# Pedestrian Safety Technologies

White Paper


## *How can Texas agencies improve the safety of pedestrians through identification of areas of concern and implementation of technology solutions?*

Pedestrian safety has long been an area of focus for public agencies, policymakers, and researchers. Despite previous efforts in this area, over the last decade the number of crashes involving pedestrians, and subsequently the number of pedestrian deaths, has been on the rise. This trend has been exacerbated during the COVID-19 pandemic as more people are outside seeking recreation and the number of vehicles has dropped, causing average speeds to increase. During this last decade, technology has also continued to develop. With these newer technologies, pedestrians can not only be detected better, but now have the ability to communicate with infrastructure to get real-time information on work zone conditions and intersection operations. However, along with new detection and smart infrastructure technologies that benefit pedestrians, the rise of new vehicle technologies, such as autonomous vehicles (AVs), has created uncertainty for pedestrians, who for the most part lack trust in and knowledge of AV operations. This paper explores key strategies that public agencies, policymakers, and private companies can use to ensure the safety of pedestrians, with the goal of moving Texas out of its ranking as one of the ten most dangerous states for pedestrians.

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## KEY STRATEGIES

01

**Review speed limits along high injury networks**
Risk of death and severe injuries has been found to increase with higher speeds; speed limits along high injury networks should be reviewed and lowered where appropriate in an effort to lower risk to pedestrians.

02

**Develop standardized use of intersection IoT**
As technology continues to develop and becomes more ubiquitous, agencies should develop standardized use plans for intersections, with the current suites of sensors covering more operational situations.

03

**Implement V2V and V2I safety programs**
An essential component is coordination between districts and regions to implement V2V and V2I technologies for smart work zones and other connected vehicle applications identified through previous and ongoing projects, such as Texas Connected Freight Corridors.

04

**Promote AV communications studies and pilots**
Lack of trust and effective communications between AVs and pedestrians has continued to be an issue around the public adoption of AVs. In an effort to increase the trust of AVs, the promotion and funding of studies and pilots aimed at pedestrian and AV communications should be undertaken.

05

**Encourage the development of Vision Zero Goals**
Adoption of Vision Zero goals allows agencies to create a plan for decreasing pedestrian deaths and injuries. While a number of cities within Texas have adopted Vision Zero plans, coordination and knowledge sharing can encourage the further adoption of Vision Zero goals throughout the state.

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## INTRODUCTION

Over the last several years, the number of pedestrian fatalities nationally has reached levels not seen in almost 30 years. While vehicle technology has increased passenger safety, with new automated features adding new layers of information available to drivers, pedestrians have remained susceptible to serious and fatal injuries. In a recent report, the Governors Highway Safety Association (GHSA) estimated approximately 6,590 pedestrian fatalities in 2019—the highest number of pedestrian fatalities since the late 1980s and early 1990s, and more than a 53% increase since their lowest in 2009 (GHSA, 2020; IIHS, n.d.a.; GHSA, n.d.).

This rise in pedestrian deaths has prompted public agencies to reevaluate their policies and initiatives to better account for road users other than drivers. Through the adoption of long-term goals and strategies, often referred to as *Vision Zero*, pedestrian deaths can be significantly reduced. One of the first countries to adopt such goals, Sweden recognized that traditional road safety measures assume that humans drive as perfectly as possible, never making mistakes in any given situation. This is problematic in that if a crash does occur, the blame can then be placed on the pedestrian instead of the driver. With this recognition, planners could design future system component such that the inevitable crashes do not lead to severe consequences for pedestrians (Road Safety Sweden, 2019).

Following the successes observed in Sweden and other Nordic countries, cities in the US have begun to shift from an emphasis on driver performance to overall system safety, with a focus on reducing the consequences of crashes. The same improvements observed in the Nordic countries can be achieved in the US, with efforts aimed at a few key areas. These areas include safer roads, smarter vehicles, and sensible driver behaviors. Potential solutions for each focus area are highlighted and discussed in following sections.

## A CLOSER LOOK AT TEXAS

Texas, in particular, has taken up the charge to change the course at the state level. In just the last four years, Texas has experienced a spike in pedestrian deaths, accounting for nearly 700 roadway fatalities, or approximately 18% of the 3,893 road deaths in 2020 (Pettaway, 2020). Due to the high percentage increase in pedestrian deaths, Texas was ranked by Smart Growth America as the 10th most dangerous state for pedestrians in their latest state ranking, moving back two spots after being ranked 8th in their previous report. Among the metropolitan areas listed in the report, six of the top 50 most dangerous metropolitan areas for pedestrians are located in Texas, with the Houston metropolitan area ranking at number 18 based on Smart Growth America's pedestrian danger index (Bellis et al., 2021).

The Texas Department of Transportation (TxDOT) has led numerous initiatives to promote driver and pedestrian safety. In response to the state recording a road fatality every day since November 2000, TxDOT announced its Vision Zero goals of halving the number of road fatalities by 2035 and reaching zero deaths by 2050 (Downey, 2019). A number of these initiatives are public awareness campaigns designed to engage the public in safe driving and traveling practices, such as staying alert, putting the phone down, and following posted speed limit signs and applicable traffic regulations.

Acting as an umbrella campaign covering all driving aspects, the *Be Safe. Drive Smart. Campaign* was a year-long awareness and

education initiative designed to encourage safe driving, with a focus on the state's energy sectors, work zones, and the I-35 corridor. As part of this campaign, TxDOT created a list of priority topics for safe driving, including the following practices:

- Drive a safe speed for traffic, weather, and road conditions
- Put your phone away and focus 100% on driving
- Use extra caution when driving at night or in bad weather
- Yield to pedestrians and bicyclists when turning at crosswalks
- Slow down in school zones and work zones

To reduce and eliminate roadway deaths within the state, TxDOT launched its #EndTheStreak initiative and Smart Work Zones program. These programs aim to increase driver awareness, leveraging technology to increase roadway safety. The #EndTheStreak campaign is designed as a social media and grassroots campaign to raise awareness by encouraging individuals to tag family and friends in posts, calling on them to say how they will change driving behaviors to avoid fatal crashes. Work zones are dangerous to both drivers and road crews; the use of intelligent transportation systems (ITS) can greatly improve the operations and safety of these zones. Leveraging the information that is gathered by ITS equipment, officials can reduce traffic delays, provide real-time information to travelers, and improve performance metrics for future work zone designs. Through the Smart Work Zones program, TxDOT has developed and published its *Design Guidelines for Deployment of Work Zones Intelligent Transportation Systems (ITS)*, providing guidance on zones that can benefit from ITS and guidelines on the setup of these systems.

While the above initiatives and campaigns are broad and target driving behaviors, TxDOT has also launched a campaign that is focused on pedestrians and non-motorized road users. Noting that Texas has seen a 17% increase in pedestrian fatalities from traffic crashes from 2015 to 2019, TxDOT launched the campaign to educate and bring awareness to not only drivers but also pedestrians. Through their analysis TxDOT identified the following as the top contributors to crashes involving pedestrians:

- Pedestrians failing to yield right-of-way to vehicles
- Drivers failing to yield right-of-way to pedestrians
- Driver inattention
- Speeding

Utilizing billboards and commercials, the campaign brings attention to driving behaviors and the risks that these behaviors represent for pedestrians and other non-motorized road users. To help local municipalities with pedestrian infrastructure projects, TxDOT operates the Transportation Alternative Set-Aside Program. Through this program, funds for locally sponsored bike and pedestrian projects are administered for communities with populations less than 200,000. For communities with populations greater than 200,000, the funds are distributed to the metropolitan planning organization (MPO) who then administers the funds. Past projects have included sidewalk rehabilitation and improvements, connectivity and accessibility enhancements, and the establishment of safe routes to school corridors.

While Texas' efforts have begun to yield positive results for pedestrians, Texas is continuing to look for opportunities to do better. To further improve

pedestrian safety in Texas, efforts should target three goals: Safer Roads, Smarter Vehicles, and Sensible Behaviors.

# SAFER ROADS

## Challenges

As cities have grown, ever-changing land use and transportation modes have had an impact on infrastructure needs and the safety of pedestrians. With the rise of automobiles and increased automobile speeds over the last century, sprawling development patterns have made it increasingly challenging for people to access affordable housing, employment, and other opportunities using transit and other non-automobile modes. Increased reliance on automobiles and expanding urban development have led to pedestrian challenges due to:

- Sprawling land use and autocentric street design
- High-speed facilities
- Urban intersection complexities

### Sprawling Land Use and Autocentric Design

US cities have seen significant growth over the last century, growth that has exponentially increased with the introduction of automobiles. Automobiles allowed residents to live further away from their workplaces, in areas where they could have larger homes and more affordable land, with the highway system accelerating this trend. As more residents chose to move outward from the urban core, this shift in residential location led to significant urban sprawl, with land use changing to match the increasing city sizes. As part of these changes in land use, single-use zoning was established to provide for a separation of residential, commercial, and business areas. This type of zoning further separated people from their work and led to cities having multiple central business districts. While cities kept their downtown central business districts, separate business districts formed closer to the suburbs where their employees were located. This formation of multiple business clusters around city peripherals, along with the predominance of single-use zoning and the dilution of dense populations in the urban core, reinforced the autocentric nature of US cities. The autocentric environment welcomed an increase in larger and higher-speed road facilities. Texas in particular has several examples of sprawling cities, with 5 of the top 15 largest cities in the US: Houston, San Antonio, Dallas, Austin, and Ft. Worth.

As the land patterns in cities changed, walkability decreased in concert with the increase in high-volume roads. Envisioned as a way to better connect cities and improve intercity travel, interstate highways were also used as a means to better connect those in the suburbs to the downtown core. These highways, intended to ease congestion within the core of cities, had unintended consequences. Engineers designed the highway system with a priority on efficiency—resulting in a highway system that was routed through residential areas and bifurcated previously walkable neighborhoods (Stromberg, 2016; Smithsonian, n.d.). This placement of highways has led to dangerous situations for pedestrians who need to cross these major roadways in order to access services and shopping (IIHS, 2019). As a result, a significant portion of pedestrian deaths in these areas occur away from an intersection, as some pedestrians attempt more direct routes to the businesses they need to access.

### High Speed Facilities

While lower-speed streets represent a significant portion of the network within a city, urban streets with higher speed limits (40+ mph) comprise 52% of

pedestrian death locations; in contrast, just 17% of pedestrian deaths occur on high-speed roads in rural areas (IIHS, n.d.). As reported by the Austin American-Statesman, in 2019, two out of every five people killed on the City of Austin's roads were pedestrians. Following national trends, the majority of the deaths occurred on major roads with speeds 40+ mph, including highways and service roads (Bradshaw, 2020).

As pedestrians and cyclists are travelling without structural protections around them to absorb the force of a crash, even minor increases in speed have exceptionally large impacts on the safety of pedestrians and cyclists. Tefft, in his 2013 study, discussed how the risk of severe injury to a pedestrian increases from just 10% at 17 mph to 25% at 25 mph up to 90% at 48 mph (Tefft, 2013). This increase in speed versus risk of injury is significant, as the majority of local roads that have posted speeds of 25 mph also tend to be found in residential areas with few or no sidewalks, requiring pedestrians and motor vehicles to share the road. Even more significantly, as cities have adapted to increased calls for alternative modes of transportation, many collector roads with speed limits posted between 35 and 40 mph have been fitted with cycling and pedestrian facilities, placing these users in close proximity to vehicles traveling at higher speeds.

Over the last year, a renewed interest in pedestrian-focused facilities has emerged. During the COVID-19 pandemic, many municipalities turned toward local streets to provide a safe outdoor space for local residents. These spaces, often referred to as Slow Streets or Healthy Streets, are segments of roads blocked to through-traffic that allow local residents a pedestrian-friendly space to social distance while also being outdoors and exercising. Along with these spaces, local agencies have also seen renewed interest in installing traffic-calming measures to help slow down vehicles through residential areas. These measures often include the installation of speed humps and multi-way stop signs.

**Complex Urban Intersections**

In their discussion of pedestrian fatalities, the National Highway Traffic Safety Administration (NHTSA) found that pedestrian deaths occurred predominantly in urban areas. Looking further at the data, a large portion of pedestrian fatalities occur at intersections. As intersections are complex and have a high number of vehicular and pedestrian movements, they present a unique challenge to pedestrian safety.

Even with dedicated infrastructure for pedestrians (such as crosswalks), traffic density, inadequate number of signalized crossings, and intersection geometries pose threats to pedestrians. Pedestrian signal timings rely on long-held assumptions on pedestrian walking speeds, with FHWA's MUTCD recommending an average speed of 4 ft/s for use in crosswalk timing. The use of this standard walking speed is especially problematic for the elderly and those with conditions causing them to walk slower, who are often unable to cross in the amount of time given by the traffic signal. Average walking speeds range from as slow as 2 ft/s to 3.5 ft/s depending on the individual's disability and use of assistive devices (FHWA, 2006).

In response to these challenges, agencies and researchers have suggested a number of solutions. Many of the solutions involve adjusting the timing of signals, including creating exclusive pedestrian-only phases and allowing pedestrians a head start before vehicles are given the green signal. Giving pedestrians a head start also enhances their visibility and further reiterates the pedestrians' right-of-way over turning vehicles (NACTO, n.d.).

Additionally, many agencies have recognized the benefit of alerting pedestrians to the number of seconds left within the walk phase of the signal and have over the last decade added countdowns to pedestrian signal heads. Along with the improvements to pedestrian signalization, curb extensions have been increasingly added, which shorten the distance pedestrians need to travel and allow drivers to better detect and visualize pedestrians.

## Solutions

**Multimodal Roadway Design and Road Diets**

To increase pedestrian safety, a shift from autocentric road design to multimodal designs can allow agencies to make pedestrians the focal point. As part of the efforts to improve pedestrian and bicyclist networks, cities are turning to a renewed interest in road diets (Figure 1), and the use of healthy streets. Road diets typically involve the reconfiguring of a roadway from often a four-lane undivided roadway segment into a three-lane segment that consists of two through lanes and a center two-way left-turn lane. By reducing the number of through lanes, the reclaimed space within the roadway can be used to integrate other uses, such as bicycle lanes, improved sidewalks, bus shelters, or pedestrian refuge islands to improve crosswalk safety. By better integrating these road segments into an overall plan to increase active transportation, quality of life is often improved and crashes are typically reduced in the range of 17 to 47%, accompanied by a decrease in vehicle speeds as well (FHWA, 2016).

While road diets have been successfully implemented in a variety of locations, they are not a one-size-fits-all solution. Road diet applications have historically performed best when the road has an average daily traffic (ADT) count around or less than 20,000 vehicles per day, with some researchers suggesting an upper limit closer to 16,000 vehicles per day. At higher traffic rates, road diets can actually have the opposite effects to what is desired, leading to increases in congestion and adverse

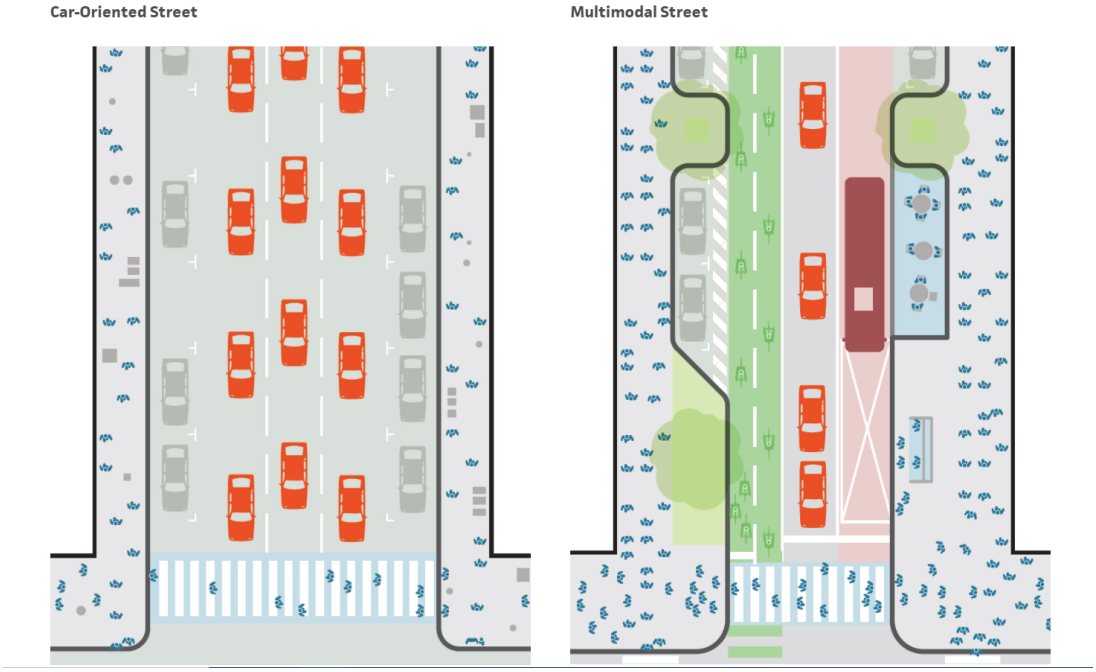


*Figure 1: Road diet before and after (source: http://carfreeamerica.net/road-diet-guide/)*

conditions for pedestrians (FHWA, 2014). However, when following the guidance on ADT, road diets can utilize underused space for multimodal uses, increasing not only the safety of the street but the overall capacity.

**Healthy Streets Initiatives**

The COVID-19 pandemic has also shed new light on the repurposing of street space. As traffic volumes decreased and working from home increased, the need for pedestrians and cyclists to have additional space to travel while socially distancing became a priority for local agencies, leading to the aforementioned Slow Streets or Healthy Streets. As these spaces were envisioned as temporary, the typical closure setup involved a simple sawhorse and barrel, as seen in Figure 2. While these streets were originally intended to be temporary, neighborhood associations have been petitioning cities to make the spaces permanent. To further their calls for permanence, some residents implemented half-day demonstrations on how these spaces could be transformed with permanent barriers replacing the construction barricades.

Along with the use of local streets to provide activity space for residents, cities have begun the process to utilize space once dominated by major highways as green spaces within urban areas. As the US highway system was developed and constructed, these major highways were located within proximity to many city downtown business districts. As a result, many downtown locations have wide sections of public space that are inaccessible due to the major highways bisecting the city through the central core. In an effort to reclaim space once taken up by highways, Dallas, for example, has utilized a cap-and-cover model to create the Klyde Warren Park for use as public spaces for recreation and entertainment. The park opened in 2012 as five acres of green space set atop a deck covering an eight-lane recessed highway. The before and after images of the park (Figures 3 and 4) show how the new configuration not only provided more recreational space but also enhanced pedestrian access to neighboring streets and buildings, such as the Dallas Museum of Art, which faces a section of the new park space.


*Figure 2: Healthy Street in Austin, TX*

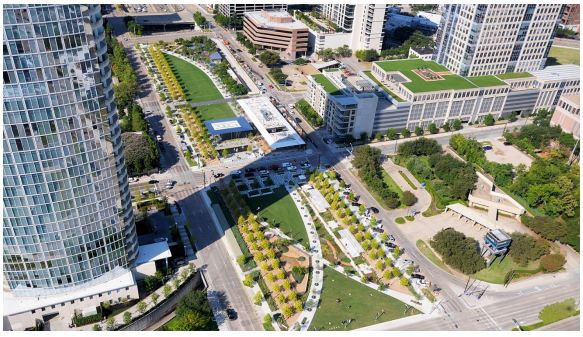

*Figure 3: Klyde Warren Park after—Dallas, TX*

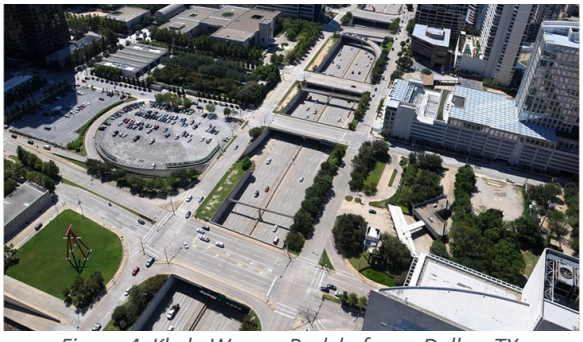

*Figure 4: Klyde Warren Park before—Dallas, TX*

**Pedestrian Detection Technologies**

In an effort to modernize the operations of both vehicles and intersections, agencies are upgrading their systems to enhance their detection capabilities.

Enhancing these technologies has several uses, including traffic data collection; traffic conflict detection; jaywalk event detection; and recording and broadcasting detailed information to alert CAVs and connected non-motorists users to movements and incidents in the immediate area.

Lidar, one technology that has seen a reduction in cost over the last few years, has been increasingly used by agencies for pedestrian detection. Unlike cameras that use images as the basis of analysis, lidar uses point clouds as the basis of obstacle detection and tracking for avoidance and mitigation, including the detection of other vehicles and vulnerable road users. While traditional camera technology is widely used, pairing these systems with lidar detectors offers several benefits, such as the ability to work in both daylight and nighttime settings, track identities of objects anonymously (providing a solution to privacy issues associated with facial recognition), and—when paired with an AI cloud system—broadcast the presence of pedestrians within the intersection.

In testing their systems, Velodyne has studied the use of lidar in both roadside units (RSUs) and vehicle-based units. They found that lidar provides 360-degree detection with high accuracy and frequency and is able to function in both daytime and nighttime conditions, capabilities not provided by camera-based solutions. In field tests conducted in Reno and Henderson, Nevada, lane-based vehicle volume accuracies were found to be 95% or higher. As part of these field tests, lidar units were incorporated into flashing beacons as part of lidar-based automatic rectangular flashing beacons. Integrating lidar with mature industry products allowed the research team to gain an advantage by providing 24/7 trajectory data for all traffic types.

As part of their ability to collect data 24/7, lidar systems have been tested in both daylight and nighttime lighting conditions. While testing organizations have standards for detection systems in daylight settings for Pedestrian Automatic Emergency Braking (PAEB) functionality, many such organizations do not have standards for testing these systems in nighttime lighting. Along with the flashing beacons, Velodyne tested their lidar platform on vehicles to determine its ability to detect pedestrians crossing the road in a nighttime setting, and thus confirm the utility of lidar in PAEB systems. The tests confirmed that camera and radar-based systems underperform in nighttime and poor lighting conditions, whereas lidar systems are able to detect the presence of pedestrians in almost all of the tests conducted. These results show that utilizing lidar, or a suite of sensors that includes lidar, can increase the detection performance of both vehicles and intersection systems as compared to relying on a single sensor type.

***SECTION SUMMARY***

- Review and enforce speed limits.
- Include pedestrians in street design by providing safe spaces for pedestrians in the streetscape.
- Consider the use of a suite of sensors for pedestrian detection in all lighting conditions.

# Smarter Vehicles

## Challenges

### Work Zones

Work zones represent a unique obstacle for pedestrians and drivers alike. As each work zone is unique, they often require drivers and pedestrians to travel in unexpected locations within the roadway or sidewalk. In 2020, Texas saw more than 22,000 crashes occurring within the state's work zones. As a result of those crashes, four construction workers and 35 pedestrians were killed (TxDOT, n.d.).

Due to construction and work zone activities, pedestrians face several challenges when attempting to navigate these areas. One of the most common challenges is uneven walking surfaces, and the potential for drop-offs close to pedestrian facilities. While these drop-offs and uneven surfaces themselves may not be the direct cause of serious harm to or death of a pedestrian, they can lead to pedestrians walking out into the road or a work zone to navigate around the uneven sidewalk, placing them in higher risk areas for serious injury.

To avoid placing pedestrians near construction activities and in direct conflict with vehicles and equipment entering or exiting a site, sidewalk diversions and detours are common. While designed to keep pedestrians safe, if these detours are not marked and signed appropriately, pedestrians may ignore warnings or cross streets at hazardous points to avoid work zones. Along with the physical diversion, many work zone and construction sites use fencing around the site in order to keep unauthorized people off the work site.

While these fences help separate pedestrians from the construction taking place, they also create a barrier that does not allow pedestrians to see when a work vehicle or piece of equipment is about to exit the site. These fences can also block pedestrian signal heads if work zones encroach on intersections, leading to pedestrians ignoring traffic signals and crossing when they think there is a sufficient gap within the traffic.

### Vehicle Size

NHTSA and GHSA have found that vehicle size affects the outcomes in crashes involving pedestrians and cyclists. Single-vehicle crashes have overwhelmingly (91%) accounted for vehicle crashes involving pedestrian fatalities (NHTSA, 2019). Passenger cars make up the majority of the vehicles involved in these crashes, but GHSA notes that SUVs are seeing a higher increase in crash rates compared to sedans (GHSA, 2020). NHTSA also went on to mention that pedestrians involved in single-vehicle crashes were often struck by the front of the vehicle rather than the side or rear.

Within the classification of passenger vehicles, understanding the relationship of vehicle size to pedestrian safety is important. Recent studies have found the probability of death for a pedestrian who is hit by a larger vehicle, compared to average vehicle size, is almost 3.5 times greater than for a pedestrian who gets hit by a smaller vehicle. A recent small-scale study performed by the Insurance Institute for Highway Safety (IIHS) found that the front-end designs of SUVs and larger vehicles, which tend to be taller and more squared off compared to sedans and coupes, may be the main factor in these pedestrian deaths (Gorzelany, 2020). One reason for this is that when hit by larger vehicles, pedestrians tend to be struck around the midsection and chest area with severe injuries to major organs, whereas smaller vehicles tend to hit pedestrians in the lower extremities, resulting in less severe injuries to major organs. These impact zones are represented in Figure 5, which demonstrates with both a sedan and SUV that a child is significantly more at risk of being injured in

areas with vital organs as compared to an adult, where the risk is greater when impacted by an SUV.


*Figure 5: Comparison of vehicle bumper height to pedestrian height*

In the US, vehicle safety standards and testing are governed by NHTSA. The tests are used to help determine how safe passengers are traveling in a vehicle, but rarely, if ever, take pedestrian safety into account. Along with vehicle safety tests having few requirements for pedestrian safety considerations, the US has also left it up to vehicle manufacturers to determine the amount of safety technologies and automated functions incorporated into new vehicle designs. As such, only 47% of 2019 vehicle models offered both crash mitigation and auto-braking features. Furthermore, in 23% of models crash mitigation and auto-braking were add-ons.

Compared to sedans and coupes, fewer models of pickup trucks have driving automation incorporated by manufacturers. This is important because the top-selling vehicles in Texas are pickup trucks, with the Ford F-Series leading sales (Insurify, 2021). Among the issues with larger vehicles is the increased size of blind spots. These blind spots can prove dangerous to pedestrians, as drivers are not aware of their presence and thus the risk of collision and injury increases. Vehicle automation technologies, such as blind spot warning, backup cameras, adaptive headlights, and pedestrian detection technologies, can help lower the risk of potential collisions with pedestrians. Due to the lack of any requirements or national goals for automation, the US Government Accountability Office (GAO) attributes the slow adoption of pedestrian detection systems on newer vehicles as a factor in the recent death tolls (Wilson, 2020).

**Vehicle Sociolinguistics**

For pedestrians, non-verbal communications from drivers are vital in showing the intent of vehicular movements. The use of non-verbal communication is vital, as misinterpretation of intent is a leading cause of injury to pedestrians from vehicles. From the National Motor Vehicle Crash Causation Survey, the “false assumption of others’ actions” was found to lead to 5% of all crashes, some of which can potentially be attributed to miscommunication between driver and pedestrian. Miscommunication or lack of communication had a significant impact on the number of pedestrians involved in fatal crashes in 2014, with around 26% of fatal crashes being attributed to “failure to yield right of way” due to the communications challenges.

While direct verbal communications between drivers and pedestrians are not feasible in most instances, pedestrians and drivers alike do use various forms of non-verbal communications. Both drivers and pedestrians use a variety of methods to communicate, including gestures, facial expressions, and built-in vehicle devices. For example, a pedestrian who is intending to cross the street in an area with no signals or stop sign may establish eye contact with a driver to determine whether the vehicle will stop for them. One study showed that when pedestrians stared directly at the driver as the vehicle was approaching, the driver yielded on average 12.6% more often than when the pedestrian did not make eye contact—not a large percentage but nonetheless significant.

Along with eye contact, drivers and pedestrians often employ gestures to signal intent; hand gestures or body posturing can be used to signal

either the pedestrian's intent to cross or the driver's intent to slow down and stop. The use of hand gestures has been identified as a useful form of communication between pedestrian and driver, as many times drivers may not be able to correctly decipher a pedestrian's intent solely based on the perceived trajectory. Body language provides vital clues to drivers to a pedestrian's intended movements, especially as it relates to crossing the street.

As AVs operate with limited driver intervention, the question of how the sociolinguistic communications between pedestrian and vehicle are incorporated into automated systems becomes a focal point. Beyond the use of turn signals, many AVs do not yet have the means to communicate intent to pedestrians. Along with communicating their intent, AVs need improvements in reading and interpreting gestures and body language of pedestrians.

## Solutions

### Smart Work Zones and Connected Corridors

Texting and in-vehicle infotainment systems have led to a rise in work zone crashes. Connected vehicle (CV) technologies offer the potential to reduce the risk of pedestrians and construction workers being injured or killed in work zones. Utilizing C-V2X and digital short-range communications (DSRC), vehicles can use safety messages to broadcast information about their movements to other nearby vehicles, machinery, and pedestrians. Furthermore, the infrastructure can broadcast information about the work zone's roadway geometry and any lane closures. In pilot projects conducted in Virginia, workers were equipped with vests containing C-V2X technologies. These vests allow workers to communicate their position through basic safety messages that can then be broadcast by roadside units to C-V2X enabled vehicles. The work will be carried out by the Virginia Tech Transportation Institute to develop the software and systems for the pilots, with Commsignia providing the RSUs and ITS stack. The project will utilize both the Virginia Connected Corridors and the Virginia Smart Road Corridor. Other alerts and warnings, such as upcoming lane shifts and lane closures, can also be broadcast to notify drivers of the presence of workers (Jonston, 2020). As distracted driving is a significant issue within work zones, the pilot project aims to broadcast safety messages directly to drivers through the infotainment systems in CVs in an effort to focus driver attention on road conditions.

In 2018, USDOT chose the Wyoming DOT as one of three CV pilots to deploy CV technology along a 400-mile stretch of I-80. The pilot equipped 300 vehicles including snowplow trucks, patrol cars and fleet trucks, along with 75 roadside units with CV technologies. The vehicles and roadside units used DSRC to broadcast and receive messages. Along with broadcasting weather conditions, the pilot program broadcasted work zone activities or restrictions, detours, collision avoidance, and the presence of maintenance and emergency vehicles downstream of a vehicle's current location (Powell, 2018; Gopalakrishna et al., 2019).

In Texas, the Texas Connected Freight Corridors (TCFC) will be Texas' largest deployment of CV technology. The project is developing vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications with commercial vehicles to address safety and mobility needs. The project is developing up to six CV applications, including work zone warning. The TCFC project is planning on utilizing knowledge gained through Texas' Smart Work Zone program in which ITS are leveraged to provide construction-related information to drivers and obtain performance metrics for future work zone improvements. To better disseminate the data that

is collected through these programs, Texas participates in the USDOT Work Zone Data Exchange program, in which data and metrics from a number of states and locales can be exchanged and reviewed in order to highlight solutions that increase the safety of work zones for both drivers and workers.

**Automated Features on Larger Vehicles**

Automated vehicle features have slowly gained traction over the last decade. These technologies have included not only lane assist and adaptive cruise control but also blind spot warning systems, collision warning systems, and pedestrian detection systems. Along with the increase in technology available, there has been an increase in the number of vehicles where these automated features are standard, primarily on smaller passenger cars. Although studies in the past have found that the technology still needs improvements, it continues to advance. A recent study by the IIHS found that the Subaru EyeSight technology can reduce pedestrian-related insurance claims by up to 35%. A slightly higher reduction was found for cars that were equipped with the second generation of EyeSight, due to its upgraded cameras having wider detection capabilities (Mays, 2018).

Just as important as the evolution of vehicle technologies and the improvement of pedestrian detection capabilities, the introduction of these technologies in larger vehicles will be crucial to preventing crashes that lead to pedestrian fatalities. As discussed above, pedestrians struck by larger vehicles have a high probability of death compared to being struck by a smaller vehicle. As such, it is important that automated features that can detect and respond to pedestrians not only be available for smaller vehicles but larger SUVs and pickup trucks as well. Recently, Ford and Dodge announced that models of their Ford F-150 and Dodge Ram 1500 trucks would feature automated features, such as automatic braking, with pedestrian detection also being included on the new F-150s (Kurczewski, 2021). The inclusion of automated braking and pedestrian detection features on these models is significant as they represent a large market share of pickup trucks that are favored in Texas.

**Innovative Vehicle Communications**


*Figure 6: Automated vehicle pedestrian communication*

To improve communication between AVs and pedestrians, OEMs made efforts to develop and increase effectiveness of communication systems that employ LED displays, lights, and sounds. Lyft, Uber, and Drive.ai have all tested forms of LED sign displays (Figure 6) or window displays to help communicate with pedestrians. While Lyft and Drive.ai focus on providing information to pedestrians on the vehicle's intended movement, Uber has chosen to take the route of notifying the pedestrian of when or where to walk.

In their Voluntary Safety Self-Assessment, Ford showcased their efforts to create a standardized communications format utilizing a light bar near the top of the front windshield. To communicate, the light bar uses white lights that flash in certain patterns to notify pedestrians of its movement intentions. For example, the white light passes back and forth slowly when the vehicle is yielding, and when the vehicle is stopped and preparing to move,

the lights blink rapidly to attract attention. Ford limits the use of light colors to white and amber based upon the Federal Motor Vehicle Safety Standards. While they recognize the benefits of developing intent communication, Ford also recognizes that unless the development of systems is uniform and standard between developers—such that every car communicates the same way—using lights and onboard signals won't be enough. As such, this opens up avenues of exploration for CAV task forces, such as the Texas Governor's CAV Task Force, which could encourage research looking into the creation of uniform communication forms between CAVs and pedestrians.

***SECTION SUMMARY***

- Increase V2V and V2I work zone efforts to notify drivers and pedestrians of work zone disruptions.
- Promote the integration of automated functions in larger vehicles, such as pickup trucks and SUVs.
- Explore communication tools between AVs and pedestrians.

## SENSIBLE BEHAVIORS

### Challenges

**Lack of Public Awareness and Empathy**

In an effort to understand dangers to pedestrians, officials often rely on crash reports that represent pedestrian deaths and injuries in terms of statistics and neglect to humanize the issue. Crash reporting is a useful tool to better identify the most dangerous areas for pedestrians and shed light onto dangerous behaviors of both drivers and pedestrians that lead to crashes. While reports are provided, not every instance of a pedestrian crash or death is required to be reported and sent to DOTs. As stated in TxDOT's *Instruction to Police for Reporting Crashes,* only crashes that involve at least one vehicle in transport (on a roadway or in motion within or outside the trafficway) will be classified as a reportable traffic crash. That does not prohibit agencies from creating a report for other crashes, but simply stipulates that agencies are not required to send such reports to TxDOT. While this covers a majority of traffic crashes, with the rise of non-motorized forms of transportation (scooters, e-bikes, etc.), an increasing number of crashes involving pedestrians and non-motorized forms of transportation could be left out of statistics. Furthermore, guidance is given that only crashes involving injury, death, or damage greater than $1,000 should be submitted to the state DOT.

Crash reports offer critical insight for not only agency officials in the identification of stretches of roads and intersections for improvements to pedestrian safety, but also for the creation of education and safety campaigns to bring awareness to behaviors that place drivers and pedestrians at risk for fatal crashes. Reports can also be used by researchers to help identify pedestrian movements and thus better understand how to incorporate

those movements into planning processes to reduce the risk of potential harm and death (TxDOT, 2019).

Along with police agencies reporting crashes involving pedestrians, news agencies often report traffic crashes as part of their news coverage. In a study looking at news coverage of pedestrian involved crashes, Ralph et al. found that, while subtle, news stories often shifted the blame from drivers onto pedestrians. The researchers found that blame, and thus role in a crash, was shifted by using certain phrases that emphasized a vehicle's actions instead of the driver's (e.g., "a car jumped the curb" versus "a driver drove over the curb"). This use of object-based versus human-based language was particularly worrisome when it came to the reporting of hit-and-run crashes, in which reporters often used the phrase "the vehicle drove away," with more than a quarter of the articles analyzed by the researchers failing to mention the driver at all. The researchers suggest that reporters should move beyond the discussion of blame and begin to contextualize pedestrian-related crashes with a public health focus, with coverage that communicates preventive information targeting enforcement of speeding, distracted driving, and impaired driving (Ralph et al., 2019).

**The Devastation of Drunk Driving**

Further compounding the problems of infrastructure, driver and pedestrian intoxication lead to increased risk of injury and death. Alcohol-impaired driving accounted for 28% of all traffic deaths in 2016, with more than 1 million drivers arrested for driving under the influence. Although this is a significant number of arrests, it only accounts for roughly 1% of the annual self-reported alcohol-impaired driving violations amongst US adults. Figure 7 charts annual incidents of drunk driving through 2014.

Furthermore, NHTSA has found that a significant portion of pedestrians involved in fatal collisions were intoxicated; these findings indicate that approximately one in three fatal pedestrian crashes involved a pedestrian with a blood alcohol content (BAC) above the legal limit, and an estimated 17% of drivers with BACs above the legal limit. The IIHS has found that fatal pedestrian crashes involving intoxicated persons have declined from 1982 but

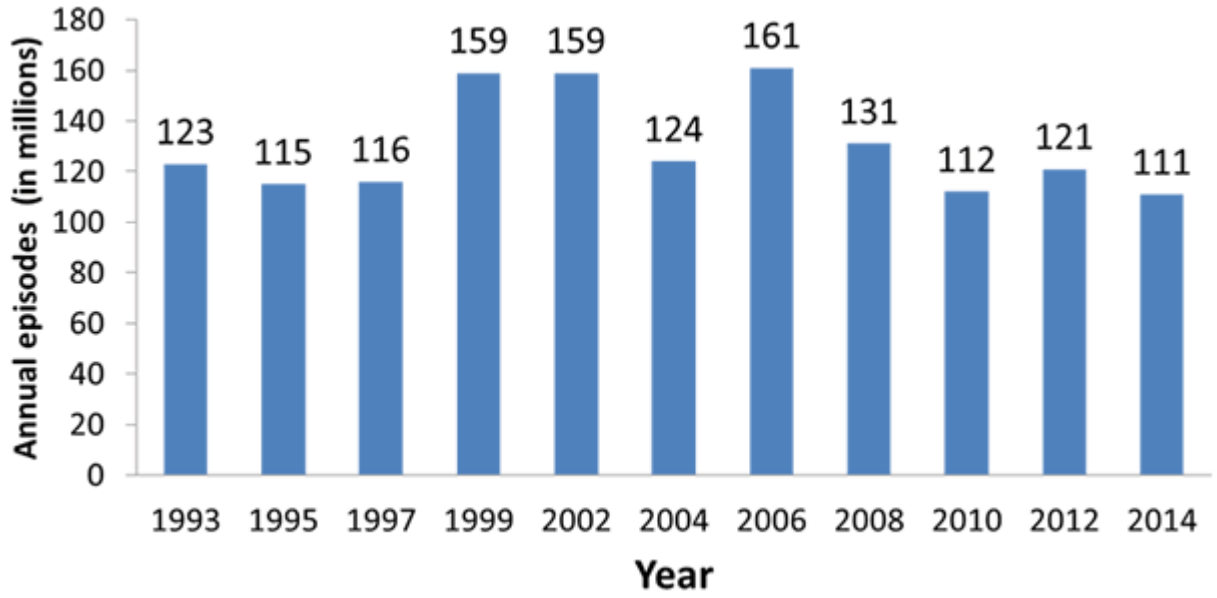


*Figure 7: Drunk driving episodes per year*

still represent a significant portion of pedestrian deaths at night (NHTSA, 2019; IIHS, n.d.).

Furthermore, pedestrian fatalities have been found to be the highest over the weekend, with Friday and Saturday nights being popular days for people to go out to restaurants and entertainment (IIHS, n.d.). One potential reason for the increased number of pedestrian deaths on the weekend is an increase of intoxicated drivers and pedestrians on these days, with almost half of all crashes involving a pedestrian death also involving alcohol. With an increased number of people out at night on the weekend, it is not surprising that the number of pedestrian deaths also increases during nighttime conditions (75% of pedestrian deaths) as lighting conditions make it difficult to detect and avoid pedestrians.

**Challenges to Vulnerable Populations**

The challenges described in previous sections are especially problematic for vulnerable populations, including those experiencing homelessness, older populations, and those with visual or physical impairments. Of the pedestrian deaths in Austin in 2019, half of the deaths involved a victim who was homeless. This highlights the danger of many homeless camps being located near or under major highways and overpasses, requiring pedestrians to cross heavily trafficked roads. Other factors that contributed to pedestrian deaths followed national trends, including speeding, failing to yield, and impaired and distracted driving (Bradshaw, 2020).

Along with those experiencing homelessness, older populations face increased risks when attempting to cross the street. As discussed earlier, intersection crossing times often use a rule of thumb value, leading to situations in which the crossing time is not adequate for a range of pedestrian users. As result of these timings, and other intersection complexities, 40% of pedestrian deaths involving those aged 70 or more occur at intersections, as opposed to 22% of pedestrian fatalities involving those aged below 70 years, highlighting the need to rethink the methods used to design intersections and consider user groups outside the average user (NHTSA, 2019; IIHS, n.d.a, IIHS, n.d.b).

Recognizing the safety needs of vulnerable pedestrians, the Americans with Disabilities Act (ADA) of 1990 established standards for facilities to be provided for those with disabilities, including the visually impaired and those with mobility impairments. As part of these standards, the ADA establishes how curb ramps, pedestrian push buttons, and tactile markings should be installed or retrofitted to guide users through intersections. While ADA standards provide the design basis for pedestrian facilities, many intersections still use old designs that do not promote safe pedestrian movement. This situation is an ongoing barrier for those with disabilities, as facilities only need to meet ADA requirements if they are newly built or altered, leaving room for intersections that haven't undergone rehabilitation work to remain outside of ADA compliance.

With old designs and outdated facilities present at intersections, those with visual impairments and physical disabilities are placed in direct conflict with vehicles. These intersections often lack proper tactile warnings that provide information to those with visual impairments on where the sidewalk ends and the crosswalk begins. Along with the lack of auditory signals, the lack of tactile devices can result in those with visual impairments crossing the street at a dangerous location. The same situation can occur if proper curb ramps are not provided for those using wheelchairs and other mobility assistive devices. Without a proper ramp available, these pedestrians may be forced to use routes that place them in the roadway, using the same space as vehicles.

# Pedestrian Safety Technologies

White Paper

## Solutions

### Vision Zero Campaigns


*Figure 8: Cover of Washington, DC's Vision Zero Plan*

In an effort to reverse the trend of increasing pedestrian deaths, transportation agencies have joined together to create Vision Zero. Vision Zero is a safety strategy aimed at reducing and ending traffic-related fatalities and serious injuries, while increasing safe and healthy mobility for all. Sweden first adopted Vision Zero goals in the early 1990s, leading to major reductions in traffic deaths. Sweden further embraced the goals of Vision Zero in 1997 when the country's parliament adopted long-term goals and strategies. Since this adoption, Sweden has decreased its traffic-related deaths by more than half. This reduction in traffic deaths was accomplished through the recognition that many crashes are caused by human error, and that the transportation system should be designed such that a crash does not lead to the loss of a person's life. As Sweden saw success in its traffic death reduction, other countries began to adopt Vision Zero goals and strategies. Recently Oslo, Norway announced that it has achieved its goals, with zero traffic-related deaths in 2019.

As the benefits of implementing Vision Zero strategies in Sweden were seen, momentum has increased in the US, with cities across the country adopting Vision Zero plans. Among the cities implementing Vision Zero goals is Washington, DC (Figure 8). Publishing their plan in 2016, the District Department of Transportation (DDOT) developed goals and policies through the use of interagency workgroups. These workgroups focused on priorities within data, enforcement, education, and engineering. Figure 9 provides the DDOT goals.

As well as having workgroups, DDOT engaged its citizens through public outreach. Through the public outreach, DDOT received a total of 2700 survey responses. From these responses, it was found that 16% of responders reported that they had been seriously injured in a traffic crash, with 47% of those injuries occurring to people walking or biking. To help frame their Vision Zero plan, the public outreach also asked the public to list their top concerns when traveling. As is typical for most jurisdictions, the top three concerns were speeding drivers, distracted drivers, and people ignoring traffic signals. As not all issues are captured through crash statistics, the DDOT created safety maps to further capture unreported incidents and potentially hazardous situations. Utilizing the maps created and data collected, the connections between crashes and other factors were explored, with factors including photo enforcement, speed and crashes, arterials and crashes, and vehicles for hire. From the feedback and analysis, the Vision Zero plan created focused on four themes: Create Safe Streets, Protect Vulnerable Users, Prevent Dangerous Driving, and Be Transparent and Responsive.

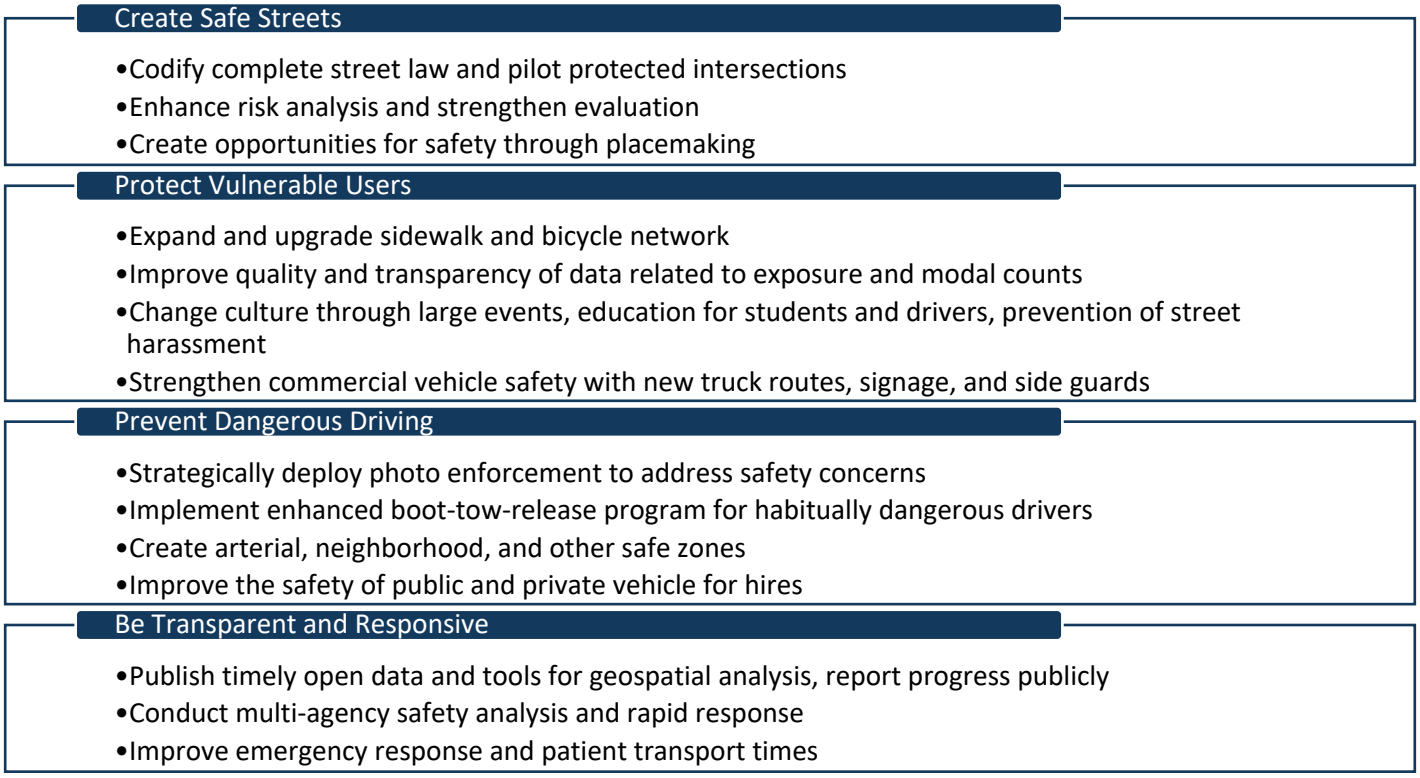


*Figure 9: DDOT Vision Zero Goals*

In Texas, six cities have adopted Vision Zero goals: Austin, Dallas, Ft. Worth, Houston, Laredo, and San Antonio. Many of the agencies involved first analyzed crash data and highlighted areas of safety, known as high-injury networks, which account for the highest number of traffic deaths. In their plan, the City of Austin has identified a number of near-term actions to be completed, including the need to advance public transportation initiatives, advance active transportation initiatives, update transportation elements within the city land development code, and participate in the Capital Area Metropolitan Planning Organization (CAMPO) 2045 planning process. These short-term actions are steps necessary to meet the city's Vision Zero goals by reducing the number of single-occupancy commuting vehicles and increasing the network of bicycle and pedestrian facilities around the city to encourage active modes of transportation.

**Drunk Driving Prevention Technologies**

According to a recent IIHS article, alcohol impairment has been a factor in approximately 30% of US roadway deaths every year for the past decade, affecting both drivers and pedestrians. Focused on ending alcohol-related driving deaths, the Automotive Coalitions for Traffic Safety (ACTS) and NHTSA have partnered with automakers to create a research program to develop technologies to detect alcohol in a driver's system. This research program, Driver Alcohol Detection System for Safety (DADSS), was started in 2008 and expanded in 2013. DADSS aims to integrate alcohol detection technologies into vehicles in the form of a breath-based and touch-based detection system.

The breath-based system is capable of instantaneously measuring the alcohol content of the driver's breath upon the ignition of the vehicle. Depending on the driver, the tolerance of detection

can be set to “zero-tolerance” for drivers under 21 or set to the legal limit of 0.08 (Ryan, 2019). The touched-based system is designed to use infrared technology to measure blood alcohol levels under the skin surface. It should be noted that neither technology is an engine ignition lock, with the engine being allowed to turn over if the driver hits a limit higher than allowed. While the engine can turn over, the designers of the system have created it in such a way the car will not move, enabling the driver to charge their phone to call a cab or a ride-hail service. In a step forward in developing the systems, the breath-based system has recently been given a Society of Automotive Engineers (SAE) standard, SAE J3214—Breath Based Alcohol Detection Systems. The standard defines accuracy and precision requirements of breath alcohol concentration measurements as well as the acceptable testing criteria and parameters (DADSS, 2021).

DADSS has partnered with both Virginia and Maryland to integrate and test their prototypes in fleet vehicles. Through a partnership with James River Transportation, the Virginia Department of Motor Vehicles announced that they would conduct in-vehicle, on-road test trials of the breath-based alcohol detection system. These test trials, the first conducted by a state, used NHTSA highway safety grant funds to fund the program. Prototypes of the detection system were installed in four vehicles in the James River Transportation commercial fleet. In 2019, the prototype testing expanded when Maryland announced its partnership. The Maryland Department of Motor Vehicle Administration installed the technology in seven state-owned vehicles. As part of their Driven to Protect Initiative, the partnerships with both Virginia and Maryland aim to field test the breath-based system in an effort to provide data and feedback collected from the prototype sensors, and from drivers themselves.

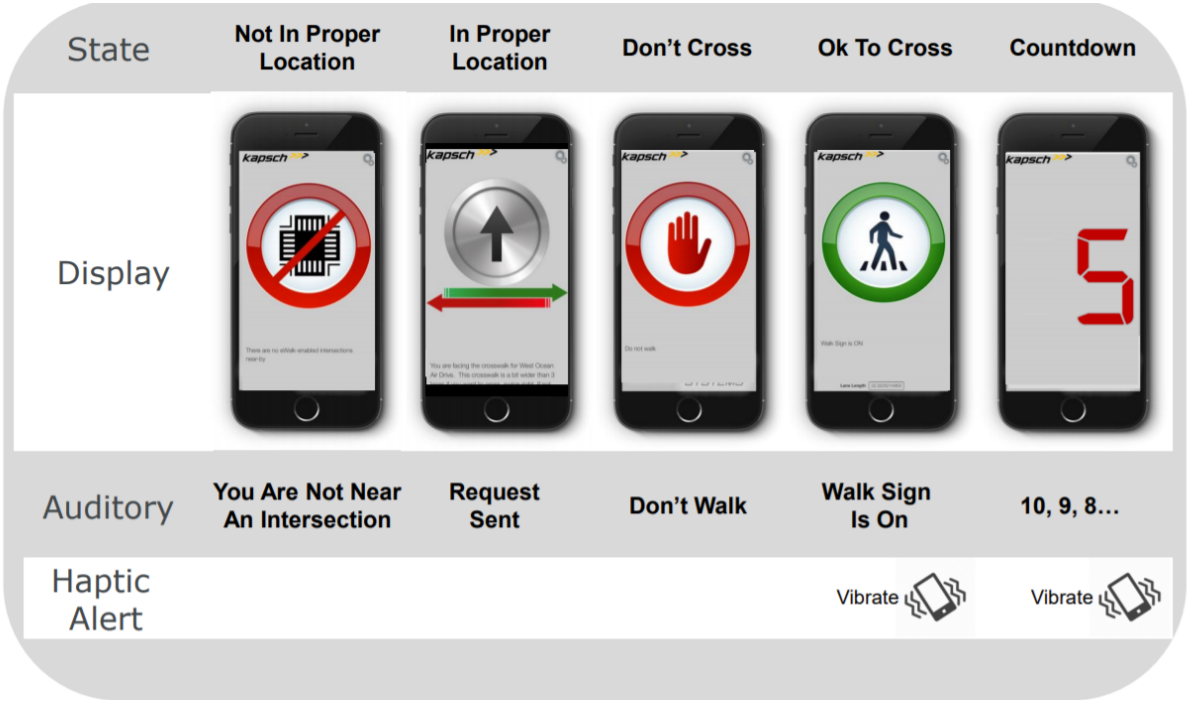


*Figure 10: eWalk smartphone app interface*

**Technologies to Assist the Mobility-Impaired**

The elderly and visually impaired often face the largest brunt of difficulty in navigating crosswalks. Developed in an effort to assist the visually impaired with navigating crosswalks, eWalk is a smartphone-based app created by Kapsch using smart infrastructure technologies (Figure 10). The app allows for a user to communicate, via the app and servers in an RSU, to activate the traffic signal. Once the traffic signal is activated, the app generates auditory and haptic alerts to help navigate the pedestrian through the intersection, with additional alerts for when the walk phase is ending and the pedestrian countdown has begun. The application uses GPS along with algorithms to determine the direction of travel for the pedestrian and help alert the pedestrian to the correct location to activate the signal and cross safely.

With the app communicating directly with infrastructure through the use of RSUs, Kapsch has expanded its use to provide information to AVs as well. Utilizing a cloud-based approach, Kapsch improved the eWalk app to alert vehicles approaching midblock crossings of the presence of a pedestrian, helping promote slower speeds for those vehicles. A further refinement of the app has allowed for better detection of pedestrians who might be blocked from view by parked vehicles or during low light situations.

A similar smartphone-based app, PedNav, has recently been validated by the Minnesota DOT. The app, developed in cooperation with researchers from the University of Minnesota, provided guidance to blind and visually impaired pedestrians through both signalized and unsignalized intersections. Utilizing traffic signal data and intersection data stored into a digital map base, a network of Bluetooth Low Energy (BLE) beacons was deployed at intersections and other posts in the research area to provide location data to pedestrians as they navigated their route. Additional hardware was installed within the control boxes for intersection that would broadcast real-time traffic signal phasing and timing (SPaT) information. With the use of a cloud-based server to store and transmit the location and SPaT data, the research team was able to validate the effectiveness of both position and message accuracy at six different intersections while providing notifications to pedestrians on the signal phasing and walk countdown timing (MNDOTRESEARCH, 2021).

***SECTION SUMMARY***

- Identify priority corridors for the implementation of safety strategies.
- Explore the inclusion of new drunk-driving technologies as standard options on vehicle fleets.
- Incorporate ITS solutions into intersections to aid smartphone-based apps for the mobility impaired.

## OPPORTUNITIES FOR TEXAS

Many states and cities in the US have drafted and adopted Vision Zero principles and goals to reduce and eventually end road deaths. While these goals are lofty, they are achievable within the timeframe if consideration is aimed at key areas, review and enforcement of speed limits, implementation of smart work zones, and promotion of Vision Zero goals. The following takeaways from the topics discussed here can lead to significant drops in pedestrian fatalities.

When considering improving the safety of roads, speed limits must be addressed. Speed has been found in multiple research efforts to play a significant role in the severity of pedestrian injuries and deaths. Along with speeds, accommodating the presence of pedestrians in street design and rehabilitation can increase both the safety and mobility of pedestrians. Finally, as drivers and pedestrians are increasingly distracted by smartphones and other such personal devices, the implementation of improved pedestrian facilities at intersections can help both drivers and pedestrians. To enhance pedestrian safety, Texas should consider lowering speed limits on high-injury networks, with a focus on those facilities where significant pedestrian fatalities occur.

As important as road design is to pedestrian safety, vehicles need to be considered as well. Vehicle size is one determinant of injury severity for a pedestrian in a collision; thus, larger vehicles in particular could benefit from the inclusion of automated features as standard options. Expanding V2V and V2I capabilities can also lead to increased safety not only at intersections but also in work zones, where unforeseen lane shifts and vehicles entering and exiting the roadway with little notice are often encountered. While pilots have been conducted in a few districts, TxDOT should magnify its investment in smart work zone programs and the TCFC project by expanding the CV technology to other districts.

Finally, while efforts can be aimed to create safer roads and smarter vehicles, agencies should continue promoting sensible behaviors and bringing awareness to the dangers of risky driving. As part of their Vision Zero goals, many cities conduct campaigns to raise public awareness of the dangers posed by unsafe driving behaviors. These campaigns can be targeted at drivers along the high-injury corridors identified by agencies, as these corridors represent the most significant number of safety issues. This process can be accomplished not only at a local level but also regionally and at the state level to identify high priority corridors between jurisdictions. As only a handful of cities across Texas have adopted Vision Zero goals, TxDOT should work with those that have not yet adopted Vision Zero goals and coordinate state and local action plans.

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