other motorized vehicles should be prohibited from using a shared-use path. A shared-use path which is built with a buffer from the roadway provides more protection to these users from motor traffic, but uses more ROW. This trade-off must be weighed whenever a shared-use path is considered (18, 19).

When should this treatment be implemented?

A shared-use path should be considered in areas where pedestrian and/or bicyclist volume is high while vehicle traffic speed limits are low. A shared-use path should not be placed adjacent to a high-speed roadway without the use of some protective barrier. They should be avoided along high-access corridors when possible due to the increased potential for conflict with motor vehicles. In urban areas where higher traffic volumes and high access may be unavoidable, a shared-use path should be implemented with careful consideration of potential conflict areas and safety concerns (109).

What are the recommended design characteristics of this treatment?

The design of a shared-use path is flexible enough to allow engineers and designers to change them to best suit the needs and desires of their area. See *Shared-Use Path Adjacent* for a discussion of what materials to consider.

A shared-use path is commonly designed for travel in two opposing directions in a single treadway. Oftentimes, the two paths are separated only by pavement markings. Other designs are possible, such as a divided shared-use path for each direction of travel or a physical barrier separating the two travel flows. The minimum width for a typical 2-lane path is 10 feet, though 12-14 feet is recommended to accommodate substantial use by all mode types. North Carolina

and Massachusetts recommend multi-use path widths of 10 – 12 feet and 8 – 14 feet, respectively. North Carolina recommends that multi-use paths be installed along parkways or rural roads. Massachusetts recommends that reduced widths only be used under constraints and wider paths be utilized when possible to accommodate a variety of users (105, 108). A minimum 2-foot buffer between the road and the shared-use path is recommended by FHWA (16). All signs, posts, and other physical obstructions should be at least 3-feet away from the path. In total, a shared-use path is recommended to be placed 5-7 feet from the edge of the roadway. However, engineers may adjust this buffer width where necessary or extend it to fit the needs of the project. In areas where proximity to the roadway is a great safety concern, such as along higher speed or higher volume corridors, a physical barrier such as bollards may be used to separate motor vehicle traffic on the road from the VRUs on the shared-use path (109).

VI.2 VRU Improvement Opportunities on Roadways

'Share the Road' Signs

Figure 70: Standard 'Share the Road' Example (126)

What is this treatment?

According to the MUTCD, a 'Share the Road' sign is an option which may be considered, "In situations where there is a need to warn motorists to watch for bicyclists traveling along the highway." (127)

Which VRUs benefit from this treatment?

Bicyclists benefit from this treatment.

What are the important VRU considerations related to this treatment?

A "Share the Road" sign is only a small supplemental treatment which may be applied to raise awareness among motor vehicles to watch out for potential bicyclist traffic.

When should this treatment be implemented?

A “Share the Road” sign is a low-cost solution to improving bicyclist safety within a road network. Studies have shown that they can reduce bicyclist-vehicle collisions when properly implemented. They may be used in conjunction with other bicyclist safety countermeasures or as a minimum treatment in areas where a bicycle lane, sharrow, or other treatment is inappropriate (127).

What are the recommended design characteristics of this treatment?

The MUTCD provides specific design standards for various types of “Share the Road” signs in their manual (127). The standard design is shown below in Figure 71.

Figure 71: Standard ‘Share the Road’ Sign (127)

Wide Shoulder

Figure 72: Standard Wide Shoulder Example (5)

What is this treatment?

On rural and some suburban roads, widened paved shoulders may be used in place of sidewalks, bike lanes, or other facilities to accommodate the relatively lower usage by those VRUs.

Which VRUs benefit from this treatment?

Pedestrians and bicyclists are the typical targets for widened shoulders. However, farm equipment, equestrians, and golf carts can also benefit from using a widened shoulder to travel in some areas. Additionally, they can aid motor vehicles – especially older and younger drivers – along high-speed highways to allow a buffer area to recover if they accidentally drive off the edge of the travel way. Older drivers with poorer reflexes and often decreased visuo-motor capabilities and younger drivers with little experience are especially at risk of these types of crashes (43).

What are the important VRU considerations related to this treatment?

An extended shoulder provides only minimal protection to VRUs from motor vehicles. If a high volume of VRU traffic is anticipated, other countermeasures may be more appropriate. In rural areas, a rumble strip along the edge of the outside lane is an effective countermeasure that helps prevent motor vehicles from leaving the road. This protects those traveling in motor vehicles and creates a buffer that separates the motor vehicles from VRUs travelling along the shoulder. However, a continuous rumble strip is creates a barrier that impedes bicyclists and is unsafe for them to travel on. Gaps should be built into the rumble strip every couple of feet to allow cyclists to safely maneuver between the shoulder and the outside lane, as shown in an example from FHWA in Figure 73 below.

Figure 73: Wide Shoulder w/ Rumble Strip w/ Gaps Example (5)

When should this treatment be implemented?

Extended paved shoulders should be implemented along rural roads with minor or limited access and some higher speed suburban roads with minor access. They should be used when VRU traffic such as pedestrians or bicyclists are expected, but there is not significant enough

volume to require a specific countermeasure, or the corridor is too long or in some way designed such that sidewalks or shared-use paths cannot be justified.

What are the recommended design characteristics of this treatment?

ATA recommends 2 foot shoulders in urban areas and 4 foot shoulders in rural areas and areas where cyclists travel. ITE recommends that shoulders along bicycle routes should ideally be 8 feet wide to allow a safe buffer space between vehicles and cyclists along higher-speed corridors. State guidance varies. Massachusetts, Connecticut, and North Carolina recommend 4 – 5 foot shoulders (105, 108, 117). Texas guidance also recommends 4 foot shoulders, but recommends that they be widened on roads with speed limits greater than about 35 mph (30). Virginia, Arizona, and Georgia recommend wider shoulders of 6, 6 – 10, and 10 – 14 feet, respectively (106, 107, 109). Georgia recommends wider shoulders to allow vehicles to move at higher speeds. City guidance also shows a large amount of variance, with 4 – 5 foot shoulders on the low end in cities such as Dallas and Louisville, and 6 – 10 foot shoulders on the high end in cities with more rural areas, such as Basalt (116, 120, 127).

Sharrow

Figure 74: Standard Sharrow Example (128)

What is this treatment?

Marked shared lanes or "Sharrows," are pavement markings used on a slightly wider outside travel lane when separate bicycle facilities are not feasible or appropriate but the volume of bicyclists is high enough to demand some sort of safety response (113).

Which VRUs benefit from this treatment?

Bicycles use Sharrows.

What are the important VRU considerations related to this treatment?

A Sharrow does not provide any physical separation or barrier between bicyclists and motor vehicles – they are still traveling in the same space on the road (113).

When should this treatment be implemented?

Sharrows should be implemented when there is a relatively high volume of bicycle traffic but the conditions of the road make it infeasible or inappropriate to provide the cyclists with a dedicated separated solution. They help direct bicyclists to travel along the most appropriate corridors in a transportation system, such as between dedicated bicycle paths or lanes. They also give a visual indication to motorists to look out for bicyclists travelling in the area.

What are the recommended design characteristics of this treatment?

Sharrows are recommended only on low-volume, low-speed roadways to accommodate low levels of cyclist usage. They should be implemented on travel lanes with a minimum width of 10 feet, though wider lanes of 11-11.5 feet are preferred (15, 18, 20, 21).

Bike Lane

Figure 75: Standard Bike Lane Example (20)

What is this treatment?

Through pavement markings and signage, a standard bike lane designates an exclusive space for bicyclists to travel on in the roadway. They are typically located on the right side of the street, adjacent to motor traffic flow in the same direction between the travel lane and the curb, roadside edge, or parking lane (20, 21).

Which VRUs benefit from this treatment?

Bike lanes enable bicyclists to travel quickly, safely, and efficiently within a transportation network.

What are the important VRU considerations related to this treatment?

While bike lanes increase cyclist comfort on heavily trafficked roads by providing a clear distinction between motor vehicles and bikes, there typically is no physical separation between the two modes. As such, on streets with higher traffic volumes or a posted speed limit higher than 35 mph, more elaborate countermeasures may be necessary for the safety of these VRUs.

Buffered bicycle lanes or dedicated cycle tracks may be more appropriate countermeasures in these conditions if cycling traffic is a priority (20, 21).

When should this treatment be implemented?

The major national design organizations, including ATA, FHWA, and ITE, recommend that bike lanes be used wherever sufficient demand and suitable ROW conditions allow for a bike lane. Connected bike lanes can be used to create a safe, dedicated cycling network and control where these users go in the transportation network. A standard bike lane without a buffer is most appropriate on roads with speeds of less than 35 mph (15, 16, 18).

What are the recommended design characteristics of this treatment?

The minimum width of a bike lane to allow for a safe navigable space for the cyclist to travel is 5 feet. In cases where ROW is tight, to meet that 5-foot limit, 1 foot of curb and gutter length may be considered as part of the bike lane. In general, though, bike lanes are recommended to be designed to be 5-6 feet wide. A 6-foot-wide lane can allow two cyclists to ride next to one another to pass, while a wider lane may wrongly encourage motor vehicles to attempt to use the lane (15, 16, 18). FHWA recommends that the bike lane end 45 feet before the intersection to allow cyclists to enter the traffic stream and act as a vehicle at intersections (18). However, other practices disagree. States and most cities agree with ITE's guidelines that bike lanes should either stop at the intersection or extend all the way through with a hashed line (16).

Cycle Tracks

Figure 786: Standard One-Way CycleTrack Example (20)

What is this treatment?

A cycle track is an exclusive bicycle facility separated from both motor traffic and the sidewalk by a buffer (either a physical buffer or empty space). It combines the user experience of a separate path with the on-street infrastructure of bike lane to give bicyclists an exclusive travel space within the transportation network. The design of a cycle track can vary to accommodate either one-way or two-way traffic, be at street or sidewalk level, or use color, texture, or physical objects such as bollards to create a distinct buffered zone between motor traffic and cyclists (20).

Which VRUs benefit from this treatment?

Bicyclists gain benefits from cycle tracks.

What are the important VRU considerations related to this treatment?

As an exclusive dedicated travel space for bicyclists only, cycle tracks offer the most protection for these VRUs while also creating efficient travel ways for them. However, this

protection comes at great expense, so this type of countermeasure should only be implemented where there is a large volume of cyclists and they are a priority (20).

When should this treatment be implemented?

Cycle tracks should be implemented whenever a conventional bike lane does not provide a significant enough countermeasure either due to high vehicle traffic speeds or volumes. They should only be installed in areas with significant cycling populations (20).

What are the recommended design characteristics of this treatment?

In terms of design a cycle track is a flexible countermeasure. It can be designed as a 1-way or 2-way system, depending on local needs. A minimum 3-foot buffer space should be implemented between the cycle track and the roadway. Where this buffer space is unavailable, other countermeasures such as bollards may be considered to impose a physical buffer between travel ways. A 1-way cycle track should be at least 5-7 feet wide, while a 2-way cycle track should be 10-feet wide at a minimum, 12-feet wide recommended (15, 16, 18). Figure 77 below shows NACTO's standard design for a 1-way cycle track.

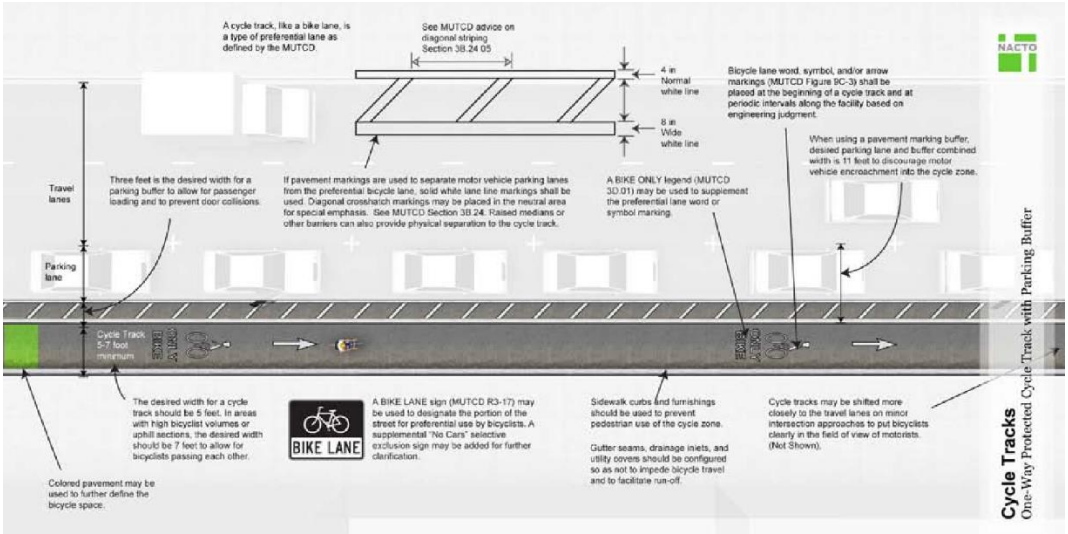

Figure 797: NACTO One-Way CycleTrack Design (20)

Contraflow Bike Lane

Figure 78: Standard Contraflow Bike Lane Example (20)

What is this treatment?

A contraflow bike lane is a standard bike lane where cyclists travel in the opposite direction of the motor vehicle traffic in the adjacent travel lane.

Which VRUs benefit from this treatment?

Bicyclists benefit from contraflow bike lanes.

What are the important VRU considerations related to this treatment?

In a contraflow bike lane, cyclists are traveling against and alongside opposing vehicle traffic. This potentially dangerous circumstance should be implemented in limited situations to minimize additional conflicts and the potentially unexpected circumstance from a motorists' point-of-view of on-coming bicyclists (20).

When should this treatment be implemented?

A contraflow bike lane is typically implemented to increase the connectivity of a bicycle network. They may be used under the same general circumstances as a standard bike lane. They

may be employed on low-speed roads (less than 35 mph) with low vehicle volumes. They are most commonly used along one-way roads so that cyclists may travel in both directions on the street (15, 16).

What are the recommended design characteristics of this treatment?

A contraflow bike lane has the same design characteristics as a standard 5-6-foot-wide bike lane (15, 16). A rendering of a contraflow bike lane from NACTO is shown below in Figure 79.

Figure 79: Standard Contraflow Bike Lane Example (20)

Motorcycle Lane

Figure 80: Standard Motorcycle Lane Example (130)

What is this treatment?

In areas where motorcycle traffic volumes are very high, a single travel lane may be dedicated exclusively to their use. Dedicated motorcycle travel lanes can most commonly be found in some Asian countries where motorcycles make up a higher proportion of vehicle traffic. In the US, these treatments are typically not implemented. The researcher was unable to find any examples of motorcycle lanes used in the US.

Which VRUs benefit from this treatment?

Motorcyclists benefit from motorcycle lanes.

What are the important VRU considerations related to this treatment?

If a motorcycle lane is wide enough, it may encourage users in the lane to travel side-by-side. Depending on the desired conditions, this may be unsafe for the VRUs. Additionally, if the lane is too wide, motor vehicles may try to use it as a standard travel lane (130).

When should this treatment be implemented?

A motorcycle lane should only be implemented in areas where there is a very high motorcycle volume. General levels of this VRU can safely navigate most standard roadways.

What are the recommended design characteristics of this treatment?

To accommodate a single path of motorcyclists, a motorcycle lane should be at least 1.7 meters wide. To allow motorcyclists to travel side-by-side, the lane may be extended up to 3 meters wide (65). A two-stage left turn box design is recommended for motorcycle lanes at intersections. This is because in countries where motorcycle lanes are implemented, more than 50% of motorcycle accidents occur at intersections. A two-stage left turn box works similarly to a bike box, allowing motorcyclists to gather together at the head of an intersection and make their movements first (130).

Shared Motorcycle/Bus Lane

Figure 81: Standard Motorcycle/Bus Lane Example (130)

What is this treatment?

A shared motorcycle/bus lane is a standard bus lane or HOV lane which motorcyclists are also allowed to use for travel.

Which VRUs benefit from this treatment?

Motorcyclists

When should this treatment be implemented?

Where motorcycle traffic volumes are very high. This policy has not been adopted in the United States.

What are the recommended design characteristics of this treatment?

Standard bus or HOV lane design (130).

Chicane

Figure 82: Standard Chicane Example (20)

What is this treatment?

A chicane is an artificial narrowing or turn in a road used as a traffic calming measure.

Which VRUs benefit from this treatment?

All VRUs gain some benefits from a chicane, as they slow the speed of all traffic, though older and younger drivers may receive the most benefit.

When should this treatment be implemented?

A chicane should be considered as a traffic calming measure typically in suburban neighborhoods where controlling vehicle speeds is a priority. They should be used in place of speed humps wherever there are large volumes of pedestrians, bicyclists, motorcyclists, or other VRUs. According to ATA, chicanes are appropriate on low volume (ADT < 5000), lower speed (speed limit < 35 mph) roads and are best on neighborhood streets (15). State guidance avoids

providing standards for many traffic calming measures, such as chicanes. Many city guidelines also avoid specific strategies for traffic calming measures. When they are mentioned, the typical practice is to describe what the traffic calming measure is, such as in Polk County's guide, or to describe factors that may influence design considerations while still leaving the design itself to the engineer, such as in Boston's guide (114, 116).

What are the recommended design characteristics of this treatment?

A chicane should be designed as an S-shaped roadway with a return angle of 45 degrees or a more gradual taper and transition. The exact shape can be modified to fit the circumstances of the available ROW (20, 21). ATA recommends that chicanes be at least 20 feet long, with their width varied based on available space, and an 8:1 taper length (15). State guidance avoids providing standards for many traffic calming measures, such as chicanes. Many city guidelines also avoid specific strategies for traffic calming measures. When they are mentioned, the typical practice is to describe what the traffic calming measure is, such as in Polk County's guide, or to describe factors that may influence design considerations while still leaving the design itself to the engineer, such as in Boston's guide (114, 116). Dallas recommends chicanes be an "S" shape with a horizontal deflection based on the design speed of the roadway (128).

Speed Humps

Figure 83: Standard Speed Humps Example (122)

What is this treatment?

A speed hump is a low ridge set in a road surface to control the speed of vehicles.

Which VRUs benefit from this treatment?

No VRUs gain significant benefits from speed humps and many, including bicyclists and motorcyclists, are harmed more by speed humps than they are helped by them.

When should this treatment be implemented?

ATA recommends that speed humps be used on low volume (ADT < 4000), low speed (Speed limit < 30 mph) roads, preferably on neighborhood streets as a traffic calming measure to increase pedestrian safety. ATA recommends avoiding using them on bicycle priority corridors (15). Most states avoid giving recommendations regarding traffic calming measures, but

Massachusetts recommends speed humps be used on minor collectors and local roads with speeds of 15 – 20 mph and are inappropriate on higher-classified streets (45).

Speed hump usage varies widely across the US. Many cities avoid specific standards in their guides as well, often simply listing that speed humps can be used as a traffic calming measure (115, 120, 128 132). However, where recommendations do exist, they often conflict. Basalt, Sacramento, and Tacoma recommend that speed humps only be used after all other options are explored. These cities recommend that other traffic calming measures such as chicanes be used instead, as speed humps cause wear to vehicles and can be difficult for large vehicles to navigate (117, 133-135). For cyclists, Cleveland recommends that speed humps either be avoided or designed with gaps for bikes to avoid them (136). New Haven recommends that speed humps be used on low volume roads (ADT < 10,000) (137). ITE recommends that speed humps be used midblock on residential streets away from bus routes or emergency response routes on roadways without curb extensions (16). In general, speed humps are recommended to be used on neighborhood or local streets to reduce speeds.

What are the recommended design characteristics of this treatment?

ATA recommends parabolic or sinusoidal speed humps that are 12 feet across and 3.5 – 4 inches high (15). ITE provides a similar set of recommendations at 12 – 14 feet across, 3 – 4 inches high, and placed in a series spaced 300 to 600 feet apart. ITE also recommends advanced warning or signage and some type of pavement marking to ensure the speed hump is visible (16). Most states avoid giving recommendations regarding traffic calming measures, but the Massachusetts Complete Streets guide provides a similar recommendation to ATA and ITE, with speed humps that are 12 – 14 feet across and 3 – 4 inches high (109). Most cities avoid specific standards in their guides as well, but those that do tend to agree with ATA. Fort Lauderdale, New

York City, and Philadelphia have similar speed hump recommendations of about 12 – 13 feet across and 3 – 4 inches high (112, 113, 138, 139).

Lighting

Figure 84: Standard Lighting Example (15)

What is this treatment?

Adequate lighting is a primary concern for VRUs, as higher VRU crash rates occur under poor lighting conditions.

Which VRUs benefit from this treatment?

All VRUs

What are the recommended design characteristics of this treatment?

ATA recommends a typical lighting height that works well for pedestrians is between 12 – 17 feet (14). On lighting height, states and cities tend to disagree, both with the national guidance and with each other. Massachusetts recommends 12 – 15 feet high light posts because they support a calm traffic environment, while Georgia recommends lighting height of 30 – 50

feet, as the primary road user they are concerned with serving are automobiles (45, 69). In cities, lighting height can range from 12 – 14 feet in Seattle, 11 – 25 feet in Boston, 16 – 18 feet in NYC, etc. (114, 116, 123). Part of the reason there is so much variation in these requirements is that lighting may be used for varying purposes.

ATA recommends lighting spacing of 20 – 40 feet to serve pedestrians and other vulnerable road users (15). The studied state complete streets guides do not provide standards for lighting spacing. Few cities provide standards for lighting spacing, but again, there is no agreement. Boston recommends a lighting spacing of 50 – 120 feet based on the roadway type, Philadelphia recommends pedestrian street lighting be spaced every 60 feet, and San Diego recommends that standard street lights be staggered every 150 feet near bus stops and every 300 feet otherwise (112-114).

Tighter/Wider Radius of Curvature

Figure 8105: Standard VRU Accessible Curb Example (21)

What is this treatment?

While many roadway designs use tighter curb radii to limit speeds and make crossing distances safer for pedestrians and other VRUs, a wider curb radius can help older drivers navigate turns safely.

Which VRUs benefit from this treatment?

Pedestrians benefit from tighter curb radii, while elderly drivers benefit from a wider radius of curvature. These recommendations are at odds with one another, so designers must decide which users to design for.

What are the important VRU considerations related to this treatment?

A wider curb radius creates a longer crossing distance for pedestrians at intersections.

When should this treatment be implemented?

A wider curb radius should only be implemented at intersections where the elderly vehicle crash rate is high. Otherwise, a tighter turning radii is recommended to improve safety for pedestrians.

What are the recommended design characteristics of this treatment?

ATA offers only general guidance that tighter turning radii are preferred because they result in lower vehicle speeds and shorter crossing distances for pedestrians (15). ITE recommends that turning radii be between 10 – 30 feet for pedestrian and cyclists (16). Figure 86 below shows a few design options for curb radius.

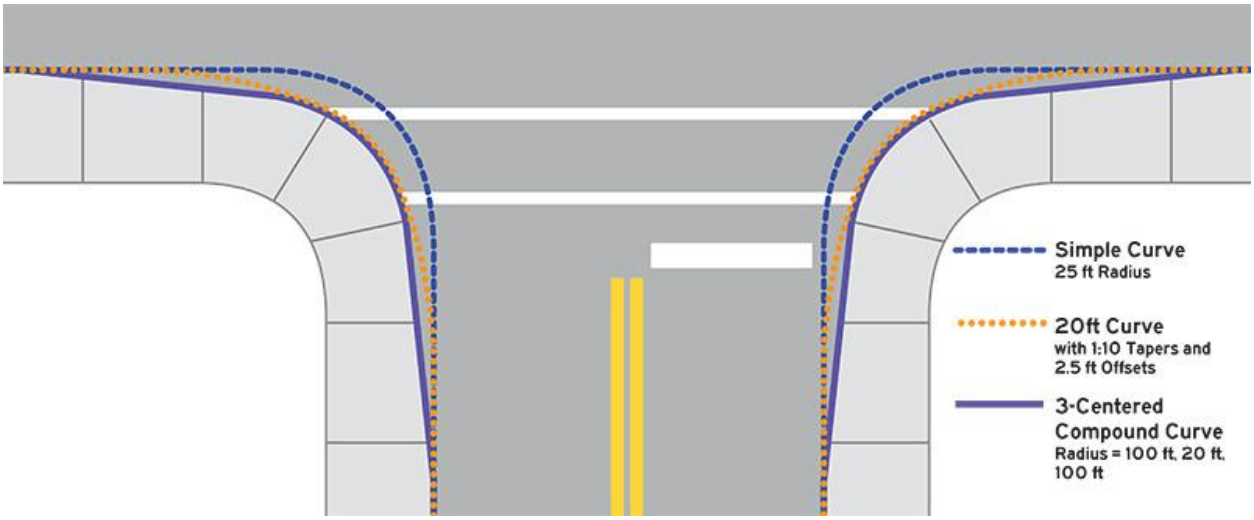

Figure 86: Standard VRU Accessible Curb Example (5)

VI.3 VRU Improvement Opportunities at Crossings

Standard vs Raised vs Zebra Crosswalks

Figure 87: Standard Raised Crosswalk Example (122)

What is this treatment?

There is general agreement about the geometric design of various crosswalks among complete streets guides. Agencies tend to differ however in the choice of what type of crosswalk provides the safest environment for all users. ATA recommends that standard crosswalks be used as the norm, while ITE adds that raised crosswalks may be more appropriate in some high-volume areas to increase pedestrian visibility in the crosswalk (15, 16). State and city guidance follow this same advice.

Which VRUs benefit from this treatment?

Pedestrians

What are the important VRU considerations related to this treatment?

While a raised crosswalk provides the most protection and visibility to crossing pedestrians, they also reduce traffic speeds.

When should this treatment be implemented?

Researchers suggest that traditional continental-style crosswalks are sufficient in most situations (140). Some researchers purport that zebra striping may be superior to other painted crosswalk designs as they may visibility for drivers (141). One study found that red-colored brick crosswalks are safer for pedestrians than painted or unmarked crosswalks (140). A study in Tanzania found that younger pedestrians preferred level crosswalks while most older pedestrians felt more comfortable with a raised crosswalk (142). Researchers agree that a raised crosswalk may be considered when reducing vehicle speeds is a priority (141). Crosswalks can be enhanced on complete streets with good lighting, special paving treatments, planters, pedestrian refuge islands, benches, and other amenities (143).

What are the recommended design characteristics of this treatment?

The minimum crosswalk width is 6 feet wide, per FHWA (16). However, wider crosswalks should be used to accommodate larger pedestrian volumes. Most cities and states omit standard sidewalk widths, allowing those decisions to be made on a case-by-case basis.

Pedestrian Refuge Median

Figure 88: Standard Pedestrian Refuge Median Example (21)

What is this treatment?

A pedestrian refuge median or island provides a respite to pedestrians and other users crossing wide roads.

Which VRUs benefit from this treatment?

Mostly pedestrians, but also bicyclists and other VRUs.

When should this treatment be implemented?

ATA recommends that pedestrian refuge islands be used on roads with speeds of 30 mph or less and an ADT of 20,000 or less, while ITE recommends that they be used at any unsignalized crossing or at any crossing where the roadway width exceeds 60 feet (15, 16). FHWA simply recommends that pedestrian refuge islands be used to shorten crossing distances,

but specifically recommends their use for elderly pedestrians (17, 19). FHWA's simple guidance is all most states and cities recommend as well. A few exceptions exist, though. Southern Nevada's guidance backs up ATA's recommendation, while San Francisco and San Mateo echo ITE's guidance (112, 144, 145).

Some researchers recommend that medians be used on all urban collector and arterial roads, excluding industrial areas. These medians may serve as pedestrian refuge islands (146). In general, researchers agree that a pedestrian refuge island is one effective way to reduce crossing distances for pedestrians. Curb extensions and narrowing the street width can also be considered (147). One study in Tanzania found that about half of pedestrians preferred crosswalks with a raised median to serve as a buffer area (142).

What are the recommended design characteristics of this treatment?

Nearly all national, state, and city guidance on median type agree that in most cases, a raised median is preferred to serve as refuge for pedestrians and other vulnerable users. Some researchers agree with the standards of a raised median. A raised median provides a buffer between traffic lanes along with a safe spot for pedestrians.

There is little agreement amongst Complete Street guides on median width. ATA recommends a 6-ft. median for pedestrians and a 10-ft. median for cyclists (15). ITE allows for a broad range of median sizes ranging from 4 – 18 ft., and NACTO recommends 10-ft. for cyclists (16, 20). Most states and cities prefer not to standardize median sizes to allow engineers and planners a chance to make that decision based on engineering judgement and local context. Some offer a broad range for context, like Dallas's Complete Streets Design Manual, which states that medians can range in width from 6 – 20 feet or more. The 6-ft. minimum is a requirement in several cities, such as Dallas and Portland, as well as states such as Virginia, to provide adequate

space for pedestrian refuge (107, 128, 163). Some research articles agree with a median width between 4-18 ft.

Midblock Crossing

Figure 89: Standard Midblock Crossing Example (21)

What is this treatment?

A midblock crossing is a marked roadway crossing that allows pedestrians and other non-motorized users to cross a roadway safely between intersections.

Which VRUs benefit from this treatment?

Mostly pedestrians, but also bicyclists and other VRUs

When should this treatment be implemented?

ATA and ITE provide similar recommendations for traffic conditions that support midblock crossings. ATA recommends that they be used on roadways with 4 lanes or less, speeds of 40 mph or less, and an ADT less than 15,000 (15). ITE shares that same speed recommendation, but only recommends midblock crossing use on roads with an ADT less than

15,000 if a median is present – otherwise, ITE reduces their recommendation to roads with an ADT of 12,000 or less. Additionally, ITE requires that there be 25 pedestrian crossings per day to justify a midblock crossing (134, 135). No state or city Complete Streets guide provides a specific recommendation for what environments they can work in, like the national guidance. When developing roadways to support multiple modes, especially pedestrians, researchers recommend midblock crossings to reduce crossing distances for pedestrians. Researchers also typically only recommend midblock crossings on low to mid-speed roadways (143).

ATA sets no minimum distance from intersections for a midblock crossing to be used, instead offering the guidance that midblock crossings be established based on an engineering study to reduce random crossing movements (15). Indeed, some states such as Georgia and Vermont provide similar guidance to ATA, while many other states use the same reasoning as ATA, but establish minimum standards (110, 111). North Carolina and Virginia recommend that midblock crossings be used every 600 feet, and Massachusetts recommend their use every 500 feet (106, 107, 109). At the national level, ITE provides a more liberal recommendation than the states with midblock crossings encouraged every 400 feet from an intersection in urban areas (16). Most cities avoid putting a number on this measure. Those that do, though, set conflicting standards, suggesting that this measure can change greatly in different locations. Fort Lauderdale recommends avoiding midblock crossings, but allows for their use with crossing signals when crossing spacing exceeds 400 feet (139). Philadelphia recommends that safe crossing opportunities be offered in urban areas every 300 – 500 feet, with midblock crossings added as needed to meet said criteria (113). Tacoma, WA allows for midblock crossings to be used in combination with transit stops on blocks longer than 500 – 600 feet (134, 135).

The latest research comes to conflicting conclusions regarding midblock crossing distance. According to one study, they have only a limited local impact on LOS (148). Another study found that midblock crossings are usually not necessary in downtown areas where signals are spaced more closely, but recognize that in suburban areas, distances between signals is too great to expect pedestrians to cross. While the researchers do not recommend a specific acceptable distance for pedestrians, they recommend that crossing should exist near bus stops (149). One study on pedestrian crossings suggests that density of crossings in urban areas should correlate with population density. In lower density areas, crossings are recommended every 800 to 1600 meters (~2600 to 5200 feet), every 300 m (~1000 ft.) in denser areas, and every 100 m (~300 ft.) in the urban core (150). In general, research has found that midblock crossings increase the LOS for pedestrians (151).

What are the recommended design characteristics of this treatment?

ATA recommends that midblock crossings be 6 feet minimum in width (15). This size meets ADA standards and allows for a pedestrian refuge area. No Complete Streets guides address this measure at the state level, and only a select few cities provide any sort of recommendations. Among those that do, however, Portland recommends that midblock crossings simply be the width of a standard crosswalk – which for them means 10 feet wide (163). This seems to be the standard implication across most other Complete Streets guides.

ATA recommends that midblock crossings be no more than four lanes of traffic across without using a crossing island (15). This is the standard adopted by many guidebooks for pedestrian refuge islands, though only few cities and no states provide that guidance in this context. Among those few, Portland echoes the ATA recommendation that midblock crossings include a median island when crossing four travel lanes or 50 feet (163).

Research has led to the MUTCD recommending a pedestrian walking speed of 3.0 ft./sec to be used when evaluating crossing distance/time (150). However, the FHWA recommends using an average walking speed of 2.8 ft./sec when designing crosswalks for the elderly (35).

As a minimum measure for crosswalks, warning road signs should be used at all crosswalks to indicate pedestrian movements in lightly traveled areas (149, 150). See the MUTCD for more details. Simple signage is encouraged for easy identification by the elderly (141). Pedestrian signals are also widely recommended at signalized intersections (35).

PHB/HAWK

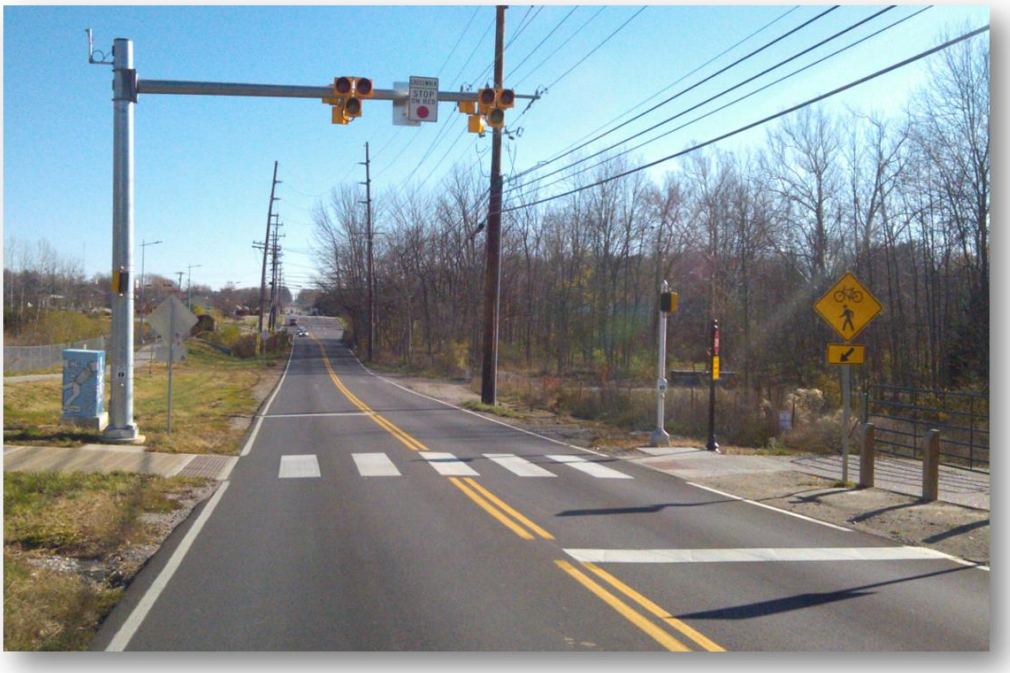

Figure 90: Standard PHB/HAWK Example (151)

What is this treatment?

A Pedestrian Hybrid Beacon (PHB) or HAWK beacon (High-Intensity Activated crosswalk beacon) is a traffic control device used to stop road traffic and allow pedestrians to cross the road safely outside of an intersection or standard midblock crossing.

Which VRUs benefit from this treatment?

Pedestrians and bicyclists can both benefit from a PHB.

When should this treatment be implemented?

ATA recommends that a PHB system be used when traffic control signals are not justified but traffic gaps do not permit safe bicycle or pedestrian crossings. ATA refers to the MUTCD standards which state that a PHB system may be considered when 20 pedestrians

and/or cyclists per hour cross at this mid-block crossing. Additionally, a max speed of 35 mph on the roadway is recommended for safe crossings (15). The MUTCD uses roadway speed, crossing length, and vehicle volumes in the following two figures to determine whether a PHB signal is justified (127):

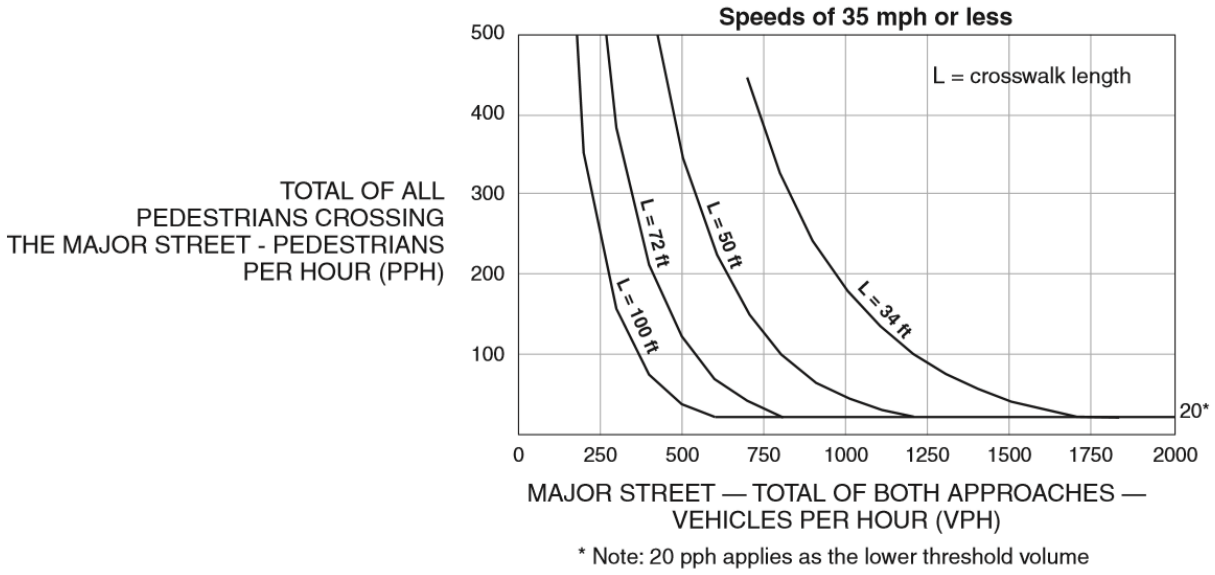

Figure 9111: MUTCD Guidelines for Installation of HAWK Signals – Low-Speed Roads (127)

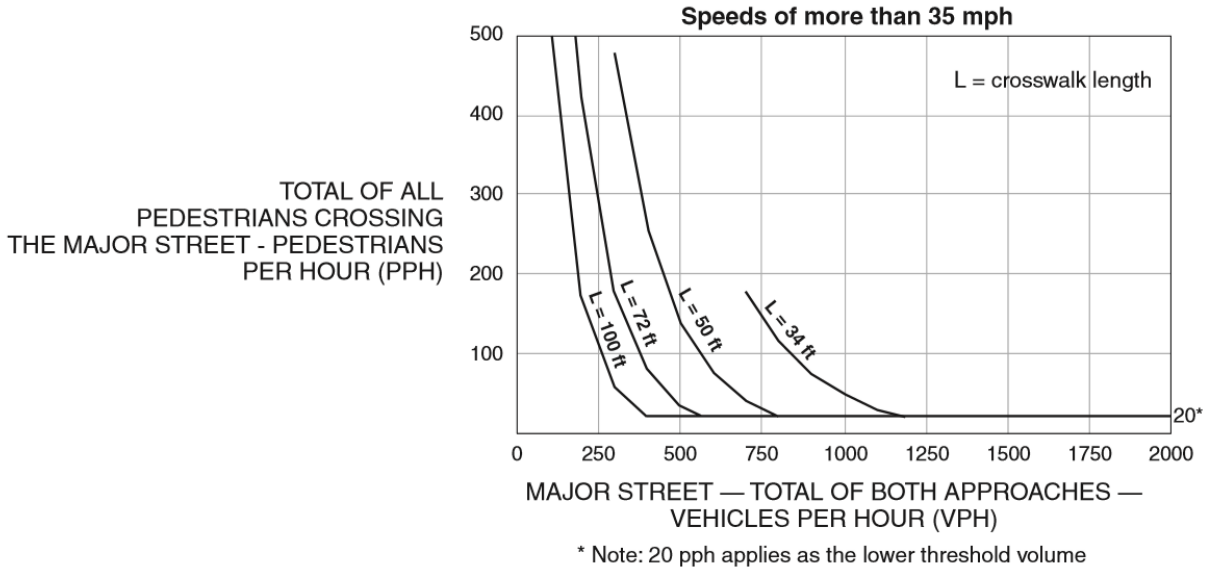

Figure 92: MUTCD Guidelines for Installation of HAWK Signals – High-Speed Roads (128)

What are the recommended design characteristics of this treatment?

A crossing at a PHB signal is similar to a standard crosswalk or midblock crossing except for the special PHBs. Two signal heads at either end of the crosswalk are equipped with push-buttons to activate the beacon, pedestrian crossing signal heads at either end of the road, and traffic signals to tell vehicle traffic to stop when the signal is activated (127).

Bollards

Figure 93: Standard Bollards Example (152)

What is this treatment?

Bollards and railings can be used to create a buffer between the roadway and any dedicated VRU facility to provide extra protection for the VRUs. They may be permanent or removable fixtures.

Which VRUs benefit from this treatment?

Pedestrians, bicyclists, and golf carts can benefit from the use of bollards as protection.

When should this treatment be implemented?

National guidance generally agrees that bollards and railings are appropriate on urban roads with lower speeds where an adequate buffer between motor vehicles and bicyclists and pedestrians cannot be obtained. (15, 16, 18, 21). State and city guidelines do not disagree with these standards.

What are the recommended design characteristics of this treatment?

ATA allows for a lot of variance in bollard shape, recommending that bollards be 4 – 24 inches in diameter and 3 – 4 feet high (15). FHWA recommends that bollards be spaced every 10 – 40 feet and be given a 1.5 – 3-foot buffer zone (19). Most states and cities neglect to provide standard sizes for bollard shape entirely, allowing engineers and planners the freedom to determine the type of barrier that makes the most sense in each scenario.

VI.4 VRU Improvement Opportunities at Intersections

Traditional Intersection

Figure 94: Standard Traditional Intersection Example (21)

What is this treatment?

The standard method of handling when two or more roads intersect.

Which VRUs benefit from this treatment?

All VRUs

What are the important VRU considerations related to this treatment?

In order to best accommodate older drivers, intersections should be designed to meet at as close to 90 degree angles as possible. If pedestrians, bicyclists, or other VRUs need to cross the roadway, standard crosswalk and signaling rules apply. Consider curb bulbouts, crosswalk design, and pedestrian refuge medians.

Additionally, right-turn corners may be appropriate at standard intersections. ATA recommends that right-turn corners be implemented at turns with a wide-turning radius and excessive pedestrian crossing distances, while FHWA focuses on cyclist use of right-turn corner islands to recommend they be used at areas where two separated bike lanes intersect to encourage two-stage turns for cyclists (15, 17, 19). Few states consider right-turn corner islands, but they agree with ATA. City guidelines also agree with the broad definition given by ATA, while no manuals focus on FHWA's bike-oriented use. Many city guides provide additional standards for right-turn channelization islands, including: >200 right-turns per hour and/or where many truck turning movements occur (120, 145, 154-156).

ATA broadly recommends that right-turn corner islands should be designed based on the space available between the right turn lane and the through lanes. While all state and city design standards fit this generic goal, several go further in describing the shape of a channelizing island. These guides agree that the channelized turn separating the island from the corner should be 55 – 60 degrees and that the corner radius of the island should be about twice as long as it is wide, with a long radius of 150 – 300 feet followed by a short radius of 20 – 50 feet (111, 113, 120, 138, 154, 156). There appears to be little disagreement over these standards.

Roundabouts

Figure 95: Standard Roundabout Example (5)

What is this treatment?

A roundabout is a circular intersection in which traffic flows continuously around a center island. This allows users to move continuously through an intersection rather than stop at a sign or signal and wait for the ROW. Smaller roundabouts with few lanes can be used as a traffic calming measure. Larger roundabouts with more lanes can be used to regulate heavy vehicle traffic flows.

Which VRUs benefit from this treatment?

All users can potentially benefit from the use of roundabouts. However, there is a divide over their usefulness for bicyclists and older drivers. Consistent, simply designed roundabouts however can improve travel for these VRUs as well.

What are the important VRU considerations related to this treatment?

When designing a roundabout, it is important to make users understand how each mode should travel through the roundabout. Should cyclists disembark and treat the roundabout as if they were a pedestrian or should they stay with vehicle traffic? Should dedicated facilities be created within the roundabout for other VRUs? It is vital to understand these problems and portray the intended pathway through the roundabout plainly to each user.

When should this treatment be implemented?

All the guidance is in general agreement that roundabouts should be used for cyclists and pedestrians when reduced speeds are desired (15, 16). The decision to make a roundabout is typically dependent on many other factors. Pedestrians should be accommodated with 6 ft. minimum refuge islands and cyclists should be encouraged to use the roundabout in normal traffic lanes. Bike lanes should not be installed in roundabouts (157).

Research is split on the effect of roundabouts on cyclist safety. While they reduce the number of conflict points at an intersection and have proven safety benefits for motor vehicles, a Belgian study found that roundabouts increased bicycle injury rates. Other studies have observed that roundabouts can complicate the relationship between cars and bikes, especially when cyclists enter/exit a roundabout (7). An Indian study found that elderly drivers, pedestrians, and cyclists feel very concerned when traveling through roundabouts and their needs and limitations should be considered when designing a roundabout intersection (158). After a study in Flanders in 2006, researchers concluded that roundabouts pose more danger to vulnerable road users than typical intersections (158). Elderly road users may have difficulty navigating new roundabouts due to their relative infrequent occurrence within the US. Therefore, they are not recommended in areas with a disproportionately high proportion of elderly persons.

What are the recommended design characteristics of this treatment?

NCHRP's 2nd edition of Roundabouts: An Informational Guide provides abundant guidance and recommendations for designing roundabouts. Most state and local agencies provide only limited guidelines on roundabout design, instead leaving engineers and transportation planners to use national guidelines from FWHA. Rather than lane width, roundabout size is recommended based on the inscribed circle diameter. For single lane roundabouts, a small roundabout diameter of 105 ft. is required to accommodate a WB-50 (WB-15) design vehicle. To accommodate a WB-67 (WB-20), NCHRP recommends that single-lane roundabouts have an inscribed diameter of 130 – 150 ft. Multilane roundabouts range from 150 – 250 ft. in diameter (157).

Both ATA and ITE recommend that roundabouts be one-lane to better accommodate pedestrians and cyclists (15, 16). FHWA also recommends that roundabouts be one-lane to best accommodate elderly users (17). For vehicle-priority, ITE recommends 1-lane roundabouts for an AADT of 20,000 or less and 2-lane roundabouts for an AADT of 40,000 or less (16). State and local guidance agree that 1-lane roundabouts are typically preferred for cyclist and pedestrian usage, but none provide guidance based on AADT like ITE did. NCHRP provides an extended methodology to estimate traffic flows in a roundabout in Roundabouts: An Informational Guide, 2nd Edition, and how to apply this information to design choices. For example, if the volume-to-capacity ratio of the roundabout exceeds 0.85, changes to improve the roundabout flow should be made, such as adding additional lanes (157).

FHWA recommends that pedestrian refuge/splitter islands be utilized at a roundabout to accommodate elderly pedestrians (17). State and city Complete Streets guides, though, tend not

to create separate design recommendations for subsets of the vulnerable user population. Regarding pedestrians, ATA echoes FHWA's recommendation, unchanged for all pedestrians. However, ATA also recommends that roundabouts remain a single-lane to equally prioritize all vulnerable road users (15). ITE recommends that pedestrian crossings be placed at least 25 feet from each entry (19). States and cities that discuss roundabout design all agree with ATA's general recommendation for pedestrians. Only a few discuss the location of these crossings, and fewer agree with ITE. Georgia's guidance agrees with the ITE guidance for where to locate pedestrian crosswalks in a roundabout (110). However, North Carolina only requires that these crosswalks be placed one car-length away from each entry, based on similar guidance from Los Angeles (106). This is only a minimum requirement and the recommended design examples in North Carolina's handbook all appear to utilize distances greater than a standard car length.

Regarding cyclists in roundabouts, ATA recommends that signage indicating cyclists are sharing the road be present in and around the roundabout. Additionally, if the roundabout is greater than one lane wide, bike ramps should be used to allow cyclists to access the sidewalk and treat the roundabout like a pedestrian. ITE has very similar standards, recommending that bikes either mix with traffic at a roundabout without using pavement markings or that ramps be installed at all entrances to again allow bikes to act as pedestrians (15, 16). City and state guidance also generally agrees with these standards.

Curb Bulbouts

Figure 96: Standard Curb Bulbout Example (21)

What is this treatment?

A curb bulbout (also known as a neckdown, curb extension, bump-out, etc.) is a traffic calming measure which extends the sidewalk into the roadway, reducing crossing distance for pedestrians and other road users.

Which VRUs benefit from this treatment?

Primarily pedestrians, but also bicyclists and some other VRUs

When should this treatment be implemented?

National guidance from ATA, FHWA, and ITE agree that curb bulbouts are a useful tool to increase awareness of pedestrians and reduce pedestrian crossing distances (15, 16, 19). ATA goes a bit further in recommending when they can be used, specifically low-volume (ADT < 20,000), low-speed (speed limit < 30 mph) roads (15). While state and city guidelines do not

include ATA's specific speed and volume requirements, there is total agreement that curb bulbouts should be used wherever possible at pedestrian crosswalks.

What are the recommended design characteristics of this treatment?

The national guidance disagrees slightly on curb bulbout shape. ATA recommends that curb bulbouts be 7 – 8 feet wide, usually where curb parking exists (15). ITE standards state they must be at least 6 feet wide (16). The ATA manual describes a curb bulbout that takes up the approximate width of a parking lane, while ITE standards are set to allow for the shoulder to continue at a curb bulbout. However, state and city guidelines almost universally do not provide specific guidelines for curb bulbout shape, instead stating that curb bulbouts should simply be the width of the outside lane – typically a parking lane. In practice, these guides will often match the national standards.

Combined Bike Lane/ Turn Lane

Figure 9712: Standard Combined Bike Lane/Turn Lane Example (20)

What is this treatment?

A combined bike lane/turn lane provides a suggested space at an intersection for bicyclists to travel and safely wait for a traffic signal within a dedicated motor vehicle turning lane. A dashed line within the turn lane indicates where the cyclist should travel (20).

Which VRUs benefit from this treatment?

Bicyclists

What are the important VRU considerations related to this treatment?

There is some disagreement over the best implementation strategy for this and other types of bicycle measure which travel through an intersection. FHWA recommends that the bike lane end 45 feet before the intersection to allow cyclists to enter the traffic stream and act as a vehicle at intersections (18). However, other practices disagree. States and most cities agree with ITE's

guidelines that bike lanes should either stop at the intersection or extend all the way through with a hashed line (16).

When should this treatment be implemented?

ATA, FHWA, and ITE recommend that bike lanes be used at intersections with significant bicycle usage and conflict between vehicles and cyclists but lower traffic volumes than for more extreme measures like a bike box (15, 16, 18). NACTO agrees and further specifies that this type of measure should be implemented on streets where a right-turn lane exists but there is not enough ROW to maintain a standard-width bicycle lane, or on streets where there is already a high proportion of right-turning vehicle traffic (20).

What are the recommended design characteristics of this treatment?

The full lane width should be at least the standard width for a right-turning lane at an intersection. The suggested bicycle area indicated by a dotted 4-inch line should be a minimum of 4-feet wide (20). A NACTO recommended design rendering appears below in Figure 98.

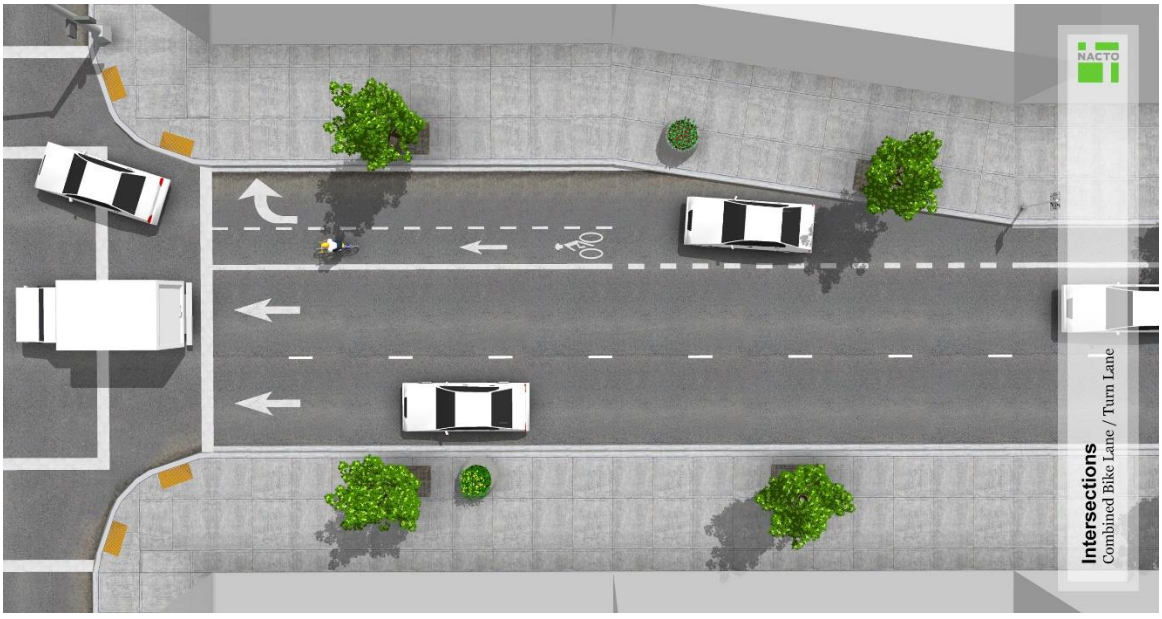

Figure 98: NACTO Combined Bike Lane/Turn Lane Rendering (20)

Bike Box Intersection

Figure 99: Standard Bike Box Example (20)

What is this treatment?

A bike box is a designated area at the head of a traffic lane at a signalized intersection which indicates where cyclists should stop to queue at the intersection. It provides a safe, visible location for cyclists to gather and begin travelling ahead of motor vehicle traffic at intersections (20).

Which VRUs benefit from this treatment?

Bicyclists

When should this treatment be implemented?

Bike boxes are arguably the most significant – but also most intrusive – bicycle safety countermeasure that a facility could decide to implement at an intersection. Each design guide may word it slightly differently, but the message is the same from the cities, the states, and

national guidance from ATA, FHWA, ITE, and NACTO: bike boxes should be considered at signalized intersections with high conflict between bicycles and motor vehicles (particularly right-turning vehicles and left-turning bikes) (15, 16, 18, 20, 21). Bike boxes should be considered where bicycle traffic peaks and experiences the most interaction with high motor vehicle traffic.

What are the recommended design characteristics of this treatment?

ATA, FHWA, and NACTO all recommend that a bike box be 10 – 16 feet deep. This also lines up with AASHTO's standards for bike boxes. The only slight difference is that FHWA recommends that the bike box extend across all travel lanes only if allowing left-turns for cyclists is a priority, while NACTO recommends that the bike box always extend across the travel way (15, 18, 20). Several cities, such as Knoxville and Louisville, recommend using AASHTO's standards (60, 129) of 10 – 16 feet. A few others – Boston and Polk County – simply recommend the average, 13 feet (114, 116). An example rendering from NACTO of an ideal bike box appears below in Figure 100.

Figure 10013: NACTO Bike Box Rendering (20)

VI. SUMMARY OF INFRASTRUCTURE IMPROVEMENTS

The goal of this thesis was to provide guidance for improving Alabama state highways to support the safe travel of vulnerable road users. VRU considerations were gathered from the current state of literature to gain a better understanding of the challenges that these users face on the road. The 2013-2015 CARE database of Alabama crash statistics was used to identify trends in VRU safety and to create an ordered probit model to analyze what factors were most significant to understanding the crash. The results of this analysis serve to highlight what risk factors are most important among VRUs. The current national, state, and local guidance on designing for VRUs was consulted and used to provide guidance on what countermeasures should be used, when to use them, and design tips on how to deploy those measures. Countermeasure suggestions were tailored based on urban/suburban/rural communities, roadway type, posted speeds, traffic volumes, and VRU volumes. Taken all together, this thesis aims to provide Alabama transportation planners and engineers with guidance on what specific concerns VRUs face within the state and what potential measures can be taken to improve VRU safety.

In the future, more work should be focused in the following areas to continue to improve the safety of VRU groups in Alabama:

- More work needs to be done to find the best bicycle solutions at intersections. This is a very dangerous part of the roadway for bicyclists, but currently, there is very little specialized intersection cycling infrastructure in Alabama. Research should focus on determining the best countermeasures for the level of cycling use within the state.
- Further studies should focus on standardizing roundabout designs; A standard approach should be developed for when roundabouts be used in place in of intersections. A

consistent policy for how VRUs should navigate the roundabout should be developed to be easily understood. Some national guidance exists, but recommendations vary.

- Most VRU crashes are concentrated among older and younger drivers. More research is required to determine methods to target the safety of these VRUs and reduce these crashes.
- Further work should focus on examining how VRUs travel in rural environments to find the best countermeasures to these challenging environments and gain a better understanding of how these systems are currently utilized.
- There is currently very little guidance for designing roads to make traveling safer for farm equipment, golf carts, or transport service animals. Further studies are required to better understand the needs of these users in the state of Alabama and come to a consensus on how to design for these unique vulnerable users.

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