An Equity-Driven Approach for School Zone Safety to Inform Safe Routes to School (SRTS)

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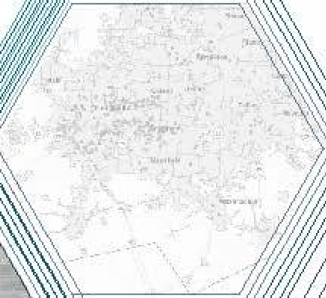

FINAL REPORT

CENTER FOR TRANSPORTATION EQUITY, DECISIONS & DOLLARS

AN EQUITY-DRIVEN APPROACH FOR SCHOOL ZONE SAFETY TO INFORM SAFE ROUTES TO SCHOOL (SRTS)

FINAL PROJECT REPORT

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16. Abstract

According to the Center for Disease Control and Prevention, injuries from road traffic crashes are a leading cause of death for children less than ten years old, a critical public health issue. School-aged pedestrians in lower-income neighborhoods may be particularly at risk. This study involved the application of a data-driven approach inspired by Vision Zero (VZ) policy goals. The research provided engineering and educational safety countermeasures for areas near elementary schools serving disadvantaged populations in major metropolitan areas of Tampa Bay, Florida, and Dallas County, Texas. This study's elements were developed in close discussion with the stakeholders to incorporate engineering and educational countermeasures into Safe Routes to School (SRTS) programs. Pedestrian education-related activities were evaluated using Virtual Reality-based (VR-based) pilot testing on elementary school children. The schools for this study were selected from schools within low-income neighborhoods in Dallas County. A key contribution of this study is to demonstrate the use of results from contextual collision data to inform scenarios evaluated in VR-based experimentation. Study participants found the training program to be immersive and realistic. Before-after observations also showed that the participants were significantly more likely to engage in safe crossing behaviors after the training.

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ABSTRACT

According to the Center for Disease Control and Prevention, injuries from road traffic crashes are a leading cause of death for children less than ten years old, a critical public health issue. School-aged pedestrians in lower-income neighborhoods may be particularly at risk. This study involved the application of a data-driven approach inspired by Vision Zero (VZ) policy goals. The research provided engineering and educational safety countermeasures for areas near elementary schools serving disadvantaged populations in major metropolitan areas of Tampa Bay, Florida, and Dallas County, Texas. This study's elements were developed in close discussion with the stakeholders to incorporate engineering and educational countermeasures into Safe Routes to School (SRTS) programs. Pedestrian education-related activities were evaluated using Virtual Reality-based (VR-based) pilot testing on elementary school children. The schools for this study were selected from schools within low-income neighborhoods in Dallas County. A key contribution of this study is to demonstrate the use of results from contextual collision data to inform scenarios evaluated in VR-based experimentation. Study participants found the training program to be immersive and realistic. Before-after observations also showed that the participants were significantly more likely to engage in safe crossing behaviors after the training.

1. Introduction

1.1 Background

Even as the trends in traffic fatalities for motorists have been improving, vulnerable road users (VRUs, specifically pedestrians and bicyclists) have seen an alarming rise in fatalities in recent years. According to the Centers for Disease Control and Prevention, injuries from road traffic crashes are a leading cause of death for children under the age of 10, a critical public health issue. This is particularly important because school-aged children account for nearly one-fifth of the total pedestrian fatalities (*Dangerous by Design*, 2019). Moreover, over 52% of school-aged pedestrians killed in school transportation-related crashes are 5-10 years old. Within the "Safe System Approach," the six key principles are related to this study in many aspects, such as:

- Death/serious injury is unacceptable for school-aged pedestrians/pedalcyclists,
- Humans commit motor vehicle operation errors on roads where school-aged children cross the roads to schools,
- Humans are vulnerable, particularly the children aged 5 to 11 years,
- The responsibility is shared among the roadway users, local authorities involved in the roadway design that is appropriate for the characteristics of the design vehicle, law enforcement agencies, and post-crash care system,
- Addressing road safety concerns is a proactive approach because of the lessons on the risks of the past and knowledge gained to mitigate those risks,
- Redundancy is crucial when all parts of the roadway system are strengthened.

Figure 1.1: Safe System Approach with the five elements and six principles with study relevancy (*Zero Deaths - Safety | Federal Highway Administration*, 2022)

School-aged pedestrians in lower-income neighborhoods may be particularly at risk. This study involved the application of a data-driven safe system approach inspired by Vision Zero (VZ) policy goals.

1.2 Motivation

According to a 2019 report from National Highway Traffic Safety Administration (NHTSA), 2018 was the deadliest year for pedestrians and cyclists in the US since 1990. This fact is especially alarming from an equity standpoint because motorist deaths have been declining over recent years. According to a recent study (*Dangerous by Design*, 2019), school-aged children account for nearly one-fifth of the total pedestrian fatalities. Considering school-aged pedestrians killed in school-transportation-related crashes, over 52% belong to the age group 5 to 10 years (*NHTSA*, 2020).

Fortunately, the SRTS programs provide a venue to address safety issues related to active transportation for school-age children. As noted in a recent research report published by Co-PI, Dr. Pande, and his colleagues, federal funding for SRTS programs was first instituted under the federal legislation, Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (Voulgaris et al., 2020). Under subsequent federal legislation of 2012 and 2015 (Moving Ahead for Progress (MAP-21) and Fixing America's Surface Transportation Act (FAST Act), respectively, the federal SRTS program was combined into a new program called the Transportation Alternatives Program (TAP). Under this new arrangement, State DOTs and

Metropolitan Planning Organizations (MPOs) receive funding for active transportation programs that may be directed towards SRTS projects.

Most existing studies entailing the examination of the effectiveness of SRTS have involved evaluating these programs using the change in mode share for active modes (walking and cycling to school) as the performance criteria. It is understandable since the increase in children's overall physical activity is associated with several health benefits, including better cardiovascular health and reduced risk of obesity (Janz et al., 2002). The impact of SRTS programs in terms of improving the safety of vulnerable road users (VRUs) is less studied (DiMaggio et al., 2016). Recent research on quantitative and qualitative analysis of SRTS programs in the San Francisco Bay Area concluded that if the programs improve VRU safety, they may be expected to further increase active travel mode share (Voulgaris et al., 2020). This indicates that increasing active travel mode share and improving safety are goals that complement each other.

In this study, we focused on improving safety near schools serving disadvantaged populations since there is evidence that more impoverished neighborhoods typically face more pronounced safety challenges (Cottrill & Thakuriah, 2010). The roadway environment can explain a substantial portion of the excess rate of road traffic injuries in the most impoverished urban areas (Chakravarthy et al., 2010). However, we did not find literature that specifically addresses this in the context of school zones. The Engineering and Educational components of SRTS programs provide us with a framework to advance Vision Zero (VZ) if interventions offered under these programs can meaningfully improve safety. Also, there is evidence that low-income schools are overrepresented among schools supported by SRTS programs (McDonald et al., 2013). There may be an opportunity to advance VZ equitably through engineering and educational interventions offered through SRTS programs. From discussions with our stakeholders, we learned that since the states, particularly Florida, have been making significant efforts to improve SRTS programs, these programs would be a decent venue to implement the findings from our research and enhance the existing programs.

1.3 Project Objectives

The aim of this research project was to develop an equity-driven program to improve safety for elementary school students. The findings of this research are expected to inform the policymaking and implementation of the Engineering and Education elements of the Safe Routes to School (SRTS) programs. We proposed to apply a systemic safety approach that is consistent with the Vision Zero policy goals in this project. According to Thomas et al. (Thomas et al., 2018), "Systemic approaches seek to not only address locations with prior crash occurrence but also those locations with similar roadway or environmental crash risk characteristics." Linking crashes within the elementary school zones with the roadway and environmental factors were considered critical for implementing this systemic approach and ultimately added value to the development of the education modules.

Towards that end, we assembled a database for traffic crashes near the schools serving disadvantaged populations. The analysis of this database supported a mechanism to identify priorities for engineering and education programs to reduce crashes in the study area. By focusing on schools serving disadvantaged populations, this research also has significant equity implications. It is an essential aspect of this work since there is evidence in the literature (e.g., (Chakravarthy et al., 2010) that pedestrian crashes are more prevalent in more impoverished neighborhoods even after accounting for the population's age, education, and population density. SRTS programs in the three largest states with CTEDD consortium partners, California, Florida and Texas, would serve as the outlet for this work's findings. The specific objectives of this research were as follows:

- Develop a data-driven approach to assess elementary school zones' safety issues near the schools serving disadvantaged populations (identified based on factors including % of pupils receiving lunch vouchers).
- Based on crash data analysis, identify prioritized locations with risk factors and relevant engineering interventions that may be integrated with future SRTS program activities.
- Based on crash data analysis, identify children's education initiatives, and develop a VR-based approach to evaluate these initiatives.
- Provide recommendations for implementing the most effective safety-related educational approaches for students with schools serving disadvantaged populations.

These initiatives provided an equitable framework to improve the children's safety and overall well-being.

2. Literature Review

2.1 Background

Child pedestrian injuries and fatalities are caused by complex interactions among unsafe roadway environments, children's stature, and their limited cognitive abilities (Peden & World Health Organization, 2008). The literature review, provided in this section, focuses on the risk factors regarding child pedestrians' injuries and fatalities near school zones; child pedestrians' perception of traffic infrastructure and the environment (e.g., number of lanes, vehicle type, time of day, weather conditions, etc.); their cognition for gathering information, processing information, and making a decision; social and environmental influences on children's pedestrian behavior. The following subsections will cover the risk factors of behavior based on the previous studies and the need for training programs with the summary in the conclusion subsection.

2.2 Risk Factors for Pedestrian Behavior

2.2.1 Cognition

As pedestrians are one of the most vulnerable road users, they must have proper cognitive skills for information gathering, information processing, decision making, and decision initiation. To gather information from a traffic environment, pedestrians need strong visual attention. Pedestrians must attend to all relevant information from available visual cues to identify important information. Sometimes distraction can affect pedestrians' attention and lead to collisions. In the case of school-going children, both talking on phones and talking with companions were found to cause significant increases in risk-taking and significant decreases in safety while crossing a street (Pešić et al., 2016).

Once pertinent information has been gathered by attentive pedestrians, they need to process this information and simultaneously make an estimation of whether the conditions are safe or unsafe for their specific maneuver. This information processing can become complex based on factors such as roadway type, traffic flow, and the presence of other road users, among others. If there is a traffic collision, vulnerable road users such as pedestrians, who are not protected by vehicle structures, are the ones who will suffer the most severe injuries. Therefore, it is critical for pedestrians to develop proper cognitive skills for information processing especially given that the roadway network in much of the US is not designed with a safe-systems approach.

The skill set mentioned above is highly dependent on the age of the child pedestrians. In a traffic safety context, children are defined as persons aged from 0 to 15 years. There are considerable differences in the abilities of younger and older members of this less than 15-year-old cohort. In cognitive development literature, Jean Piaget's (1952) (Piaget, 1952b) theory of development stages has been used to further classify the children's ability to interact with the roadway environment by age (Piaget, 1952a). Specifically, children under six years do not have fully developed and differentiated sensory functions. They cannot focus on two different tasks (e.g., finding the correct route and checking for traffic signals). They cannot combine two separated perceptions into one (speed and distance of approaching a vehicle from how fast the vehicle's perceived size grows). In addition, data on child pedestrian mobility, especially for children under the age of six years, is scarce.

A large body of past research showed that children's cognitive skills develop with age (Barton et al., 2012; Piaget, 1952; Wang et al., 2018). Cognitive skills, which allow the processing of multiple visual cues from the traffic environment, generally start developing from the age of 7 (Barton et al., 2012; Wang et al., 2018). By the age of 9, most children can identify safe routes for walking, safe crossing locations, and objects (cars, structures, road-users, etc.), impeding the view of oncoming traffic (Ampofo-Boateng et al., 1993; Whitebread & Neilson, 2000). Prior research with children aged 5-12 years suggested that only older children are able to discriminate between more relevant and less irrelevant visual stimuli when presented with depictions of visually complex pedestrian settings (Whitebread & Neilson, 2000).

2.2.2 Perception

To make safe decisions, pedestrians must accurately perceive all the information from the traffic environment around them. Most children develop the physical capacity to see and hear traffic (David et al., 1990) from the age of 7. However, it is not enough for pedestrians to attend to all the visual and audible cues from surrounding traffic and road users. In order to find a gap between traffic, pedestrians have to simultaneously measure and judge vehicle size, speed, distance, traffic density, and acceleration/deceleration of all approaching traffic. They also need to search for these characteristics in traffic, making a turn into their path. They also ought to account for the number of lanes, road structure, traffic signals, presence of emergency vehicles, and road-users other than motor vehicles. Past research shows that children under the age of 9 are not skilled at these estimations. They tend to notice vehicle presence and distance but do not account for the acceleration/deceleration of the oncoming vehicles (Connelly et al., 1998). Often, traffic infrastructure can make pedestrians' perception of traffic conditions more challenging. Obstructions (parked cars or trees) and road features (road bends or curves) can block pedestrian vision; inclines can affect vehicle acceleration/deceleration and challenge pedestrians' perception of those changes.

2.2.3 Social Influence

Children first learn about pedestrian behavior from their parents or family members. Research has documented that children are attentive to their parents' safety practices and that children notice when parental practices diverge from safe behaviors (Morrongiello & Barton, 2009). Therefore, the behaviors parents or caregivers model when walking between traffic can potentially influence children's practices as pedestrians. The study was based on observation/interviews with parents/caregivers of children aged 4-11 years old.

2.2.4 Environmental Influence

The environment and society a child pedestrian live in can impact their walking behavior. The most critical risk factor can be the population and traffic density of the area. Children are more likely to be hurt near schools, presumably because of higher exposure rates. Greater exposure to traffic leads to greater pedestrian injury risk. Hence, children in the urban, higher population, and higher traffic density areas are more likely to experience a pedestrian injury than those in less-populated areas (Hwang et al., 2017). A secondary consequence of this is that children from lower socioeconomic status backgrounds tend to have higher injury rates as poorer urban communities tend to have traffic infrastructure that is not well-designed and well-maintained (Hwang et al., 2017). This study defined individuals aged between 5 and 19 years as children.

In summary, the literature search regarding risk factors shows that low-income school zones with poor traffic infrastructure may lack walkability for child pedestrians resulting in the need for children to be especially attentive in such neighborhoods. The lack of school-provided transportation and adult supervision results in many children from low-income families walking alone to school. While walking is an excellent physical activity, poor walking infrastructure, unsupervised walking, and exposure to school-zone traffic added to children's limited cognitive and perception skills can increase child pedestrian injury and fatality risks in low-income school zones. Hence, it is an equity concern as well. Therefore, this research intends to investigate crash data in school zone areas for VRU-involved crashes and develop a roadmap to child pedestrian training programs for elementary school children located in low-income areas.

2.3 Child-Pedestrian Training Programs

There has been much research conducted on the efficacy of various training interventions (Arbogast et al., 2014; Barton et al., 2012; Feng et al., 2020; Hammond et al., 2015; Morrongiello et al., 2018). The training programs reviewed in this section were primarily focused on elementary school children since that is the focus of this research. Parents play a vital role in teaching children how to exhibit safe pedestrian behavior. Still, research has shown that parental training alone is insufficient to teach children safe road crossing skills (Schwebel et al., 2012). One study involved the design of a gamified e-learning platform that provides learners incentives similar to those used in games to look at different criteria of pedestrian training, such as traffic knowledge, situational awareness, risk detection, and risk management (Riaz et al., 2019). This self-learning computer-based training program requires minimal supervision and uses gamification elements and features context-related footage to train young pedestrians. The researchers found that participants' skills improved in each of the four modules and confirmed this as an efficient training mode (Riaz et al., 2019). Another study was focused on examining a school-based intervention method that involves both theoretical and practical aspects of traffic safety education. The researchers compared this approach with a strenuous but costly method of training in the Iran traffic park, a training complex designed to create a traffic environment for elementary school students (Zare et al., 2021). The

Results of the study showed that the school-based intervention approach was more effective than the traffic park-based intervention approach (Zare et al., 2021).

Video training has been a popular method of training child pedestrians (Arbogast et al., 2014; Hammond et al., 2015). When Arbogast et al. (Arbogast et al., 2014) compared training through interactive video games with traditional didactic studies, they found that participants trained by playing video games performed similarly to those trained in a more conventional, labor-intensive setting. However, the video game group exhibited more appropriate behavior on specific behaviors such as exiting a parked car, signaling to a vehicle backing up, signaling to a stopped car, and crossing streets. Similarly, Hammond et al. (Hammond et al., 2015) designed an interactive hazard perception video that teaches children the skill of crossing safely between parked cars. They found the type of training that focuses more on awareness skills rather than knowledge and acquisition alone to have a more positive impact on children's behavior. Their results have shown that interactive hazard identification could improve the on-street behavior of child pedestrians. However, Schwebel & McClure (Schwebel & McClure, 2014) found that widely available videotape and website training tools that require minimum to no adult support were ineffective in improving children's pedestrian route selection. They suggested that this intervention did not improve children's pedestrian behavior compared to children with individualized training in the control group. This result is consistent with a past study outcome that reported videos and lecture-based training programs on traffic safety can successfully improve children's perception of safety, their attention, and information processing skills. Yet, such programs cannot improve their behavior as pedestrians (Percer, 2009). These results pose an important concern and highlight the need to find more effective intervention methods to train children on safe pedestrian behaviors.

Recent researchers indicate interest in incorporating VR-based training as an effective intervention method for individualized street-side training (Hammond et al., 2015; Morrongiello et al., 2018; Schwebel & McClure, 2014). Some advantages of using VR training include creating a real-world complex traffic environment in the virtual world that eliminates the need to put the child in real danger and provide an authentic context to identify dangerous pedestrian behaviors (Deb et al., 2017; Schwebel et al., 2012). Moreover, VR not only allows the identification of risky behaviors but also enables recording and further analysis for feedback and training module updates. It also allows the children to practice repeatedly with minimal adult supervision. Lastly, these training modules can be 'gamified,' making them interactive and enabling the children to gain understanding while enjoying the game (Feng et al., 2020; Morrongiello et al., 2018; Riaz et al., 2019; Schwebel & McClure, 2014).

A case study in elementary schools looked at the efficacy of implementing VR-based training and found that VR increased pedestrian performance both during and after the intervention (Feng et al., 2020). The study consisted of different locations in both urban and rural regions. Results indicated no significant difference in the performance between the two groups (urban vs. rural), suggesting that VR training can be universally applicable. Researchers also looked at having a mobile virtual environment that can be used to train children in the community (Schwebel et al., 2016). The advantage of having a mobile environment is that it can be moved around to different schools and community centers and provide intense training to multiple groups of children over a few weeks. Comparing their pre- and post-study results, they found pedestrian behavior improved modestly. In one of the previous studies, researchers compared different training interventions in knowledge gained, and behaviors changed in the children (Percer, 2009). Children who received VR training exhibited safe behavior but did not gain knowledge, and children trained via videos/software/internet gained knowledge but did not change their behavior. Children who received theoretical background information about safe pedestrian behavior followed by VR-based training gained knowledge and safe behavior. These results suggest that, although VR is an effective tool to improve pedestrian behavior, other platforms might be needed as supplements to enhance safety training.

Percer (Percer, 2009) investigated the cognitive and perceptual aspects of VR training in different traffic conditions. They provided feedback to the children on their crossing behavior to help study participants with cognitive learning. With repeated practice, children developed the allocation of visual attention for interpreting vehicle movement. Results of the study have shown that this training not only improved pedestrian behavior but also advanced their conceptual learning. These results bridged the gap that was found in another study where children did not seem to gain cognitive knowledge from VR interventions (Schwebel & McClure, 2014). Like VR, Cave Automatic Virtual Environment (CAVE) also provides a safer environment to conduct pedestrian behavior studies. CAVE is an arena surrounded by projector screens that can create a 3D environment for virtual exposure. Dommes & Cavallo (Dommes & Cavallo, 2012) used CAVE to train the elderly population by utilizing repeated practices in simulated environments, providing personalized feedback, and having educational discussions. The intervention seemed to improve their street-crossing behavior; however, the improvement was no longer observed after six months. The participants also failed to judge the speed of approaching vehicles while making their decisions showing their struggle with perception and cognition.

Lastly, to provide VR training, children should not only have no adverse effects from VR (Tychsen & Thio, 2020) but also feel the realistic immersion within VR environments. Literature has shown that VR headsets do not pose any risk of photo-induced seizure from 3D view to children, including children with known photosensitive epilepsy. Studies have also found VR to be effective for the realistic immersion of children aged four and above (Tychsen & Foeller, 2020).

Table 2.1: Summary of Intervention Programs

Paper	Intervention	Performance
Arbogast et al. (Arbogast et al., 2014)	Educational video game training; n= 348	Similar or improved
Hammond et al. (Hammond et al., 2015)	Interaction hazard perception video; n= 43	Improved
Feng et al. (Feng et al., 2020)	4 sessions of VR training; n= 79	Improved
Schwebel & McClure (Schwebel & McClure, 2014)	Videotapes and websites; n= 240	Ineffective
Schwebel et al. (Schwebel et al., 2016)	Mobile virtual environment; n= 44	Improved
Morrongiello et al. (Morrongiello et al., 2018)	VR; n= 44	Improved
Riaz et al. (Riaz et al., 2019)	Gamified e-learning platform; n= 44	Improved
Zare et al., 2021 (Riaz et al., 2019)	School based intervention; n= 132	Improved
Dommes & Cavallo (Dommes & Cavallo, 2012)	CAVE system; n= 20	Improved

2.4 Conclusions

The following conclusions regarding an effective training program may be drawn from this detailed review of the behavioral research and existing child pedestrian training programs.

- These studies have created child-pedestrian training modules for all income-group populations. However, most of the more affluent children of this age group are driven to schools by their parents. The authors believe that the training programs can be more effective if tailored towards children in low-income neighborhood schools where a larger number of children walk to school, unsupervised, on the street networks that involve higher crash risk due to the state of the infrastructure. Not focusing these training programs on low-income neighborhoods may perpetuate an equity issue.
- This research focuses on elementary school-age children (5-12 years). Since the past research has shown VR to be safe for children as young as four years old, VR-based pedestrian training is a safe way to encourage safe behavior by the children.
- The previous studies have included many scenarios considered high-risk situations for pedestrians. For example, crossing with obstructions blocking the visibility of approaching traffic (parked vehicles, blind curve, or blind hill, etc.) (Morrongiello et al., 2018), crossing while the vehicles are making left or right turns (Feng et al., 2020), crossing at wrong lights (Arbogast et al., 2014), and crossing at unsignalized intersections (Schwebel & McClure, 2014), etc. However, these scenarios have been selected by the researchers of past studies in an ad-hoc manner and may not represent all possible high-risk conditions, or even the conditions children are most likely to encounter.

To develop training programs that can address safety problems for children walking to schools and equity issues with child-pedestrian injuries in low-income areas, we need to rely on insights from crash data near school zones to identify infrastructural factors as well as behavioral factors that lead to crashes. These factors can then be used to design VR-based scenarios to create effective training programs.

3. Chapter III: Crash Data and Analysis

3.1 Background

Pedestrian fatalities continue to increase worldwide, with an overrepresentation of children aged 15 years or younger. According to the report published by the World Health Organization (WHO) on "Child Injury Prevention," pedestrian injury is among the leading causes of pediatric death in the United States and much of the world (Peden & World Health Organization, 2008; Schwebel et al., 2012). The National Safety Council estimated the cost of a pedestrian injury to be around $58,700 per event and the cost of a fatality as $4,538,000 per occurrence (Smith, 2018). The National Highway Traffic Safety Administration (NHTSA) reported 6,283 fatalities and 75,000 injuries in 2018 for pedestrians from all age groups in the United States (*NHTSA*, 2020). These statistics showed a 3.4% increase in pedestrian fatalities and a 5.4% increase in pedestrian injuries from 2017 and were the highest since 1990. Among these victims, around 17% of the pedestrians killed, and 4% of the pedestrians injured were children aged 15 years or younger (*NHTSA*, 2020).

A report on "School-Transportation-Related Crashes" states that 100 school-aged pedestrian deaths that occurred between 2009 and 2018 were due to school-transport-related crashes (*School Transportation-Related Crashes: 2009–2018 Data*, 2020). Past research has also shown that child pedestrians are at risk of severe injuries and fatalities in low-income areas especially near schools that are located to serve disadvantaged populations (Cottrill & Thakuriah, 2010; Morency et al., 2012). The severe injuries and fatalities are higher in such areas, potentially due to socioeconomic issues, which cause children to be more likely to walk than to use any other mode of transportation (McDonald, 2008), even as the surrounding roadway network remains automobile-centric. Low-income neighborhoods often also have poorly designed environments that make them prone to more traffic crashes (Hwang et al., 2017). The following subsections will cover the data collection plan, analysis framework, crash data analysis, and summary on the lesson learned as part of input for the development of the training module.

3.2 Data Collection

This section provides a descriptive analysis of crash data from the roadway network within a 0.5-mile radius surrounding the elementary schools located in two metropolitan areas (Dallas County, TX and Tampa, FL). Results are presented based on critical factors for VRU-involved collisions. The first factor investigated was the number of lanes. According to the past literature, the majority of crashes occur on two-way roads (Das et al., 2020). Previous research also shows that "two to three lanes with no physical median" is the location characteristic most associated with urban traffic crashes involving VRUs (Das & Dutta, 2020). Since our data involved multiple jurisdictions in Dallas and Tampa Bay regions and relied on state DOT databases, crashes on locally managed surface streets were missing key attributes (Texas data in particular), including the number of lanes. Hence, we could not analyze the context-specific crash data with respect to the number of lanes. Therefore, future VR experiments for this work would be informed by the number of lane information for the roads that are most encountered in the network surrounding the school. In the paper's Discussion section, we further elaborate on this limitation.

3.3 Data Analysis Framework

The typical crash data with spatial crash locations (latitude and longitude) were merged with the school zone data (particularly those of the elementary school zones in this study) and the ACS dataset in the GIS spatial platform. The crashes were assigned to elementary school locations that are within a 0.5-mile distance using the GIS crash assignment tool. After the merging of the datasets, the crash attributes in terms of age groups of school-going children/youth, roadway attributes, crash locations and action prior to the crashes are explained here.

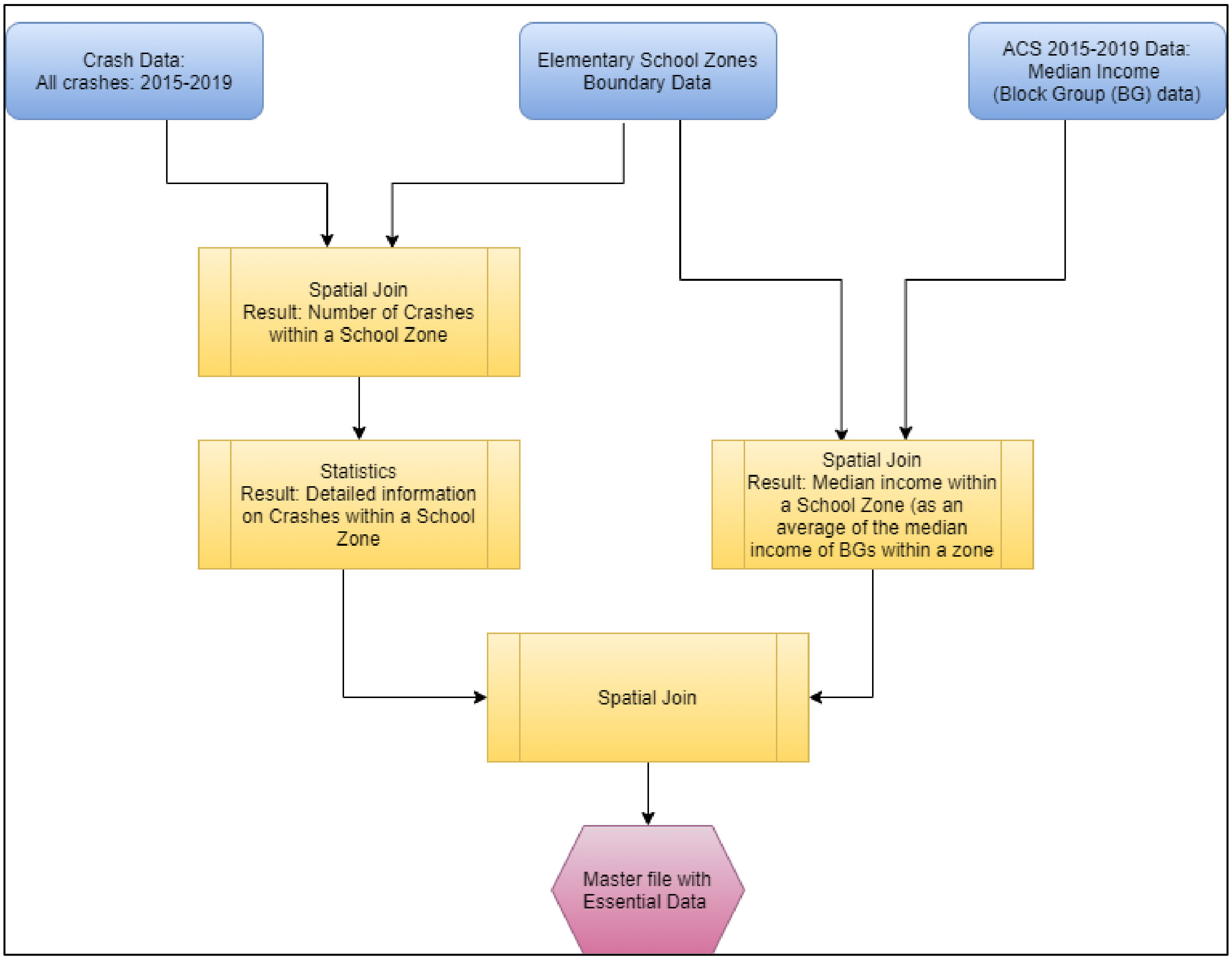


Figure 3.1: Conceptual flow-chart of crash analysis of school locations.

3.4 Crash Data Analysis

Due to the differences in the crash data collection process by jurisdiction for the corresponding law enforcement in the study areas (Tampa Bay, Florida, and Dallas, Texas), the crash data elements did not match exactly, and comparison may not be meaningful in some instances. For illustration purposes, we are presenting some insightful and detailed crash analyses from Tampa Bay, Florida, which revealed some important aspects of school zone safety. The following subsections include demographics, roadway attributes, actions of pedestrians/pedal cyclists and motorists.

3.4.1 Economics and Demographics

The crash data from the Tampa Bay area were plotted with income level and school zone, particularly the elementary school locations in GIS format. The median household income level, $27,831 to $55,660, areas are overrepresented by the clusters of elementary school locations where crashes occurred within 0.5 miles.

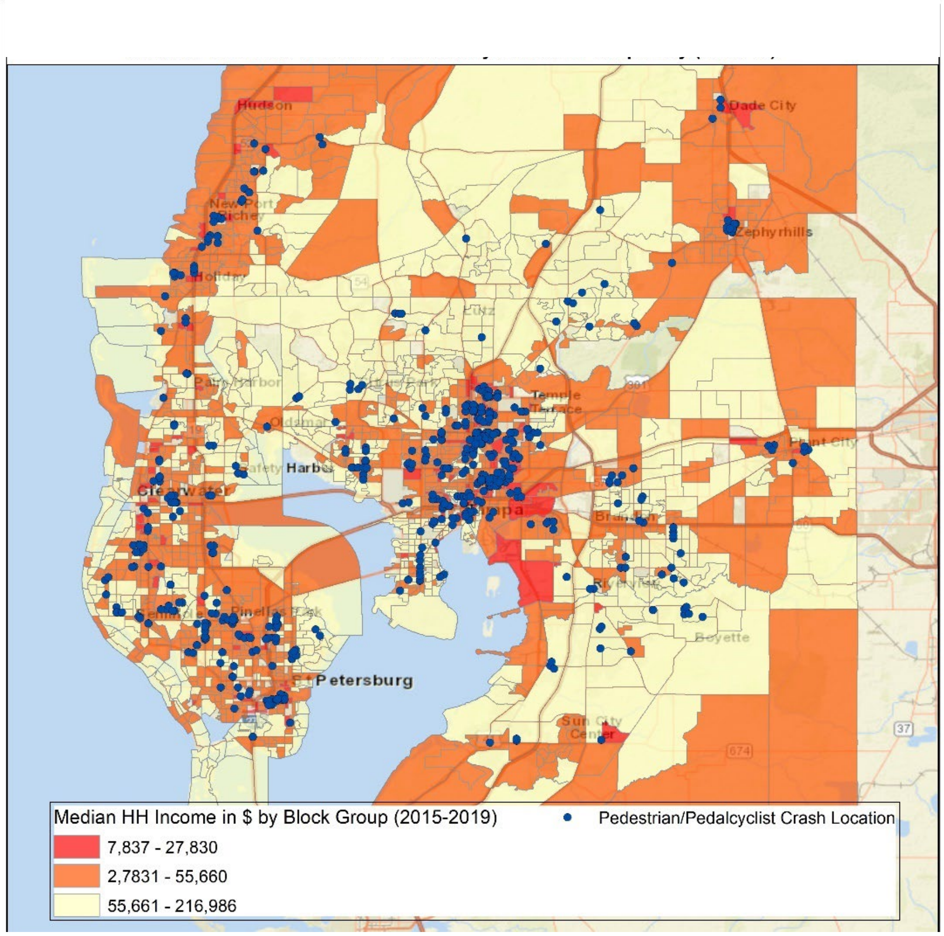


Figure 3.2: Median household income and VRU crashes within 0.5-mile of elementary schools in Tampa Bay (2015-19).

High school pedestrians/pedal cyclists aged 15-19 are overrepresented in the severe injury crash data.

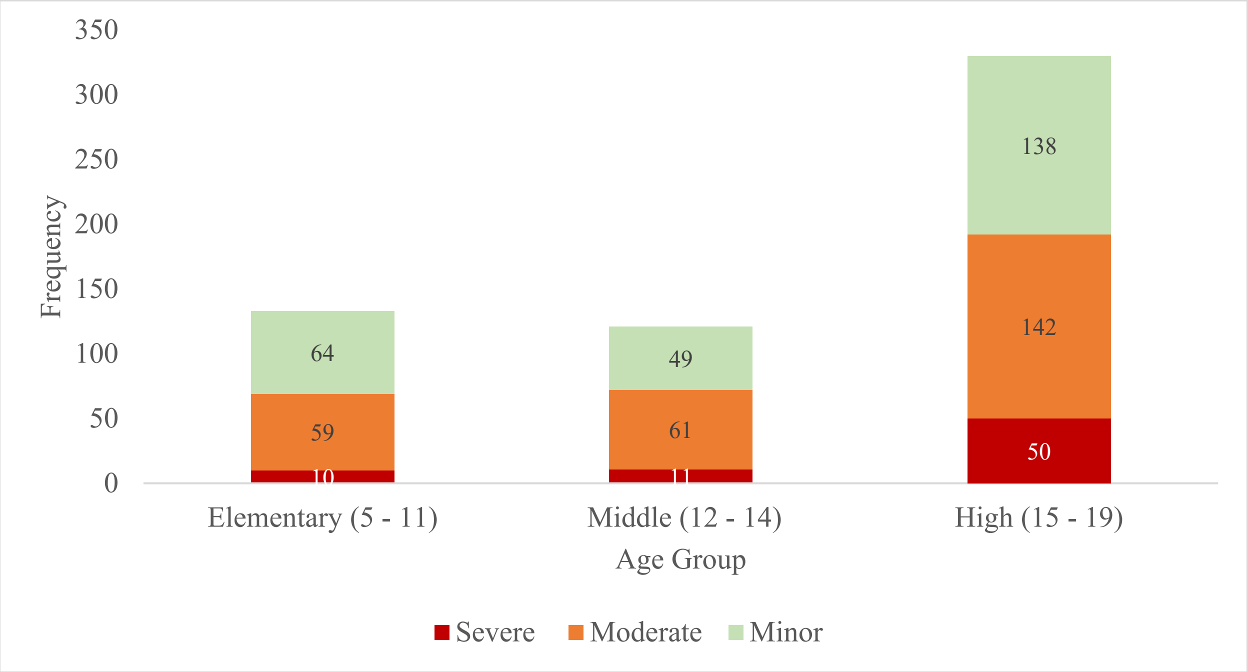


Figure 3.3: Crashes involving pedestrians/pedal cyclists' age group within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

Drivers aged 30-49 are involved in the largest number of crashes resulting in severe injury, followed by those aged 16-29 and those aged 50-65 years.

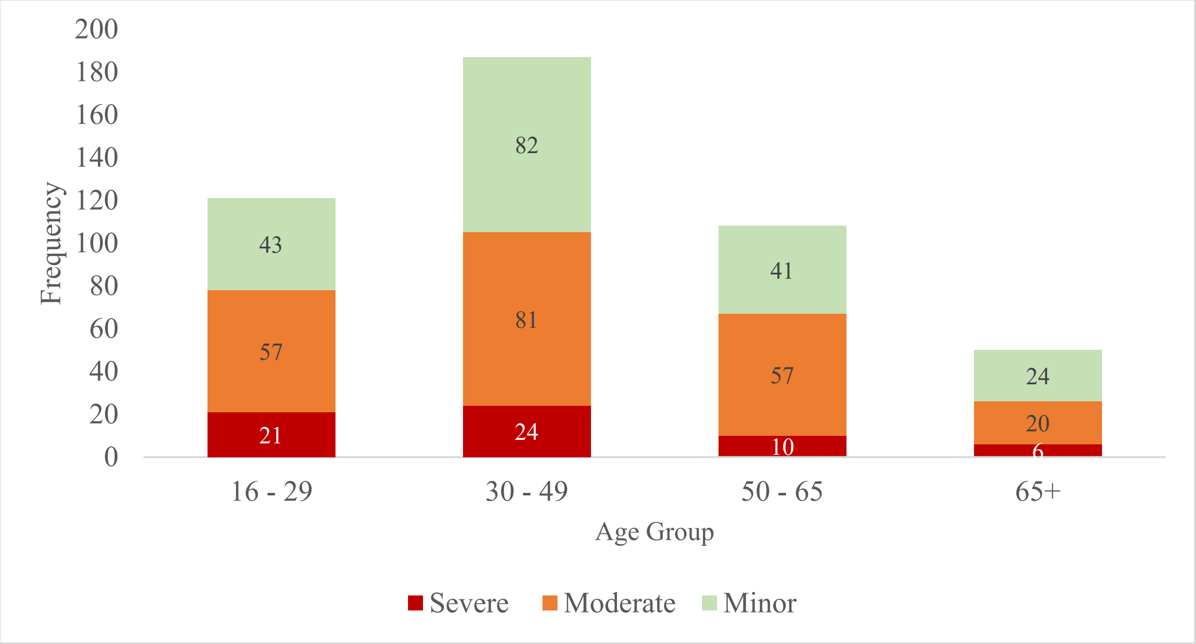


Figure 3.4: Crashes involving drivers' age group within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

3.4.2 Roadway Attributes

The VRU crashes are concentrated at the two-way, two-lane undivided roadway facilities, followed by two-way roadways with positive barriers.

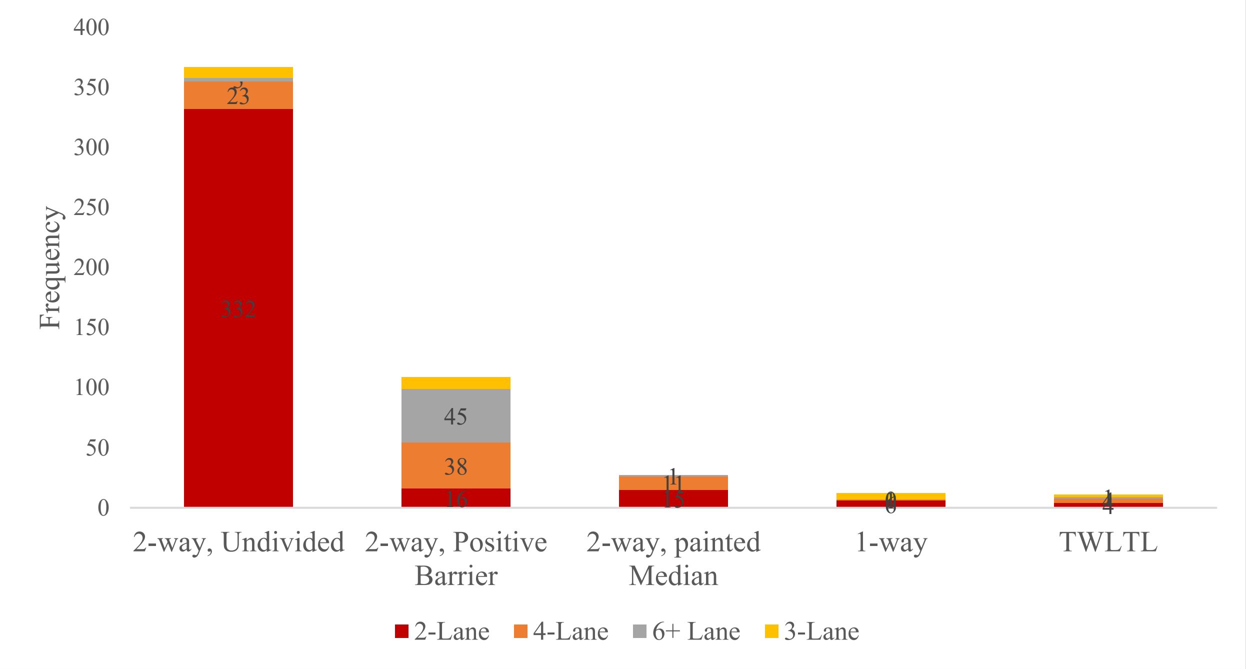


Figure 3.5: Crashes involving pedestrians/pedal cyclists' age within 0.5-mi of elementary school by the number of lanes (both directions) in Tampa Bay (2015-19).

Concerning traffic control systems on these two-way, two-lane undivided roadways, there are over-representations of roadways without traffic control, followed by roadways with traffic signals and stop signs.

Figure 3.6: Crashes involving pedestrians/pedal cyclists for traffic controls within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

Another important aspect of roadway design is the speed limit. The overrepresentation of crashes pertains to roadways with speed limits that are between 30 and 45 mi/hr. The second-highest crash frequency belongs to roadways with speed limits that are below 25 mi/hr.

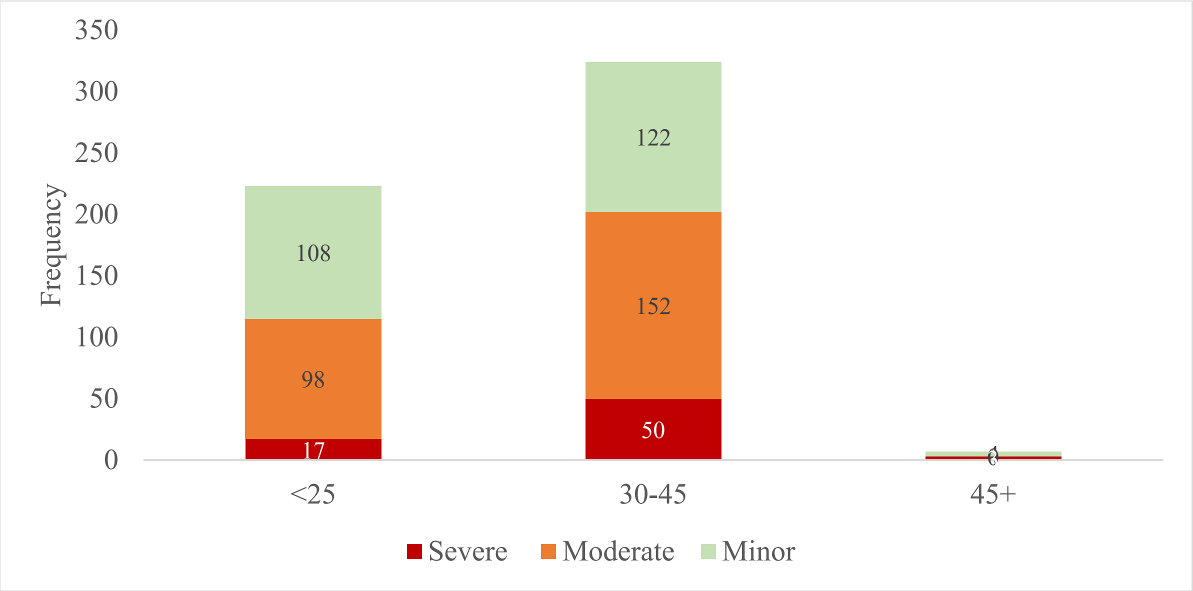


Figure 3.7: Crashes involving pedestrians/pedal cyclists for speed Limit within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

Considering the traffic exposure (even ignoring the missing values of traffic volumes), roadways with traffic volumes (AADTs) that are between 25,000 and 50,000 vehicles/day experienced the highest crash counts.

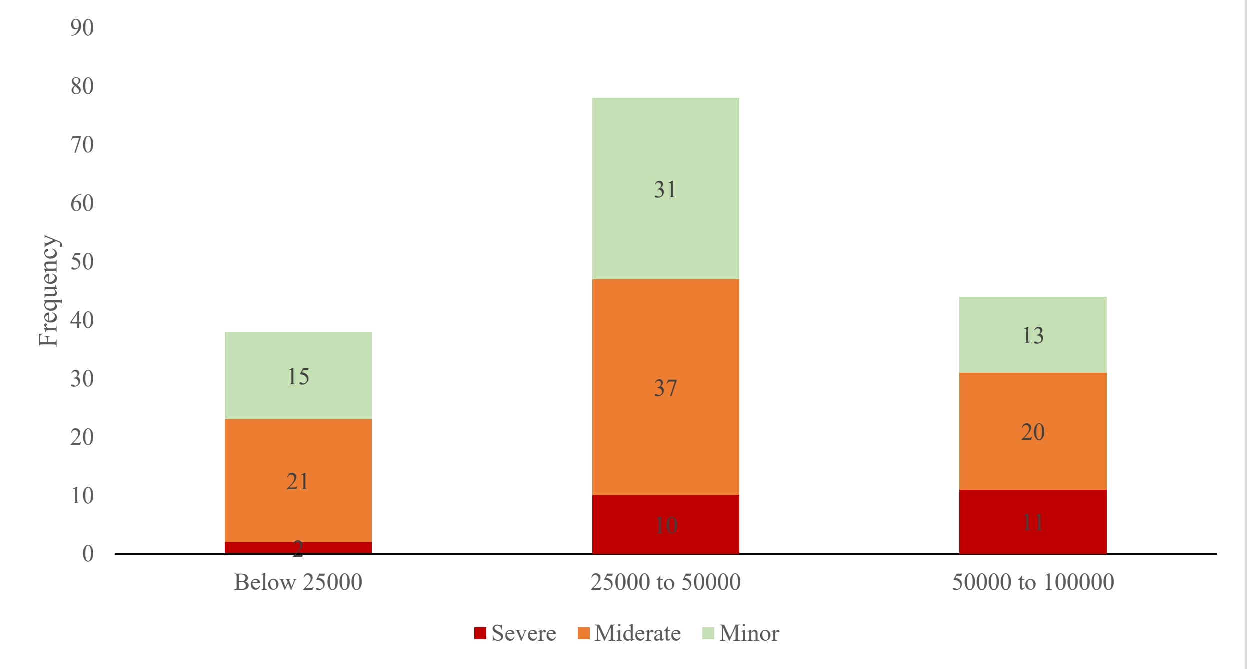


Figure 3.8: Crashes involving pedestrians/pedal cyclists for speed limit within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

Regarding crash locations, intersections with marked crossways are overrepresented in terms of crashes involving pedestrians/pedal cyclists, followed by travel lanes and intersections with unmarked crossways.

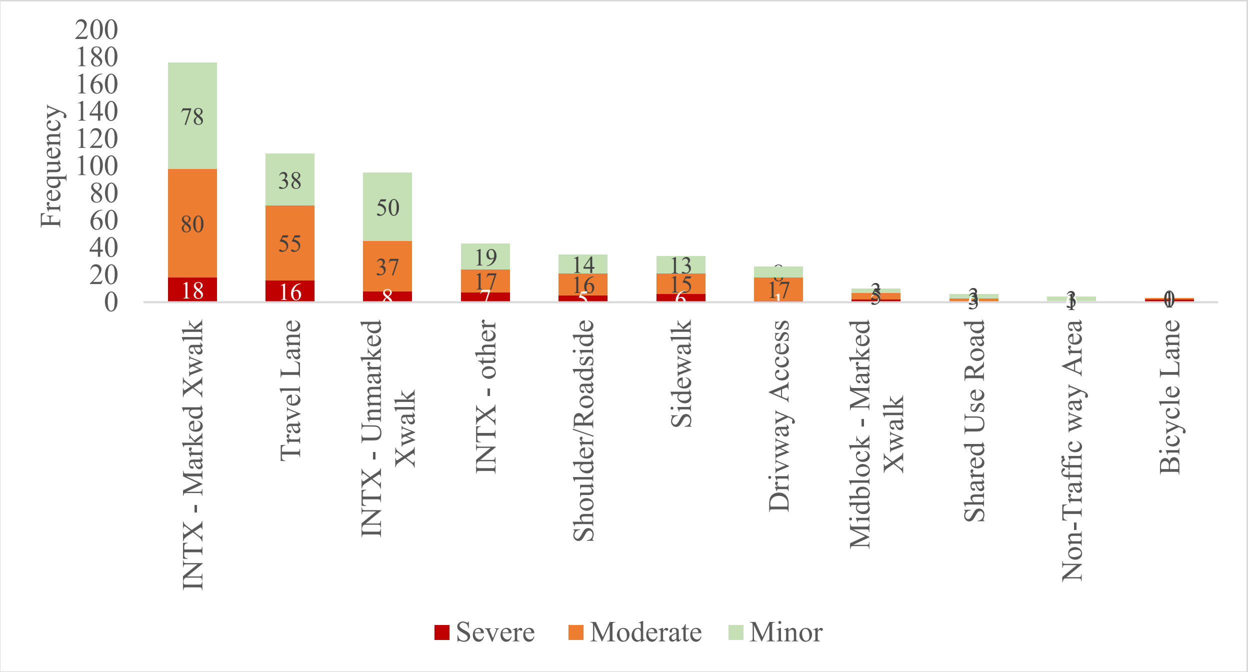


Figure 3.9: Crashes involving pedestrians/pedal cyclists location at the time of crash within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

3.4.3 Actions of Pedestrians/Pedalcyclists and Motorists

When it comes to the actions of pedestrians/pedal cyclists, crossing roadways represents most of the clusters, followed by walking/cycling on sidewalks and with traffic.

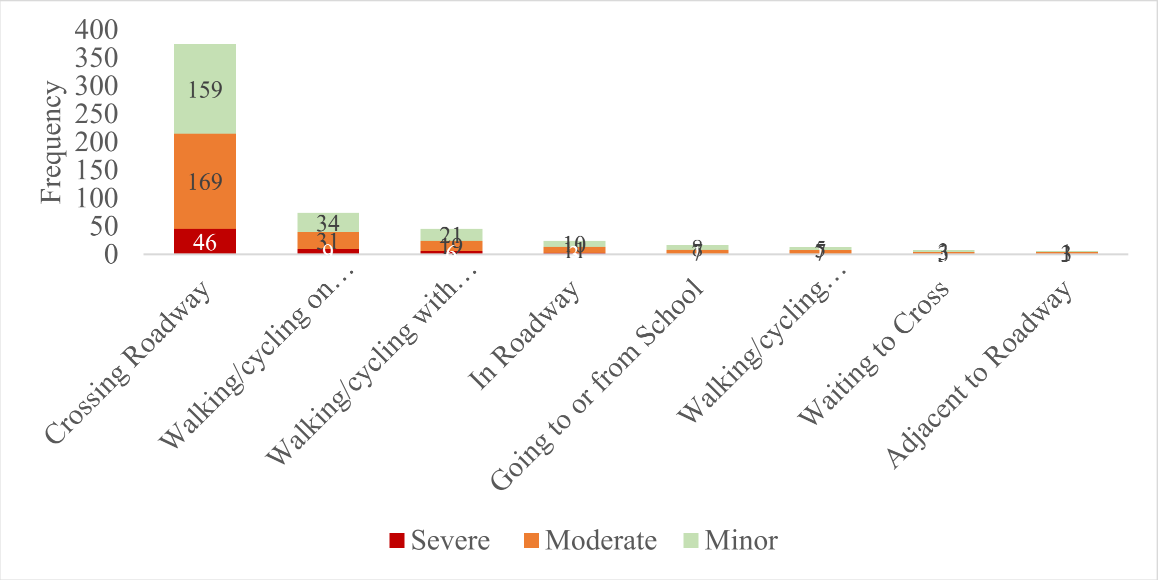


Figure 3.10: Crashes involving pedestrians/pedal cyclists actions prior to crashes within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

Considering the actions of pedestrians/pedal cyclists with the motorists, crossing roadways by pedestrians/pedal cyclists are overrepresented by the failure to yield the right-of-way and careless/negligent driving. It is noteworthy that no contributing actions of the drivers are reported in case of waiting to cross, walking/cycling with traffic, or against the traffic for the pedestrians/pedal cyclists.

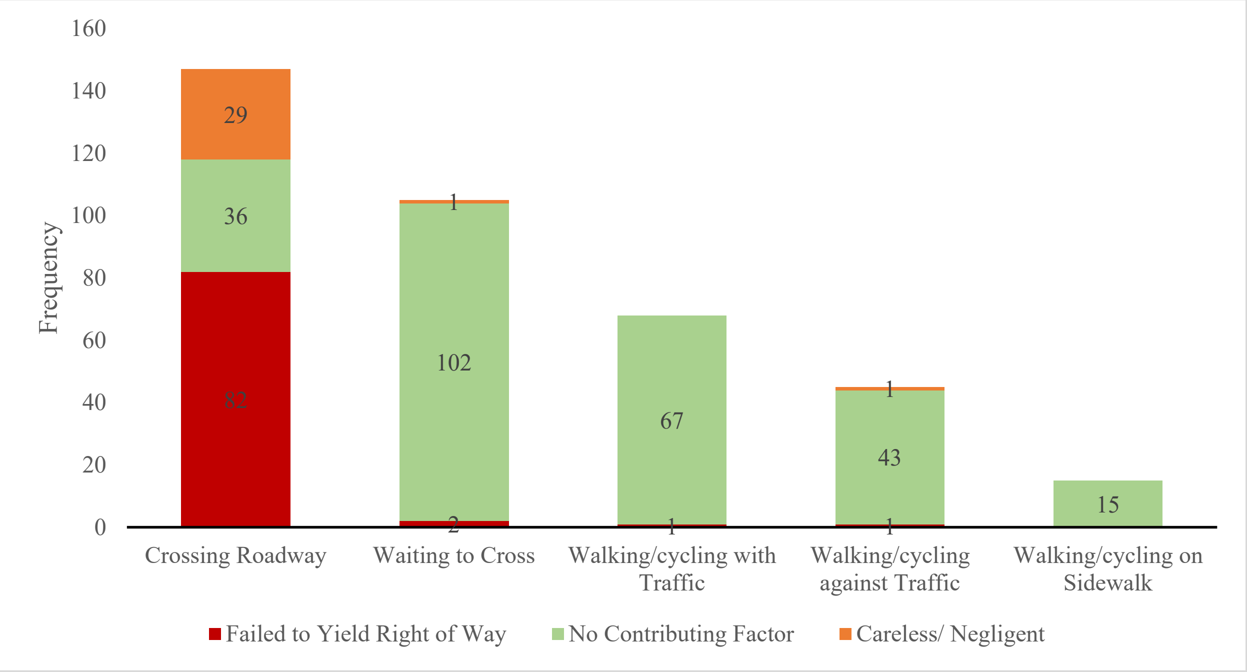


Figure 3.11: Crashes involving pedestrians/pedal cyclists and motorists' actions prior to crashes within 0.5-mi of elementary school by injury severity in Tampa Bay (2015-19).

The key contrasts between collision patterns in Tampa Bay and Dallas regions are described in our recent publication from this project (Rimu et al., 2022).

3.5 Conclusions

Major highlights of the crash analysis can be summarized as follows:

- Demographics
    - Pedestrians/pedal cyclists aged between 15 and 19 were primarily involved in these crashes.
    - Drivers aged between 30 and 49 were primarily involved in these crashes.

- Roadway Attributes
    - Two-lane undivided roads were overrepresented in these crashes.
    - Travel lane (segments) or "No Control" mostly experienced these crashes.
    - Roadways with speed limits between 30 and 45 mi/h mostly experienced these crashes.

  - Roadways with traffic volumes between 25,000 and 50,000 vehicles/day mostly experienced these crashes.
  - Intersections with marked crosswalk locations were overrepresented in terms of these crashes.

- Actions of Pedestrians/Pedalcyclists and Motorists
  - For pedestrians/pedal cyclists, crossing the roadway maneuvers were mostly overrepresented.
  - For motorists, "Failed to Yield Right of Way" was mostly observed while pedestrians/pedalcyclists were crossing the road

Moreover, from the geographic comparison perspective, important comparisons of crash analysis between Dallas and Tampa Bay are presented in Table 3.1.

Table 3.1: Summary of Crash Analysis by Most Severe Crashes and Relationship in Existing Studies

Factors	Crash by percentage		Literature review-based scenarios
	All Crashes	**Most severe Crashes**	• Pedestrian crossing light (31, 33-35, 37, 41) • Obstruction from the school bus, parked car, bushes, buildings, blind curve/hill, etc. (31, 33-35) • Car/school bus backing up (31, 33) • Companion calling from the other side of the road (33) • Companion calling to alert (31) • Demonstrating potential road hazards (32) • Demonstrating safe pedestrian behaviors (20) • 2-lane, 2-way street in the neighborhood (35) • One-way street with crosswalk; traffic included one motorcycle and two identical cars (41) • Theoretical selection with lectures on safe pedestrian behavior (37) • Traffic rules demonstration (37)
Road-way type	*Undivided Road* • Dallas: 87.2% • Tampa Bay: 77.1%	*Undivided Road* • Dallas: 77.5% • Tampa Bay: 71.7%	
Traffic control	*No Control* • Dallas: 69.8% • Tampa Bay: 56.7%	*No Control* • Dallas: 82.3% • Tampa Bay: 60.6%	
Vehicle type	*Passenger Vehicle* • Dallas: 43.1% • Tampa Bay: 64.8%	*Passenger Vehicle* • Dallas: 45.5% • Tampa Bay: 64.5%	
Speed limit	*30-45 mi/h* • Dallas: 86.1% • Tampa Bay: 58.5%	*30-45 mi/h* • Dallas: 85.9% • Tampa Bay: 71.4%	
Weather	*Clear* • Dallas: 77.8% • Tampa Bay: 85.4%	*Clear* • Dallas: 73.3% • Tampa Bay: 87.1%	

Based on the summary of crashes from Tampa Bay and Dallas, the follow factors were considered in developing the training module.

Table 3.2: Potential Factors Considered for the Development of the Training Module

1. Roadway type • Undivided • Divided	5. Speed limit • 20, 25, 30, 35, 45 (accounting for regional conditions)	9. Pedestrian location • Marked crosswalk • Unmarked crosswalk

2. Number of lanes
    - 2, 3, 6, 7 (accounting for regional conditions)
3. Traffic control
    - No control
    - Stop sign
    - Traffic signal
4. Vehicle mix
    - Passenger vehicle
    - SUV
    - Pickup truck
6. Traffic volume
    - 2500 to 5000 vehicles/day with consideration of local traffic conditions
7. Weather
    - Clear
    - Cloudy/Rainy (if required by local conditions)
8. Time of the day
    - Morning
    - Noon
    - Evening

- Midblock

10. Pedestrian action
    - Crossing
    - Waiting to cross
11. Obstacles
    - Parked car
    - Bushes/trees
    - School bus
12. Distractions
    - Companion
    - Mobile phone

The next chapter describes the development of the training module considering these characteristics.

4. Chapter IV: Simulation Development

4.1 Introduction

A virtual reality (VR)-based training module was created by adhering to recommendations from the crash data analysis. In this training, we have focused on scenarios leading to the most frequent and severe crashes in both Dallas and Tampa Bay. The training module was developed on a virtual platform so that children can have an immersive and interactive experience of walking on streets in different high-risk crossing scenarios. This tool was developed for a child-pedestrian to be able to independently make decisions to safely cross streets and walk to school.

The training module has been developed as a “VR Game” where a child can play the game as a “Player” to make it easy for children to use and learn. There are eight high-risk crossing scenarios (selected based on crash data analyses described in the previous chapter) included for training and testing purposes. Each scenario is presented as a “Level” for the game. This game was used to train and test a child player’s decision-making ability to safely cross the street. A head-mounted device (HMD), Oculus Quest, was used to immerse the players in the virtual game environment. The players will have to use a right-hand controller to change scenes: start the game, move to the next level, and end the game. As this game has been developed to effectively train children about safe pedestrian behaviors, the developer performed a quality test to ensure the effectiveness and user-friendliness of the game. The objective of this game development was to:

- Create an immersive traffic environment that replicates real-life road infrastructures, traffic, signals, and sound.
- Simulate a virtual environment where a player can have the experience of physically walking on crosswalks in the presence of virtual traffic.

4.2 Development Methodology

The training module was planned and designed by the researchers and stakeholders. A target HMD (Oculus Quest) was chosen from a list of VR headsets available from different manufacturers. After selecting the HMD, virtual traffic environments and other required environments were developed in a game engine, Unity. The developer created the necessary assets in Unity or purchased them from the Unity Asset Store. The components within the virtual environments (VEs) were scripted using the C# (C Sharp) programming language to simulate necessary traffic behavior (traffic volume, speed, and traffic signal control) and user interactions with the VR controller. Virtual reality software development kits (VR SDKs) were imported to assist with interfacing the HMD with VEs developed using Unity. A quality assurance test was conducted to ensure the realistic representation of traffic environments and effective incorporation of user interfaces. Finally, the training module was tested for its efficacy using an experimental study with elementary school-going child participants.

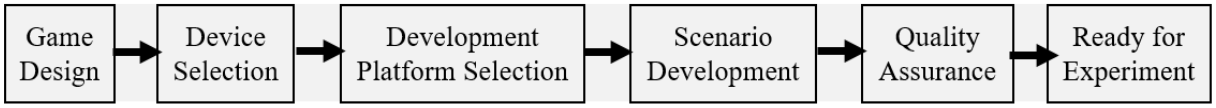


Figure 4.1: Flowchart of the training module development.

4.3 Game Design

Step 1: At first, the player will take place in the "Playground," a 30 by four square-foot floor area in our laboratory for the controlled experiment (Figure 4.2a). There will be a designated area for the player to stand and start the game. They will don the HMD and take the right-hand VR controller. The left-hand controller will not be used so that the user has fewer things to carry and fewer decisions to make.

a) Playground b) "Play Game" Menu c) Player position at the edge of the street

Figure 4.2: Game playground (a), menu (b), and player position at the street edge (c).

Step 2: After the player stands in the designated place and wears the HMD, a virtual environment appears in front of them. This environment is a room with wooden walls and a grass floor. The players are presented with a "Play Game" button dangling in front of them (Figure 4.2b). In this first VR environment, the player is asked to look around to acquaint themselves with the VR environment. They are also asked to use the controller to start the game. This environment functions as a VR familiarization environment for the child participants where they are first exposed to the VR environment and learn to use the VR environment controller.

When the player presses the "Play Game" button, he or she will be directed to a virtual traffic environment standing on the edge of a street-facing a crosswalk ahead (Figure 4.2c). The player will not have an initial idea about the street-crossing scenario. There are two white round marks on the sidewalk adjacent to the crosswalk showing the "Start Point" and the "End Point" of the crossing task (Figure 4.3a). When the player starts the game, he or she will appear on the "Starting Point" of the game.

a) Marks showing Start and End Points b) “Next Level” Button c) “Complete” Button

Figure 4.3: Game design terminal points (a), “Next Level” button (b), and “Complete” button (c).

Step 3: The player observes the traffic to search for a safe gap and attempts to cross the street. They start crossing the street to reach the other side on the “End Point” marker.

Step 4: After reaching the “End Point,” the player will turn around (180 degrees) and see a button called “Next Level” across the street (Figure 4.3b). As the playground area is a limited space within the laboratory, this turn-around is necessary to ensure that the player doesn’t walk out of the playground or walk into any obstacles (walls or equipment in the lab). As soon as the player clicks the “Next Level” button, he or she will find themselves standing on a “Start Point” of the next level, developed based on a different scene.

Step 5: The players will continue to repeat Steps 3 and 4 until they complete all eight levels of the game. The sequence of these eight levels will be randomized for each participant. When the player completes these eight levels, they will find them standing inside the wooden-wall room again with a “Complete” button in front of them (Figure 4.3c). If the player presses the “Complete” button, the game will be ready to start from the beginning for our next player.

4.4 Device Selection

For this project, an HMD (Head-mounted-device) had to be selected from numerous options for VR headsets to run the game. Among all the available options, Oculus Quest was selected for its lightweight design and consumer-oriented software. Oculus Quest runs on Android, which is a universal operating system. Because of the device’s light weight, low price, easy setup procedure, and a large number of consumers, it was chosen to reach a larger audience.

4.5 Development Platform Selection

We have chosen the Unity Game Engine developed by Unity Technologies. Unity allows its users to use the platform for educational purposes and for non-commercial use. It has released a toolkit, “XR Interaction Toolkit,” which helps the game developer to easily switch between different game platforms without changing codes. This means that the same game developed to be played in an HMD will be playable in VR devices manufactured by multiple manufacturers.

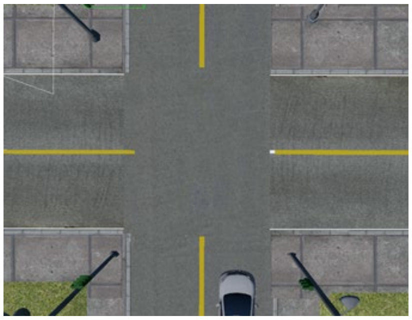
4.5.1 Scenario Development

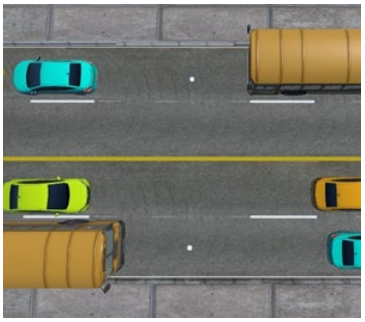
There are in total ten scenes in the game: the “Play Game” menu, eight different game levels, and the “Complete” menu. Different types of grass, streets, houses, traffic lights, and cars were used to build the environment and make it look realistic. The traffic system was made possible with the help of an asset used from Unity Asset Store called “Mobile Traffic System,” developed by Gley. For all street crossing conditions, the streets were two-lane streets. The eight levels of the game are different from each other in four fundamental variables (based on collision data analysis):

- **Traffic Speed**: It determines at which speed the vehicles will be moving in the game. For this game, two levels of traffic speed were considered: 20 mi/h and 45 mi/h.
- **Crosswalk Position**: This determines where on the street the crosswalk will be located. We have considered two different locations: at the intersection of a street and at a midblock.
- **Crosswalk Type**: Crossing areas can be both marked (Figure 4.4a) and unmarked (Figure 4.4b). An intersection can have both types of crosswalks, but a midblock can most likely have an unmarked crosswalk (Figure 4.4c). We have included both marked and unmarked crosswalks in our module.
- **Traffic control**: An intersection can include traffic control with traffic lights and pedestrian lights (Figure 4.4d). However, sometimes they may not be present (Figure 4.4e).

The attributes of the different scenarios in the game can be interpreted from Table 4.1.


a) Marked crosswalk.


b) Unmarked crosswalk.


c) Unmarked at midblock.


d) Pedestrian signal.


e) No Traffic light.

Figure 4.4: Crossing location features.

Table 4.1: Description of Different Scenes Used in the Game

Scene	Crosswalk Position	Vehicle Speed (mi/h)	Crosswalk Type	Traffic Light
"Start Game"	N/A	N/A	N/A	N/A
Level 1	Intersection	20	Marked	Present
Level 2	Midblock	20	Unmarked	Absent
Level 3	Intersection	20	Unmarked	Present
Level 4	Intersection	20	Unmarked	Absent
Level 5	Intersection	45	Marked	Present
Level 6	Midblock	45	Unmarked	Absent
Level 7	Intersection	45	Unmarked	Present
Level 8	Intersection	45	Unmarked	Absent
"Complete"	N/A	N/A	N/A	N/A

4.2.5 Quality Assurance

A quality control checklist was created to ensure that each level of the game is effectively designed and is free of bugs before it was uploaded in the HMD. It is presented in Table 4.2.

Table 4.2: Quality Assurance Checklist

No.	Criteria	What to check?
1	Traffic speed	To ensure that the vehicles in a specific game scene are moving at their desired speed. This is important because through this training, children will learn about vehicle speed and perceive the difference between low and high speed traffic.
2	Terrains and environment	To ensure that the virtual traffic environment is realistic in graphics and the player is not distracted by a broken scene, e.g., unusual gaps between streets and sidewalks, broken buildings, floating trees, etc. Therefore, a thorough inspection was made for the virtual environment so that the player behaves how they should in real-world traffic.
3	Streets	To ensure that there are no unnecessary bumps or streets are not too narrow or wide for the vehicles to move. The measurements for lane, crosswalk, and sidewalk were followed from the specified standards given by the Federal Highway Administration (FHWA).
4	Traffic sounds	To ensure that the game simulates the sound of a traffic environment for players to have a realistic experience of traffic exposure.
5	Green light timeout	To ensure that the green light in the traffic intersection does not remain for too long so that the player has a longer wait time to wait for their turn to cross the street. In the game, the green light timeout was set as 10 seconds.
6	No. of vehicles	To create high-risk scenarios for the participants in order to expose them to collision threats and to test their decision-making knowledge.
7	Intersection connections	In an ideal intersection, vehicles are supposed to be able to move in all directions randomly. If each time the vehicle stops in a specific lane, the game will not be realistic, and participants will be familiar with this specific scenario after a few levels.
8	Player position	Because the player walks in a limited space and takes a 180-degree turn as s/he advances to the next level, it is vital that the player starts the game in the desired position at each level.
9	Remove left controller	To reduce the complexity of the game control, only one controller was used. If the left controller is not removed in the development stage, the other (right) one may not function properly
10	Distance between start and endpoint	The distance between two white markers has to be 30 feet to maintain standard lane width. In addition, there can be safety issues (e.g., a player leaving the playground and crashing with obstacles).

11	Button functionality	To ensure that the buttons in every level work appropriately so that the player can advance to the next level/scene without any errors.

All these criteria were checked before we completed the VE development phase of our project. This task was challenging with student recruitment during the Covid-19 pandemic.

4.6 Future Improvement

Future improvements can be made to enhance the experience of the game. Throughout the game, only one vehicle model of multiple colors was used. The VR environment can be improved by adding new models. The option to choose an exact type of game scenario in the game menu can be added. A push-button for pedestrian crossing can be implemented as well. In terms of different traffic situations, stop sign intersections, and four-lane streets can be added for variations.

4.7 Conclusions

The game was built targeting child users aged 7-12 years. After the quality assurance checks, we have applied for approval for an experimental study from the Institutional Review Board (IRB) at the University of Texas at Arlington. This study will test the efficacy of the training module for children to develop safer pedestrian behaviors.

5. Chapter V: Efficacy of the Training Module

5.1 Introduction

The experimental module is aimed at training elementary school children about safe pedestrian behaviors within school zones using virtual traffic environments. Their interaction with traffic was recorded as the baseline or before-training data. After they were trained, they were exposed to similar virtual traffic environments for testing their pedestrian skills. Their interaction data with traffic was recorded as after-training data. The comparison of these before- and after-training data was performed to answer the following research questions:

1. Will the virtual scenarios successfully immerse participants in traffic environments?
   - Hypothesis 1a. The children will act reasonably (wait for gaps in traffic, follow traffic lights, not walk through virtual vehicles, etc.) as they should do in a real traffic environment.
   - Hypothesis 1b. The walking/crossing behavior of children will match their walking behavior in a real traffic environment (walking speed, looking for vehicles before crossing, etc.).
2. Will the training module successfully teach children about safe pedestrian behaviors?
   - Hypothesis 2a. Children will make safer decisions with less errors after training
   - Hypothesis 2b. Children will be involved in fewer collisions and near misses after training

5.2 Study Design

We have identified high-risk scenarios near school zones for pedestrian-related crashes based on traffic crash data analysis for Dallas and the Tampa Bay area. To our knowledge, this is the first study to base training scenarios on analysis of collision data. Based on these high-risk scenarios, we have designed our training and testing trials for two different speed limits (20 mi/h and 45 mi/h), three crosswalk types (marked, unmarked, and midblock), and two traffic controls (no control and traffic light). Traffic control varies based on the type of crosswalk. For example, only no-control scenarios were presented with unmarked crosswalks for midblock crossing. However, both marked and unmarked crosswalks were present for the traffic light conditions. There were a total of eight trials presented to them as baseline scenarios and then for testing trials. These trials were randomly presented to the participants for both trial periods. There was a three and half-minute video presentation to provide the children background information about the traffic environment, cues to follow before crossing a road, and safe pedestrian behavior: road structure, crosswalk, traffic signal, pedestrian crossing signals, looking for vehicles, developing decisions based on surrounding sound, etc. There were also training components shown in virtual environments to teach children about vehicle speed and distance to develop their cognitive perception of safe gaps in traffic.

5.3 Study Protocol

The interested participants were recruited after a screening survey to ensure that our participants are aged 7-12, can follow instructions, have no visual and hearing problems, and can successfully visualize and hear the virtual traffic. We also ensured that the participants could walk for at least 15 minutes to complete the experimental task of crossing streets multiple times. They were scheduled to come to the Human Factors Lab at the University of Texas at Arlington with at least one of their parents or legal guardians. The participants and their caregiver(s) were greeted by two researchers from the UTA research team. They were seated and provided with the IRB-approved consent and assent forms. One of the researchers read the consent form to the participants to inform them about the study procedure, risks, benefits, compensation, and confidentiality. The researchers answered any questions that the participants and their parents had. At that point, if the parent(s) and participant both agreed to participate, they signed the consent and assent forms. The researcher also signed the consent form and made a copy to give to the participant, and kept another for the research team.

Then, the participant was given an ID to answer demographic questions and a simulation sickness questionnaire (SSQ) with 16 survey items. The participant had to rate each survey item on a 4-point scale ranging from “None (0)” to “Severe (3)” for different motion sickness-related health issues. If they had an SSQ score equal to or below 5, they were allowed to continue with the study. Any participant with an SSQ score higher than five is not recommended to participate in this virtual training. However, we did not have any simulation sickness issues with our developed virtual training module.

The participants were then asked to wear a virtual reality headset. They were exposed to a virtual environment (VE) to be familiar with virtual reality (VR), read instructions within a VE, walk within VE, and interact with virtual components using the right-hand controller. After this exposure, the child started playing the game and crossed the street eight times for eight different scenarios, each scenario being around 30 seconds long. These data were saved as the baseline data: data without any training. After these baseline trials, the participant again responded to the SSQ and qualified participants were allowed to continue.

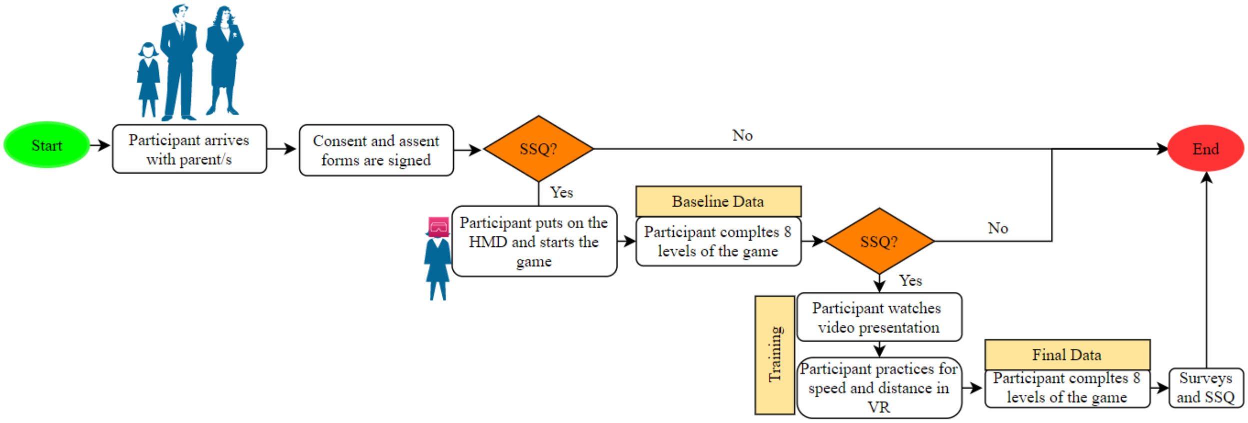


Figure 5.1: Flow diagram of the experimental study.

At this phase, the participant watched the video presentation and gained basic knowledge about traffic environments, traffic signals, crosswalks, and safe pedestrian behaviors. Then they were exposed to virtual traffic environments and were trained about low versus high speed and low versus high traffic volume to develop an understanding of safe gaps for crossing a road. After their training, the participants were tested for their pedestrian behavior by crossing roads for eight scenarios presented in a different order. The participants were again tested for simulation sickness using the SSQ in order to assure their safety to leave the lab in good health condition. The participants also answered a survey expressing their experience with virtual reality and the pedestrian training program. With this survey, the study (one-hour long) was completed, and each participant was compensated with $20.

5.4 Measures Collected

The subjective measures collected include participants' demographic data (age, gender, school, mode to travel to and from school, daily walking frequency, and weekly walking time), simulation sickness questionnaire (SSQ), and their experience survey about the training module and testing environment. The objective measures collected included the participants' pedestrian behavior concerning looking for vehicles, their walking speed, waiting time, near miss, and number of collisions with vehicles, collected from video recordings for the participants' view of the virtual world and their position data.

5.5 Results

Due to the Covid-19 pandemic, the IRB approval took longer to process and finalize. We had only five child participants and their parents who were willing to take the risk of exposure and joined the study in our lab. The Arlington Independent School District has approved our research team to implement our training in selected schools in Arlington, TX. We will start collecting data in the new school year. All the participants were boys, ranged 7-11 years, and walked less than two times and less than 15 minutes a day outdoors. Half of the children use buses to commute to school and return home, which involves some walking between home and the bus stops. For others, their parents drop and pick them up with personal vehicles. Half of the children sometimes walk alone on the streets, but only one-fourth of them cross streets alone.

5.5.1 Research Question 1: Realistic Immersion

We examined participants' interaction with the virtual traffic environment and their experience survey responses for realistic immersion. The video recording showed that children waited for a gap in the traffic; they were scared of virtual traffic and were concerned about being struck by vehicles and looked for traffic lights and pedestrian crossing signals. They also walked straight as they should on a crosswalk.

There were three survey items that indicated participants' perception of realism regarding the virtual traffic environment. Each of these survey items was rated on a 7-point Likert scale, '1' being the least realistic and '7' being the most realistic. From the survey responses, we found that most of the participants rated the virtual traffic environment, their interaction with the environment, and their activity (crossing) within virtual traffic with high scores. Table 5.1 shows child participants' survey responses (mean and standard deviations) on the realism score for the developed virtual traffic environment.

Table 5.1: Realism Scores for Virtual Traffic Environment.

Survey Item (Scored on a 7-point scale)	**Mean (SD) N=5**
The virtual streets felt real	5.50 (1.91)
It was easy to walk on virtual streets	6.75 (0.50)
My experience with the virtual environment felt natural	6.00 (2.00)

Analysis of the simulation sickness questionnaire data reveals no symptoms of simulation sickness in our participants with designed duration and number of virtual exposures. There was no record of simulation sickness development as we continued exposing participants for longer times in the virtual environment. We did not have to withdraw any participant regarding simulation sickness. This result confirms the quality graphics of our training environment and ensures that child participants can be safely exposed to our training program without the threat of causing any simulation sickness in them.

These results confirm that the participants found the virtual traffic environment realistic and behaved in the natural way that they would do in the real traffic environments. They can also safely immerse themselves in the training environment without developing simulation sickness.

5.5.2 Research Question 2: Efficacy of the Training Program

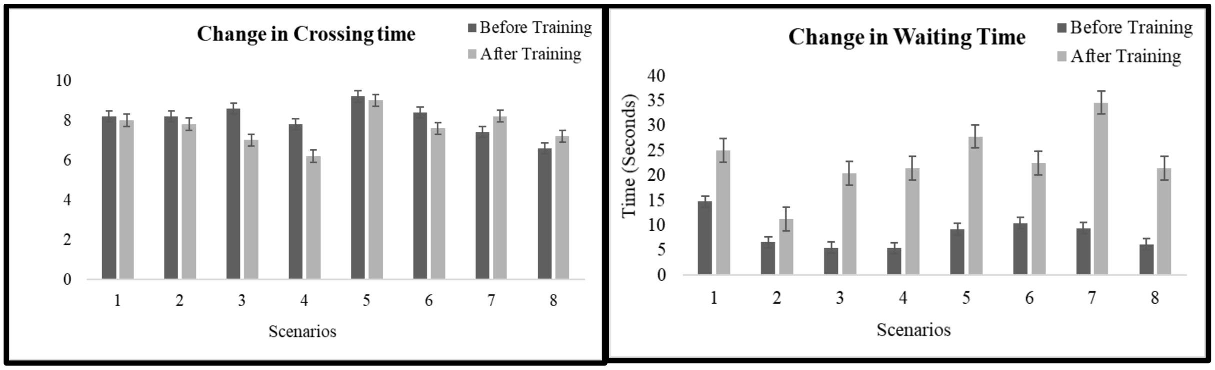
In this initial version of the educational program for child pedestrians, we have used one video presentation-based training program and one VR-based training program. Both programs are complementary to each other and are necessary to develop comprehensive knowledge about safe pedestrian behavior. Although each participant liked both programs and found them to be useful in developing their confidence toward crossing streets alone, they preferred the virtual training program to the video presentation-based training program. In the virtual training program, the children were able to gain a more profound insight of the virtual traffic and different signals, perceive vehicle kinematics (speeds and distances), and develop skills to identify safe gaps within the traffic. Each of the participants believed that their knowledge of safe pedestrian behavior improved after the training experience and that they became more comfortable crossing streets on their own.

In accordance with their subjective responses, we also analyzed participants' walking behavior in the virtual environment before and after their training. The measures that we compared include waiting time, crossing time, looking for vehicles, following traffic signals, experiencing collisions and their frequency.

Table 5.2: Virtual Reality-Based Training Scenarios' Results

Scenario	**Look for vehicle (percentage)**		**Follow traffic signal (percentage)**		**Waiting time (sec.)**		**Crossing time (sec.)**	
	Before	*After*	*Before*	*After*	*Before*	*After*	*Before*	*After*
20 mi/h_Marked_Traffic signal	100	100	66.67	100	14.75	25.00	8.20	8.00
45 mi/h_Marked_Traffic signal	66.67	100	100	100	6.60	11.20	8.20	7.80
20 mi/h_Unmarked_Traffic signal	66.67	100	33	100	5.50	20.40	8.60	7.00
45 mi/h_Unmarked_Traffic signal	66.67	100	33	100	5.40	21.40	7.80	6.20
20 mi/h_Unmarked_No signal	75	100	—	—	9.20	27.80	9.20	9.00
45 mi/h_Unmarked_No signal	100	100	—	—	10.40	22.40	8.40	7.60
20 mi/h_Midblock	100	100	—	—	9.40	34.60	7.40	8.20
45 mi/h_Midblock	75	100	—	—	6.20	21.40	6.60	7.20

The results reveal the effectiveness of the training in terms of developing safe pedestrian behaviors in children. After the training, the children searched for vehicles and threats of collisions for each of their trials, followed the instructions about traffic lights at crossing signals, and waited until they found a safe gap to cross the street. There was no significant difference in crossing times before and after training. However, there were significant differences in waiting times before and after the training.



a) Change in crossing time before and after training

b) Change in waiting time before and after training

Figure 5.2: Changes in crossing and waiting times before and after training.

5.6 Limitations

The lab has limited space, and therefore, the experiment only included a crosswalk scenario. The investigation included children aged 7-12 years old in order to control a safe study environment with children easier to instruct and supervise. With a larger free space, the threats of running into obstacles can be minimized, and children younger than seven can be included. Due to the pandemic situation, data of only a few participants were collected. The research team has communicated with the Arlington Independent School District to collect data from more children next semester. A future publication will include those data.

5.7 Conclusions

This research study was conducted to investigate the efficacy of the developed training module. The results confirm that the developed virtual training module provides a realistic presentation of the traffic environment and different objects within it.

Hence, it provides an ability to expose children to potential risks in virtual environments safely and can successfully teach children about safe pedestrian behavior. After the training, children learned to look for vehicles each time they crossed the street. They have also developed more patience to wait until they see the safe crossing signal or a safe gap within the traffic. Future training approaches can explore child pedestrians' route choices and the complete task of walking to a bus stop or walking to schools.

6. Conclusions and Future Research

Roadway pedestrian and bicyclist fatalities have risen dramatically during recent years, even as automobile occupant safety has improved in the US. The safety of child pedestrians is of particular concern. In this study, we focused on improving safety near schools serving disadvantaged populations since there is evidence that more impoverished neighborhoods typically face more pronounced safety challenges. The roadway environment can explain a substantial portion of the excess rate of road traffic injuries in the most impoverished urban areas. While the long-term solution is to make roadway networks safer by design, we need to train child pedestrians to navigate the environment as it exists in the short term. The Engineering and Educational components of SRTS programs provide us with a framework to advance Vision Zero (VZ) if interventions offered under these programs can meaningfully improve safety. Also, there is evidence that low-income schools are overrepresented among schools supported by SRTS programs. There may be an opportunity to advance VZ equitably through engineering and educational interventions offered through SRTS programs.

The aim of this research project was to develop an equity-driven program to improve safety for elementary school students. Towards that end, we assembled a database for traffic crashes near the schools serving disadvantaged populations. This research would have significant equity implications by focusing on schools serving disadvantaged communities. Scenarios for VR-based training programs should be informed by collision data contextualized for these communities.

This study was conducted using data from Tampa Bay, Florida, and Dallas, Texas.
Exploratory analysis was conducted on the safety of child pedestrians in both localities. The crash data analysis included roadway geometric design characteristics, traffic control type, vehicle mix, posted speed limit, weather conditions, time of day, pedestrian crossing location, presence of obstacles such as parked cars, and distracted pedestrians.

A virtual reality (VR)-based training module was created based on the findings from the exploratory crash data analysis. The training moduled focused on scenarios leading to the most frequent and severe crashes in the Dallas region. Similar training programs tailored to specific communities may be created based on crash data from other areas. The module was developed to effectively train children, aged 7-12 in Arlington, Texas, on safe pedestrian behaviors. IRB approval was required to conduct the training. The training module was developed on a virtual platform so that children can have an immersive and interactive experience of walking on streets in different high-risk crossing scenarios. This tool was developed for child-pedestrians to be able to independently make decisions to safely cross streets and walk to school. Pre-training questionnaires were distributed to the participants to check whether they were sensitive to VR environments. If yes, the participants were not permitted to participate in the module. Those who were admitted into the training module were provided background information and were asked to conduct dry runs on the VR environment software prior to the actual experiment to familiarize themselves with the module. Also, post-training questionnaires were distributed to ask whether the participants developed symptoms of sickness related to exposure to the VR environments. Quality assurance checks were also made to ensure that the VR platform operated without any glitches.

The VR training module survey results revealed that the children, by and large, found the immersive training environment to be realistic. There was no significant difference in crossing times before and after the training indicating that their walking speed was not affected. However, there were significant differences in waiting times before and after the training. After the training, the children were more likely to i) look for vehicles and threats of collisions, ii) follow the instructions about traffic lights at crossing signals, and ii) wait until they found a safe gap to cross the street. Hence, Before-after observations of the participants showed the effectiveness of the training in terms of developing safe walking behaviors in the children.

6.1 Future Work and Technology Transfer

The work has the potential to inform the education part of the SRTS programs. If SRTS programs can increase VRU safety, they may increase active travel mode share further since traffic safety is often cited as one of the barriers by parents for using active travel modes. In other words, increasing active travel mode share and improving safety are goals that complement each other. School districts may use the training program framework to train child pedestrians as part of the SRTS programs. From discussions with our stakeholders, we learned that the states, particularly Florida, have been making significant efforts to improve SRTS programs. Therefore, these SRTS programs would be an effective venue to implement the findings from our research and enhance the existing programs. This would be the focus of technology transfer efforts for this research.

In terms of future research directions, one may explore child pedestrians' route choices, and the training may include the complete task of walking to a bus stop or from (to) home to (from) school. The training may be conducted using VR-based environments similar to the one used in this study. We also recommend that researchers looking at developing training programs examine school zone context and collision data carefully to inform the scenarios.

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Appendix A:

Appendix B: Technology Transfer

An Appendix should be included in this final report to document the Technology Transfer activities conducted during the project term, accomplishments towards T2 adoption and implementation by relevant stakeholders, as well as any relevant post-project T2 plans.

Title of Presentation	Conference	Delivery
An Equity-driven Approach for School Zone Safety: An Exploratory Crash Analysis	TRB Annual Meeting 2022	Sunday Workshop
An Equity-driven Approach for School Zone Safety to Inform Safe Routes to School (SRTS) Programs	TRB Annual Meeting, 2022	Committee Meeting
A Roadmap for Child Pedestrian Training Program Informed by Contextual Crash Data	TRB Annual Meeting, 2022	Poster and TRR accepted paper
An Equity-driven Approach for School Zone Safety to Inform Safe Routes to School (SRTS) Programs	Stakeholder Meeting, 2021	Presentation to Florida Safe Route to School Program Director

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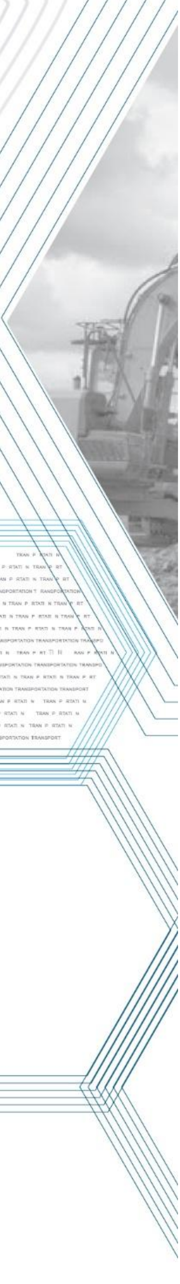

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