TTI: 0-6875-03

Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety—Phase III: Technical Report

Technical Report 0-6875-03-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

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16. Abstract

Crashes involving transit vehicles, bicyclists, and pedestrians are a concern in Texas, especially in urban areas. This research explored the potential of automated and connected vehicle (AV/CV) technology to reduce or eliminate these crashes. The project objectives focused on identifying safety concerns related to the interaction of transit vehicles, bicyclists, and pedestrians, and targeting AV/CV technologies to mitigate or eliminate those concerns. In Phase II, a concept of operations (ConOps) plan for designing, testing, piloting, demonstrating, and deploying candidate applications through an AV/CV Test Bed to Improve Transit, Bicycle, and Pedestrian Safety was developed. A smart intersection was developed and pilot tested at the RELLIS Campus.

In this research project 0-6875-03, TTI researchers implemented a smart intersection at George Bush Drive and Penberthy Boulevard (GBD/PB) on the Texas A&M University campus in College Station. The smart intersection includes Texas A&M buses turning at the intersection automatically communicating with the traffic signal and providing audible and visual alerts to waiting pedestrians and bicyclists. The system was operated, monitored, and evaluated over a 14-month period from April 2020 to June 2021.

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AUTOMATED AND CONNECTED VEHICLE (AV/CV) TEST BED TO IMPROVE TRANSIT, BICYCLE, AND PEDESTRIAN SAFETY—PHASE III: TECHNICAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

The United States government and the state of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object this report.

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I. INTRODUCTION

BACKGROUND, PROJECT OBJECTIVES, AND ACTIVITIES

Crashes involving transit vehicles, bicyclists, and pedestrians are a concern in Texas, especially in urban areas. In research project 0-6875, Texas A&M Transportation Institute (TTI) researchers explored the potential for the use of automated and connected vehicle (AV/CV) technology to reduce or eliminate these crashes. The project focused on identifying safety concerns related to the interaction of transit vehicles, bicyclists, and pedestrians, as well as targeted AV/CV technologies to mitigate or eliminate those concerns. TTI researchers identified concept applications — along with public- and private-sector partners — and developed a concept of operations (ConOps) plan for designing, testing, piloting, demonstrating, and deploying candidate applications through the project AV/CV Test Bed to Improve Transit, Bicycle, and Pedestrian Safety. A pilot of the Mobileye Shield+™ system, a camera and sensor-based collision-warning system, was conducted on one Texas A&M University bus.

In research project 0-6875-02, TTI researchers focused on preventing crashes involving transit vehicles, bicyclists, and pedestrians at signalized intersections. The smart intersection application includes buses automatically communicating with smart traffic signals to provide visual and audible warnings to bicyclists and pedestrians. The use cases and alert scenarios, system requirements, test plan, and test scenarios for the smart intersection were developed. A smart intersection was constructed at The Texas A&M University System RELLIS Campus proving ground. Proof-of-concept tests of the smart intersection and a beta Android smartphone application (app) were conducted at the RELLIS smart intersection. To gain additional insights into preferred alert communication methods and messages, focus groups were conducted with hearing and visually impaired individuals and people in wheelchairs in Houston. Surveys of pedestrians at three intersections with high volumes of turning buses were also conducted in Houston.

In this research project 0-6875-3, TTI researchers implemented a smart intersection at George Bush Drive and Penberthy Boulevard (GBD/PB) on the Texas A&M University campus in College Station. The smart intersection includes Texas A&M buses turning at the intersection automatically communicating with the traffic signal and providing audible and visual alerts to waiting pedestrians and bicyclists. The system was operated, monitored, and evaluated over a 14-month period from April 2020 to June 2021. An assessment of the Mobileye® Shield+™ V4, installed by Rosco Collision Avoidance on two new Texas A&M University buses was also conducted as part of the project.

The COVID-19 pandemic did impact the research project. The operation of the smart intersection at GBD/PB was initiated just as the shelter-in-place directions responding to COVID-19 were issued. Texas A&M University pivoted to online classes, and agencies and businesses moved to work at home. Online classes continued through the summer. The fall 2020 and spring 2021 semesters were a combination of in-person and online classes. As a result, fewer pedestrians and bicyclists were using the GBD/PB intersection for much of the assessment period. The project schedule was extended due to COVID-19, with some of the evaluation elements rescheduled to dates when more students would be on campus. In addition, project panel meetings and the Roundtable Forum were held virtually.

ORGANIZATION OF RESEARCH REPORT

This research report is divided into six sections following this introduction. Section II summarizes the development and operation of the smart intersection at the GBD/PB intersection. Section III presents the assessment of the smart intersection. The results from surveys with pedestrians and bicyclists, an assessment of video tapes of crossing behavior, online surveys of bus operators, and a review of crash and incident data are highlighted. Section IV describes the assessment of the Mobileye® Shield+ ™ Version 4 collision warning systems on two new A&M buses. Section V summarizes the Roundtable Forum conducted on June 22, 2021. Section VI includes an update of the vision, goals, and candidate applications for the test bed to improve transit, bicycle, and pedestrian safety, which was developed in Phase I. The report concludes in Section VII with a Value of Research (VoR) assessment.

II. DEVELOPMENT AND OPERATION OF THE SMART INTERSECTION

This section describes the operation of the GBD/PB smart intersection. It includes a review of the system components and the process for alerting bicyclists and pedestrians that a bus is turning left at the intersection. Figure 1 shows the location of the GBD/PB intersection on the Texas A&M University campus. As illustrated in Figure 2, buses on Route 8 (named the Howdy Route by Texas A&M), which turn left from Penberthy Boulevard to George Bush Drive at the intersection, are the focus of this project. Buses on two other routes operate straight through the intersection on Penberthy Boulevard. These buses are not the focus of the project. The path of the turning buses and the crosswalk of interest are highlighted in Figure 3. Figure 4 illustrates a bus turning left at the intersection.

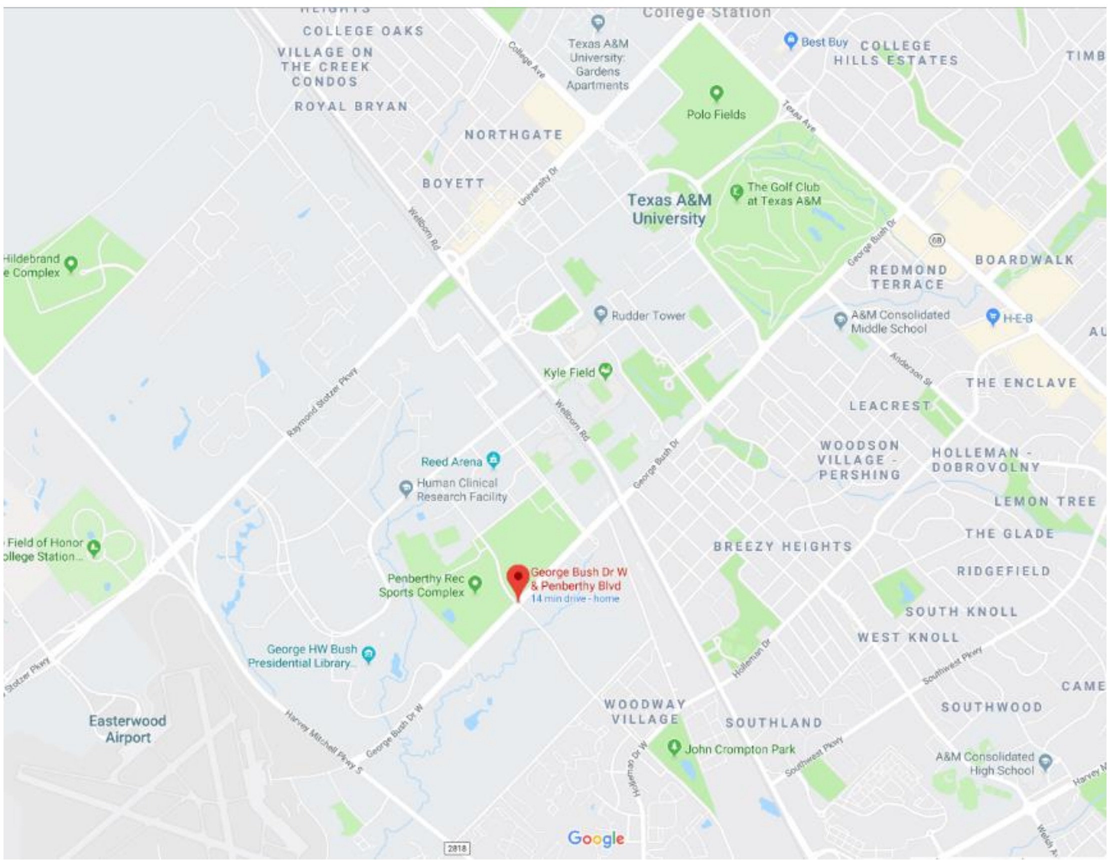


Figure 1. Location of GBD/PB Intersection.

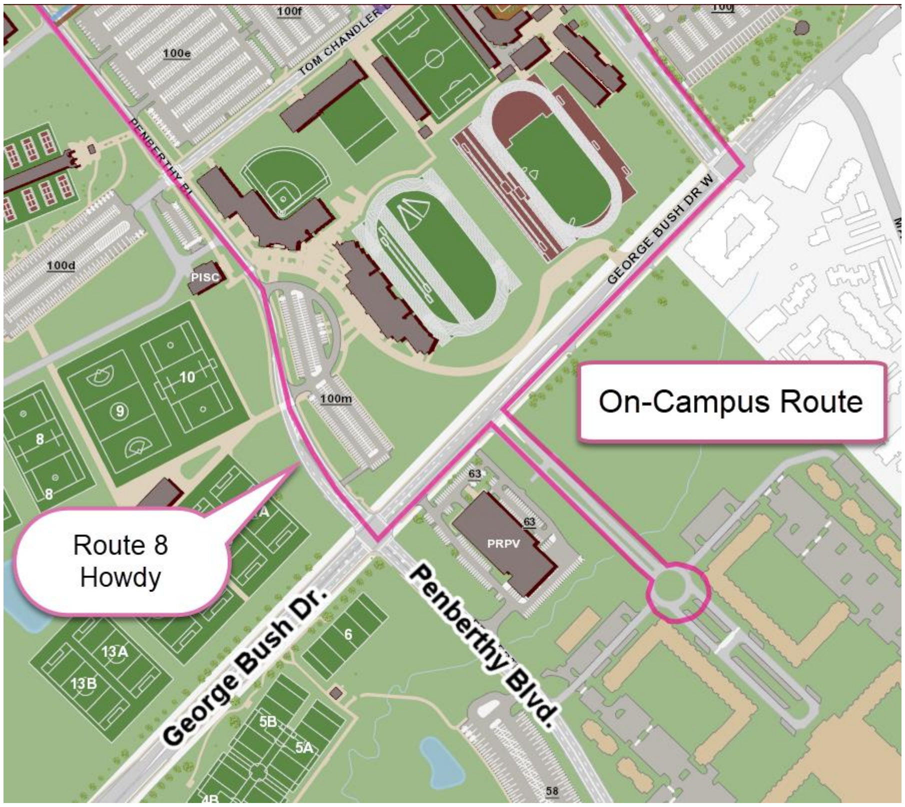


Figure 2. Route 8 (Howdy Route).

Figure 3. Crosswalk of Interest and Path of Left-Turning Buses.

Figure 4. Bus Turning Left at the GBD/PB Intersection.

The development of the GBD/PB smart intersection included the traffic signal components and the radios on the Texas A&M buses. These components are summarized next.

TRAFFIC SIGNAL COMPONENTS

Figure 5 and Figure 6 show the location of the traffic signal cabinet, the traffic signal poles, the pedestrian detection areas, and the pedestrian push buttons. The following equipment was installed at the intersection for the smart intersection application.

- A Siemens M62 controller was installed in the City of College Station traffic signal cabinet. This controller allows the project to interface with the controller without connecting to the City of College Station network, ensuring the integrity of the security of the city communication network. The M62 controller does not influence the signal operations at the intersection. The existing M60 controller is still in the cabinet as a backup in case the M62 controller malfunctions.
- A field-hardened personal computer (PC) and a modem were installed in the traffic signal cabinet.
- FLIR® infrared sensors were installed on the signal poles at the northeast and southeast corners of the intersection. Figure 7 illustrates the location of the sensors, which detect

pedestrians and bicyclists on the sidewalk waiting to cross the intersection. The sensors were channelized into detector channel #49 using temporary wiring which can be removed at the end of the project. Channel #49 is not being used by the City of College Station, and the FLIR sensors do not have any impact on the operation of the signal system.

- A Cohda Wireless™ dedicated short range communication (DSRC) radio was installed on a pole at the northwest corner of the intersection. The location of the DSRC radio, which detects when a bus on Route 8 is arriving at the intersection, is shown in Figure 8.
- As illustrated in Figure 9, fiber optic supplemental bus signs were installed on the signal poles at the northeast and the southeast corners of the intersection. The bus signs are connected to Load Switch 1 Red in the signal cabinet and are illuminated when a Route 8 bus arrives at the intersection to turn by interfacing with the controller using Special Function 8. This special function was not being used by the City of College Station. The use of Special Function 8 does not have any impact on the function of the intersection.
- Figure 10 shows the location of the Polara Accessible Pedestrian Systems (APSs), which were installed on the signal poles on the northeast and the southeast corners of the intersection. The Polara APSs provide an audio message ("Caution, Bus Turning" in English) when a Route 8 bus is turning at the intersection.

The installation of the equipment at the BGD/PB intersection represented a coordinated effort with the City of College Station. Figure 11 shows city personnel installing the supplemental bus signs. The research team met with city staff before and throughout the development of the system. The research team greatly appreciates the assistance of city personnel in the installation of the equipment.

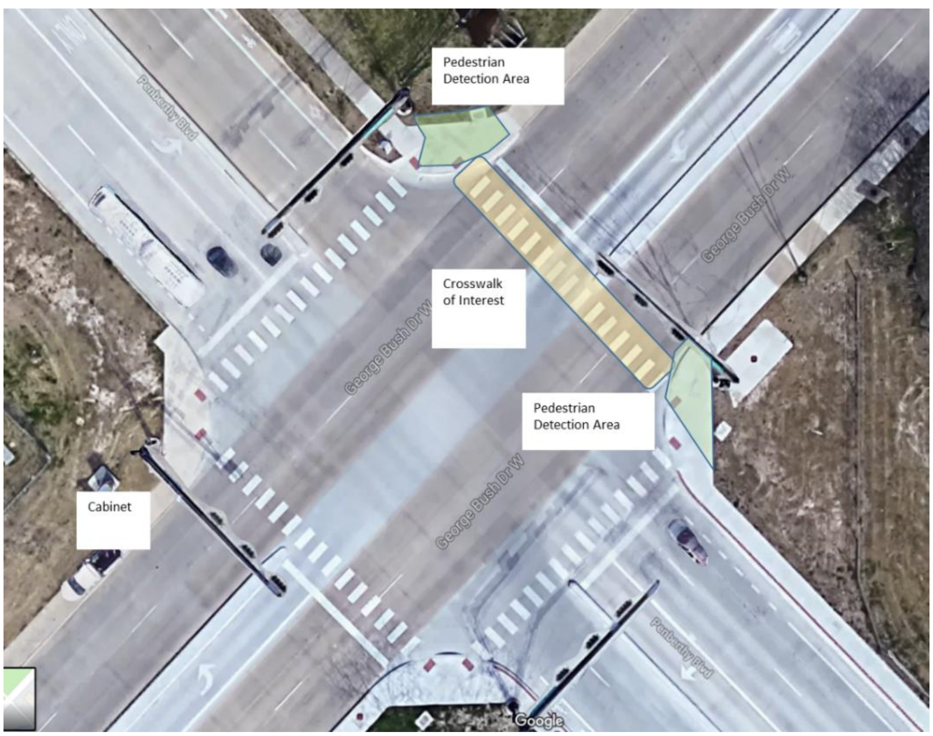


Figure 5. Pedestrian Detection Area at GBD/PB.

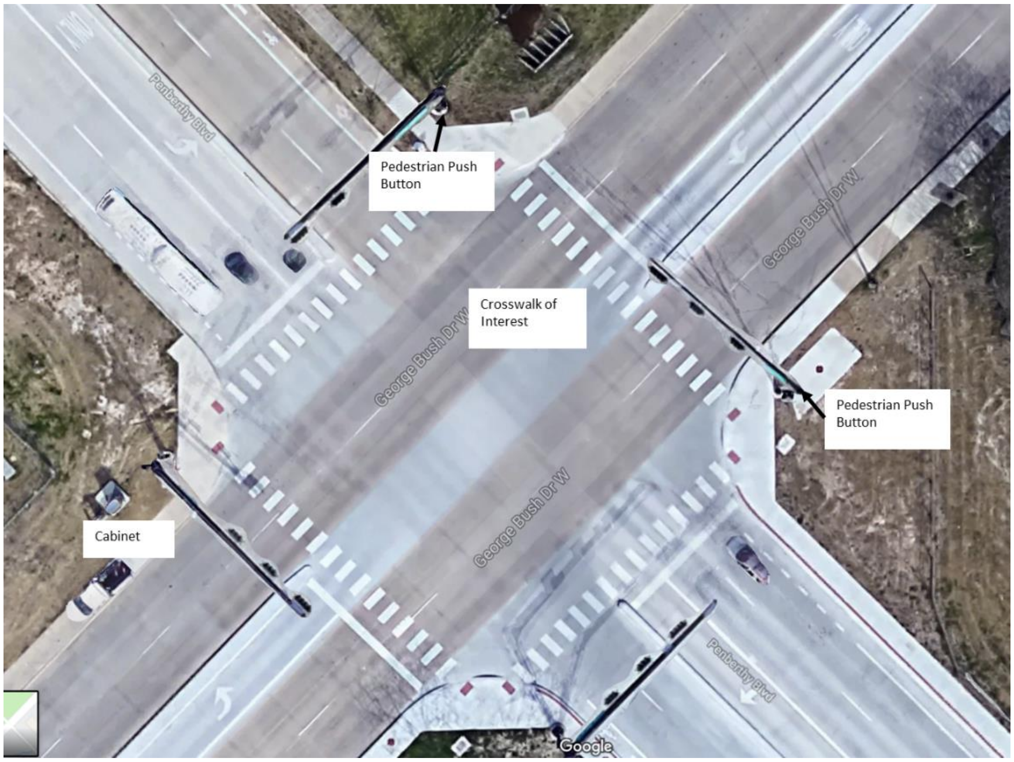


Figure 6. Pedestrian Push Button Locations at GBD/PB.

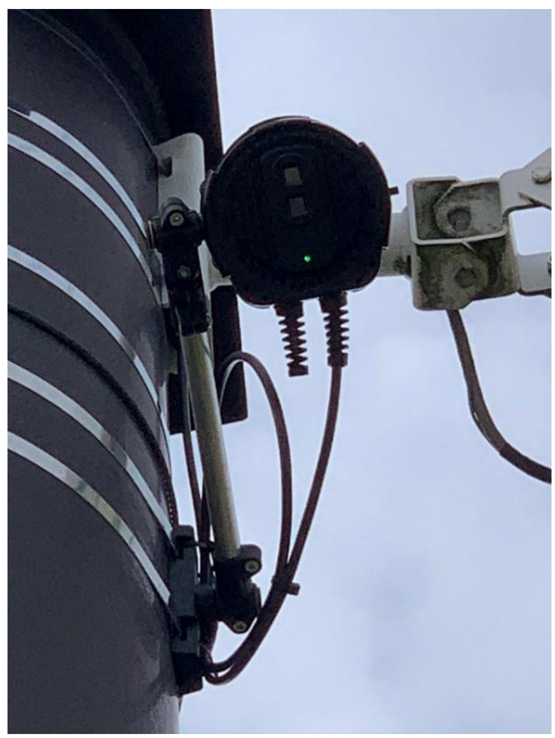


Figure 7. Location of FLIR Sensors on Traffic Pole.

Figure 8. Location of Cohda DSRC Radio.

Figure 9. Fiber Optic Bus Signs.

Figure 10. Polara Accessible Pedestrian System.

Figure 11. City of College Station Personnel Installing Equipment.

ONBOARD BUS COMPONENTS

Ten Texas A&M University buses were equipped with DSRC radios for the demonstration. Texas A&M Transportation Services selected the buses (#625 to #633 and #635, Millennium buses) for the project and installed the DSRC radios. Texas A&M personnel provided detailed documentation on the installation of the radios, which is summarized here. The research team greatly appreciates the assistance of Texas A&M Transportation Services personnel in installing the radios and overall participation in the project.

The radios were installed behind the destination sign panel above the windshield on the front of the buses, which is shown in Figure 12. The placement of the radios was selected to ensure no distraction to bus drivers or impact on bus operations. It was also selected due to ease of removing the panels for the initial installation and for ongoing maintenance and troubleshooting. Figure 13 illustrates the placement of the DSRC radio antennae on the roof of the bus. The installation took advantage of an existing opening in the bus roof. Texas A&M Transportation Services provided 12-volt power for the radios, with a switch connection so that the radio operates only when the bus engine is on.

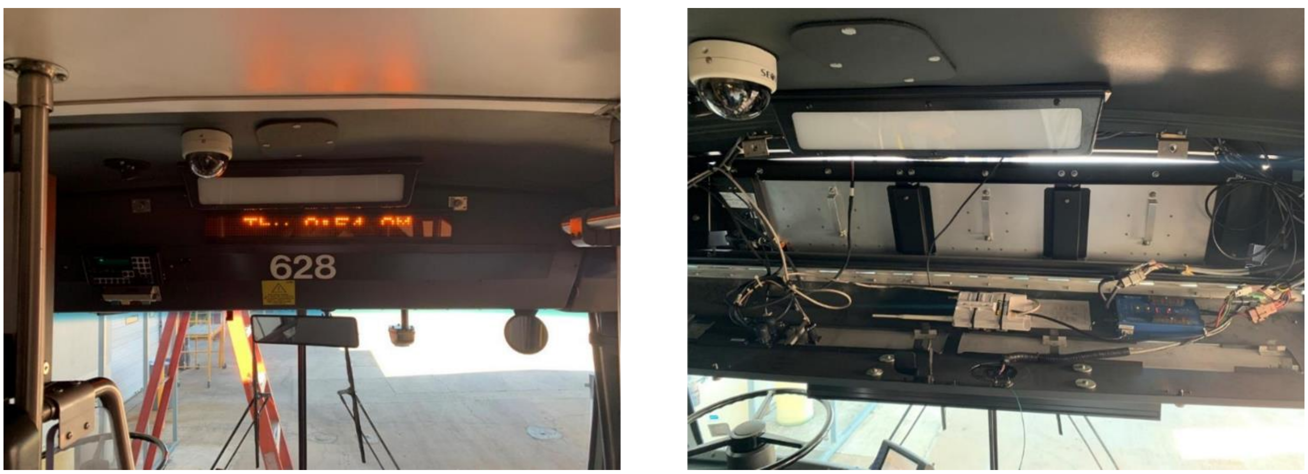


Figure 12. Location of DSRC Radios on Texas A&M Buses.

Figure 13. Radio Antennae Placement of Bus Roof.

TESTING OF THE SYSTEM

The system was configured as per the architecture illustrated in Figure 14. The system uses the various components in the following manner.

1. DSRC Roadside Unit (RSU) — Identify a bus with an onboard unit and obtain the coordinates and the heading of the bus along with a custom identification (ID).
    a. Coordinates are used to calculate the distance of the bus from the intersection.
    b. Coordinates are used to determine if the bus is in the left-turn bay.
    c. Heading is used to determine if the bus is approaching the intersection from the correct direction.
2. Cellular modem — Monitor the live feed from Texas A&M Transportation Services to match the ID of the onboard unit (OBU) and determine the next stop of the instrumented bus.
3. FLIR detector — Detect a pedestrian on the sidewalk.
4. Traffic signal controller.
    a. Monitor the presence of the pedestrian on detector channel # 49.
    b. Monitor of the signal phase is Phase 7 or Phase 8.
    c. Call Special Function 8 to display the bus sign.
5. Polara APS — Initiate audio alert using a digital i/o card.

The smart intersection at RELLIS Campus, which is equipped with a FLIR sensor, Polara APS, and a supplemental bus sign, was used to test the system.

MONITORING THE SYSTEM

The system was tested in shadow mode in mid-March 2020. With the successful completion of this initial testing, the system was fully operational by late March. Due to the pandemic, and the pivot to online classes, the Texas A&M buses continued to operate on the "break" schedule for the remainder of spring semester and the summer. This situation resulted in fewer buses traveling through the intersection. The online classes also resulted in fewer pedestrians and bicyclists using the intersection. The number of buses, pedestrians, and bicyclists increased during the fall 2020 and spring 2021 semesters but were still lower than pre-pandemic levels.

TTI researchers visually monitoring the performance of the system on an ongoing basis. Log files were created, maintained, and updated on the performance of the system. Video data from Texas A&M Transportation Services' cameras were collected and analyzed for a two-week period in May 2020. The video was compared to the log files. The results of this analysis confirmed that the system was operating properly.

Researchers logged the live feed of data transmitted by Texas A&M University Transportation Services, which is available on their website. The website contains numerous attributes of the bus service and is updated every 10 seconds. Using a specially created application, TTI researchers logged the live feed data for every bus on Route 8 approaching GBD/PB intersection. The application identifies the buses on Route 8 approaching the intersection once they reach a geofence established by TTI researchers before the intersection. The log files are independent of the log files created by the signal cabinet system at the intersection and are used to verify the overall bus operations at the intersection. These log files also identify if any non-instrumented buses are operating on Route 8, which occurred during the initial stage of the demonstration. The log files help ensure that only instrumented buses are assigned to Route 8.

The data logged by the system include the current date, time, bus number, next time for the bus, bus description, route name and number, scheduled and estimated departure time for the next stop, current coordinates and heading, speed and passenger capacity and occupancy. The information in the live feed is used by the system to confirm if the buses next stop is Parkwest Apartments as illustrated the system architecture.

The FLIR sensors were adjusted in September 2020 to enhance the detection of pedestrians and bicyclists in the intersection waiting zones. The video tape of the zones and the log files were reviewed after this adjustment. The detection of pedestrians and bicyclists in the east side zone was enhanced with the adjustment.

A log file is also created for all signal cabinet system activities at the intersection. The daily log file includes the time stamp of the arrival of the bus from when the bus is within 200 feet of the intersection, the identification number of the On Board Unit (OBUID), the distance from the stop bar, whether the bus is in the left turn bay (confirmation that the bus is turning left), coordinates and the heading of the bus, the traffic signal status for Phase 7 (left turning phase for protected movement) and Phase 8 (opposite through phase for the permissive movement) and status of the pedestrian detection. The log file also logs the time stamp of when the bus sign is turned ON and the Audio Alert is activated, and when the bus sign is turned off after the bus leaves the intersection.

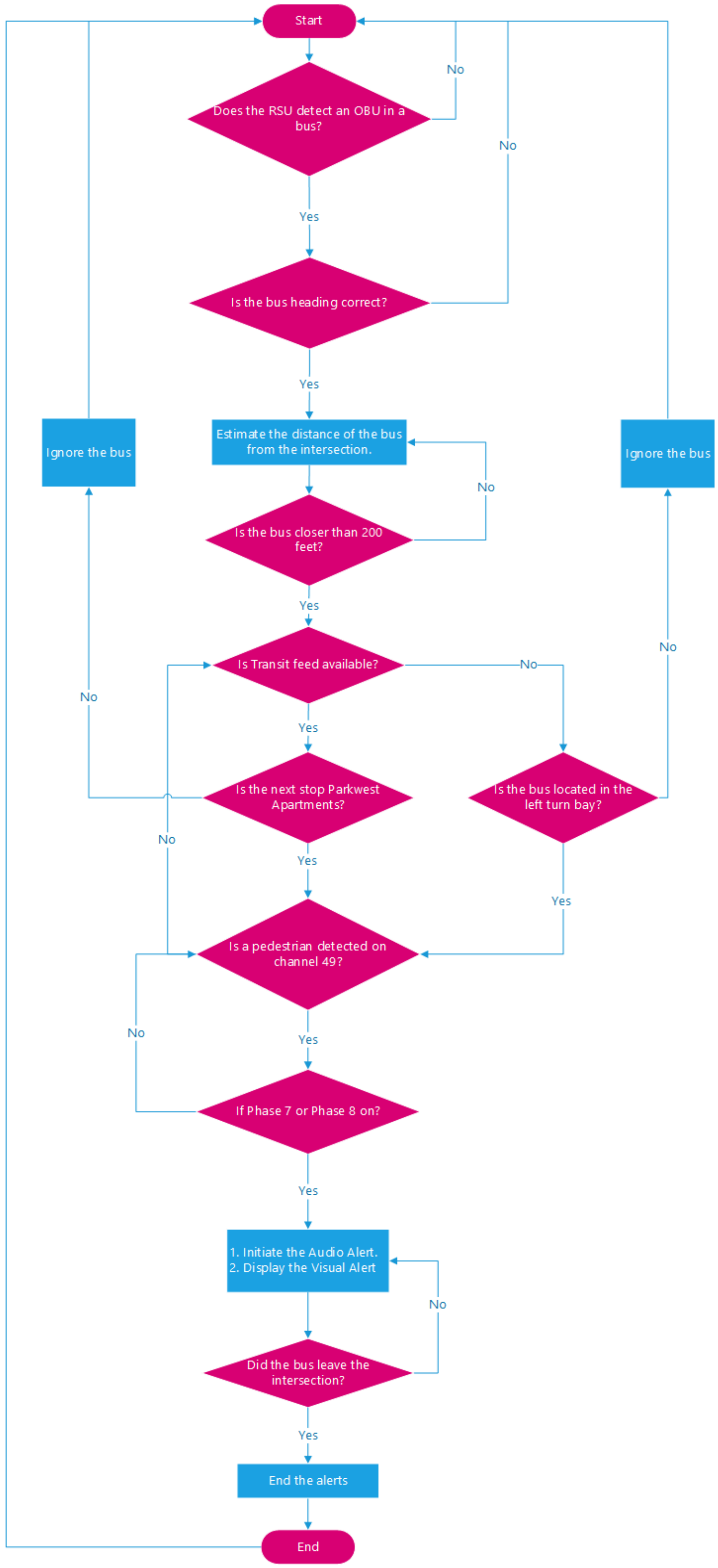


Figure 14. Flowchart of the System Architecture.

III. ASSESSMENT OF THE SMART INTERSECTION

This section presents the results of the intercept surveys of pedestrians and bicyclists conducted at the GBD/PB intersection in April 2021 and the analysis of the videotaped pedestrian and bicyclist crossing behavior before the demonstration in the fall of 2019 and in June 2021 after the demonstration had been in operation for 14 months. The results of an online survey of Texas A&M University bus operators are also summarized. Data from the TxDOT Crash Records Information Systems (CRIS) for a year before the demonstration and a comparable 12 months during the demonstration are summarized, along with information from the Texas A&M University Transportation Services Incident Reports.

PEDESTRIAN AND BICYCLIST INTERCEPT SURVEYS

TTI personnel conducted surveys with pedestrians and bicyclists crossing at the GBD/PB intersection on Monday April 19, Tuesday April 20, and Wednesday April 28, 2021. The survey procedure and the survey instrument were approved through the Texas A&M University Institutional Review Board (IRB). A copy of the survey form is included in Appendix A.

Figure 15. TTI Personnel Conducting Interviews.

As illustrated in Figure 15, TTI personnel were stationed at both sides of the sidewalk on the east side of George Bush Drive. TTI personnel approached pedestrians and bicyclists waiting to cross the street and asked if they would complete a short survey. The participants' verbal responses were entered into a hand-held tablet computer. After completing the survey, TTI personnel entered as many of the following observations as possible about the participating pedestrian or bicyclist:

- Gender.
- Approximate age.
- If a phone or mobile device was visible.
- If the participant was wearing/using headphones.
- If the participant was a pedestrian, a bicyclist, or riding on an e-scooter or some other device.
- When the pedestrian entered the crosswalk (during walk indication or not walk indication).
- If the participant crossed the street within or outside of the crosswalk or the bike lane.
- If the pedestrian looked both ways before entering the crosswalk.

A total of 97 participants were surveyed over the three days. As highlighted in Table 1, pedestrians accounted for 68 percent of the participants, bicyclists accounted for 25 percent, individuals using e-scooters represented 4 percent and 3 percent were using other devices (roller skates, skateboards). Males accounted for 55 percent of the total participants and 71 percent of the bicyclists. Females accounted for 45 percent of the total participants and 55 percent of the pedestrians.

Table 1. Intercept Survey Participants

	Male Number	Female Number	Total Number	Percent
Pedestrians	30	36	66	68%
Bicyclists	17	7	24	25%
E-Scooter	3	1	4	4%
Other	3	0	3	3%
Total	53	44	97	100%

Most participants, 95 percent, were identified as college age. A total of 45 percent of the participants reported crossing at the intersection daily, and 44 percent reported crossing at the intersection at least once per week. Only 10 percent responded that they use the intersection less than once per week.

A total of 60 percent of the participants reported they had noticed the “BUS” sign or heard the announcement while traversing the intersection. Of those responding that they noticed the sign or heard the announcement, 60 percent reported that they found it helpful. In a separate question, 91 percent of those noticing the sign or hearing the warning reported that it would be helpful for all or some people crossing the street. Participants who were more frequent users of the intersection tended to report that they noticed the sign or heard the warning than infrequent users did.

PEDESTRIAN AND BICYCLIST CROSSING BEHAVIOR

One element of the assessment involved observing pedestrian and bicyclist behavior crossing the intersection before and after the implementation of the smart intersection element. It is important to note that the smart intersection features — the supplemental bus sign and the verbal warning — were not developed to influence many of the personal behaviors of pedestrians and bicyclists examined in this assessment, including wearing earbuds to listen to music, looking at phone, or talking on a phone. Although information on all crossing behaviors is presented, the key observed behavior this project could influence was looking at the supplemental bus sign and pedestrian signal the after period. The percentage of pedestrians looking at the supplemental bus and pedestrian signal for a long time increased from 25 percent in the before period to 33 percent during the demonstration.

Figure 16 shows an aerial view of the intersection, with the pedestrian push buttons examined in the analysis highlighted. The northeast and southeast corners are the corners of interest along with the crosswalk that connects the two corners, in particular the area highlighted with a yellow line in Figure 16. Temporarily installed or city cameras were used to record the view of interest at the GBD/PB intersection. The characteristics of the crosswalk of interest are presented in Table 2. The posted speed limit for the east and west legs (George Bush Drive) is 50 mph, 40 mph for the south leg, and 30 mph for the north leg which is part of the Texas A&M campus. All legs at this intersection have four through lanes along with a left-turn lane.

Figure 16. Aerial View of Intersection.

Table 2. Site Characteristics for the George Bush Drive and Penberthy Road Intersection.

Characteristics	East Leg of Bush and Penberthy Intersection
Length of Crosswalk (ft)	77
Length of Walk Phase (s)	13
Length of Flashing Don't Walk Phase (s)	17
Push Button Required (yes or no)	Yes

Operation of the intersection was recorded in the before period from October 1 to October 22, 2019, with the assistance of Texas A&M University Transportation Services. A solar trailer was deployed with two cameras. The research team was able to position the cameras to provide both a street-level view (Figure 17) and a bird's-eye view (Figure 18) of the intersection. The two views allowed the research team to observe the following items:

- All vehicles and pedestrians passing through the crosswalk of interest.
- The waiting areas at both corners bounding the crosswalk of interest.
- The vehicular signal heads for the northbound intersection approach.
- The pedestrian signal head on the northeast corner for the crosswalk of interest.

Figure 17. Street-Level View of the Intersection (Before).

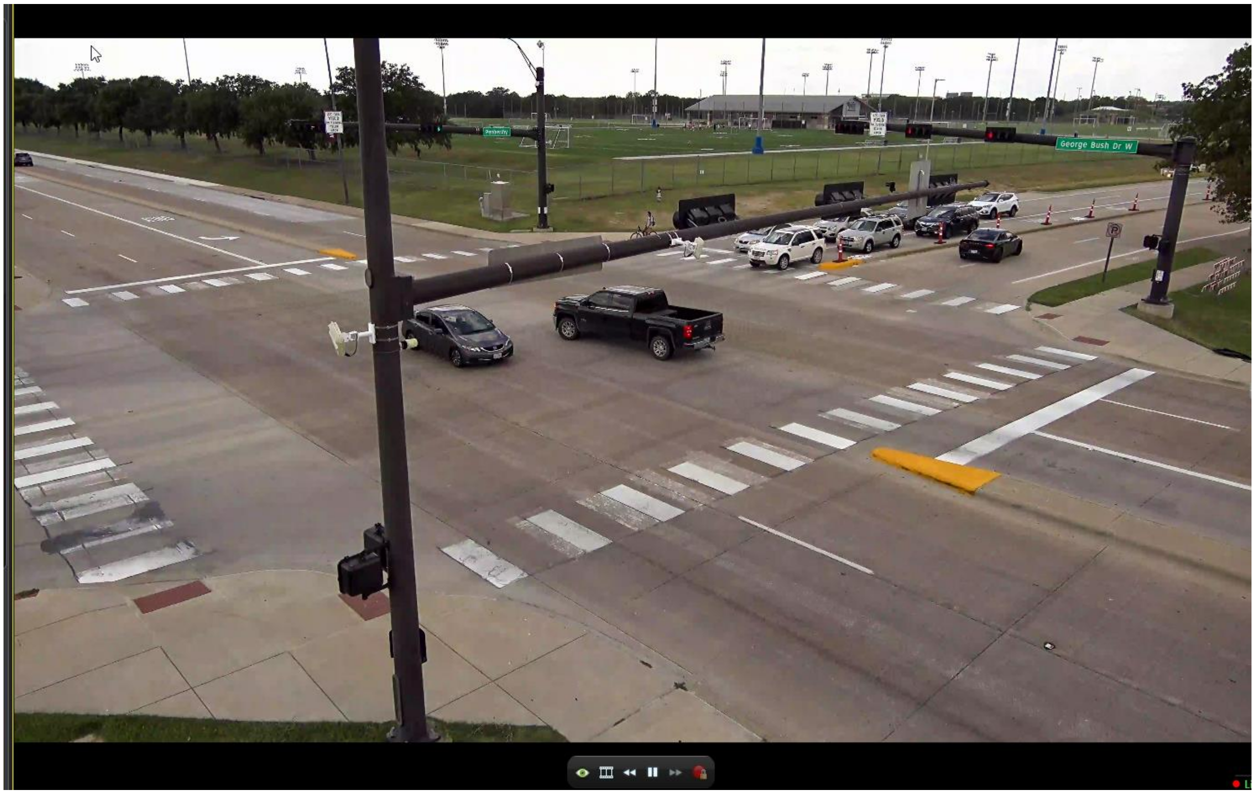


Figure 18. Bird's-Eye Camera View of the Intersection (Before).

Operation of the intersection was again recorded in the after period from March 29, 2021, to April 12, 2021, with the assistance of Texas A&M University Transportation Services and the City of College Station. The research team used a different camera setup because the two-camera solar trailer from the before period was not available for the after period. The research team obtained street-level footage from a one-camera solar trailer provided by Transportation Services (see view in Figure 19) and bird's-eye footage from the permanently installed pan-tilt-zoom camera maintained by the city (see camera view in Figure 20). The activated bus warning sign is illustrated in Figure 19 and the presence of the solar trailer is shown in the upper-right corner of Figure 20.

Figure 19. Street-Level View of the Intersection (After).

Figure 20. Bird's-Eye Camera View of the Intersection (After).

The research team downloaded and reviewed the video footage collected to obtain a preliminary measure of the sample size. Since the analysis objective was to assess interactions between pedestrians or bicyclists with left-turning buses, only time periods with pedestrian and bicyclists or bus volumes were examined. Figure 21 shows bicyclists traveling through the intersection following a left-turning bus. Based on the campus bus schedules and preliminary reviews of the video footage, the weekday period between 7 AM and 7 PM was used in the analysis. In the after period, the video footage from Friday, April 2 (Good Friday) was not used because the campus was closed in the afternoon.

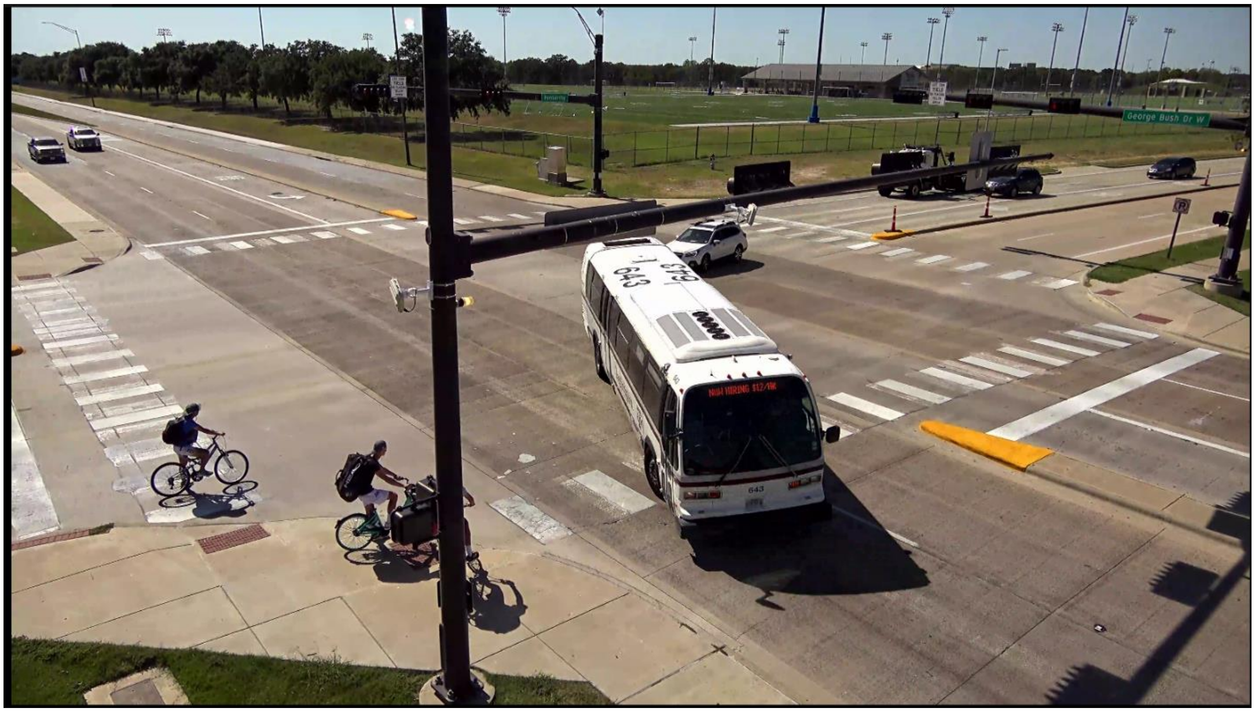


Figure 21. Example of Bicyclists Crossing the Intersection Following the Bus Turning Left.

In the before period, the research team reviewed 117 hours of video over 14 weekdays. A total of 238 pedestrians and bicyclists, as well as a few individuals using scooters, skateboards, and roller skates were identified interacting with 146 buses. In the after period, the research team reviewed 120 hours of video over 10 weekdays. A total of 144 crosswalk users were identified interacting with 102 buses equipped with the radio units. An additional 8 buses without the bus warning system were observed during the after period, but these buses and their corresponding crosswalk users were excluded from the dataset. The lower number of pedestrians and bicyclists in the after period was probably due to fewer students on campus because of the pandemic.

Data reduction occurred in the following three rounds:

1. Record time stamps for left-turning bus arrivals and pedestrian and bicyclist arrivals and departures involving the corners of interest. This step determined the scope of subsequent steps by focusing on pedestrians, bicyclists, and other crosswalk users who crossed the intersection during a signal cycle that had one or more left-turning buses present.
2. Count the volumes of crosswalk users originating from each corner during the crossings of interest.
3. Collect detailed observations of each crosswalk user, including demographics, behavior, and interactions with vehicles.

Due to the passage of time between the two periods, the research team had to identify different technicians to reduce the video footage in the after period. Similar instructions were provided to both groups along with a coding sheet to minimize differences that may be introduced by having different technicians reduce the before and after data. For both groups, the same researcher responded to questions the technicians had regarding data reduction tasks.

The factors recorded in the data reduction process are listed in Table 3. The time stamps of various events were recorded as individual crossings were observed. The crosswalk user arrival variable was the time stamp arriving at the corner. The departure variable for a pedestrian (or a bicyclist who was on the sidewalk) was the time stamp departing the corner and entering the crosswalk. For bicyclists in the bike lane, the departure time was the time that the bicyclist's rear tire departed the crosswalk on the south leg of the intersection. The behavior for each crosswalk user was reviewed to identify if they were distracted, if they pressed the pedestrian push button, and if they looked at the pedestrian signal or vehicle traffic.

Table 3. Data Reduction Variables.

Type	Factor Recorded	What Was Recorded
Time Stamps/Signal	Time Stamp of Bus Arrival	Time Stamp
	Corner of Pedestrian/Bicyclist arrival	NE (northeast), SE (southeast)
	Pedestrian/Bicyclist direction	NB (northbound), SB (southbound)
	Time Stamp of Pedestrian/Bicyclist Arrival	Time Stamp
	Time Stamp of Pedestrian/Bicyclist Departure	Time Stamp
	Time Stamp of Preceding or Current Pedestrian Phase	Time Stamp
	Pedestrian Signal Indication during Bus Turn	WALK, FDW (flashing Don't Walk), SDW (steady Don't Walk)
Pedestrian/Bicyclist Volume	Group Type	Peer, Mixed, No
	Group Count	Discrete value
	Volume with Pedestrian/Bicyclist	Discrete value
	Volume toward Pedestrian/Bicyclist	Discrete value
Pedestrian/Bicyclist Characteristics	User type	Pedestrian, Bike, Scooter, Other
	Age	1 (under 18 or kids) ,2 (18–25 or college students), 3 (26–55 or adults), 4 (56+ or elderly)
	Gender	Male or Female
	Shirt Color (to aid in checks)	Color
Pedestrian/Bicyclist Behavior	Distraction Type	None, Phone/Music, Talking, Texting, Other
	Pressed pedestrian push button	Yes, No
	Looked at pedestrian signal	Long, Some, None
	Traffic glances	Yes, No
	Entrance	Early, OK
	Within crosswalk lanes	Within, Outside
	Within bike lane	Within, Outside
	Hurried in second half of crossing	Yes, No
	Hurried through entire crossing	Yes, No

The distribution of crosswalk users who arrived when a left-turning bus was present were identified and are listed in Table 4. There was a notable decrease in the overall count of crosswalk users in the after period, likely due to the COVID-19 pandemic and the resulting decrease in campus population as many classes were still being held online and many extracurricular activities were cancelled or scaled back. The distribution between users also changed from the before to after period with a greater percentage of the users being pedestrians in the after condition (54 percent as compared to 31 percent). For ease of analysis, the individuals using bicycles, scooters, skateboards, or other (e.g., rollerblades, lawn mower) are included in the “wheels” category in subsequent discussion.

Table 4. Number of Crosswalk Users by Starting Corner.

Corner	Users	Before		After	
		Number	Percent	Number	Percent
NE	Bicyclist	59	57%	17	27%
	Pedestrian	37	36%	44	70%
	Scooter	4	4%	2	3%
	Skateboard	4	4%	0	0%
	Total	**104**	**100%**	**63**	**100%**
SE	Bicyclist	87	64%	39	48%
	Pedestrian	36	27%	34	42%
	Scooter	9	7%	4	5%
	Skateboard	2	1%	2	2%
	Other	1	1%	2	2%
	Total	**135**	**100%**	**81**	**100%**
Both	Bicyclist	146	61%	56	39%
	Pedestrian	73	31%	78	54%
	Scooter	13	5%	6	4%
	Skateboard	6	3%	2	1%
	Other	1	0%	2	1%
	Total	**239**	**100%**	**144**	**100%**

Observed pedestrians were categorized into one of four age groups: under the age of 18 or children, between the ages of 18 to 25 or college students, between the ages of 26 to 55 or adults, and over the age of 56 or elderly. In both periods, most users were estimated to be college age (18 to 25 years), which was expected given the location of the intersection on the edge of the Texas A&M campus. The distribution between male and female was about equal for the after period (56 percent male) and more heavily male in the before period (70 percent male).

Researchers classified the potential for distraction into five categories. The category of “none” represented that the pedestrian or bicyclist was not distracted. Texting was categorized as looking at and interacting with their phone. (Although pedestrians may have been checking their e-mail or playing a phone game, texting is used as a generic term to denote that behavior for this study.) Phone use was categorized as holding the phone against or near one’s face. If a pedestrian or bicyclist had headphones on, he or she was categorized as listening to music. Given that it is possible that a pedestrian or bicyclist with headphones could also be talking on the phone, it was decided to combine using headphones with those holding the phone near their face. The category of “other” distractions was used for any that were not described by other categories.

Table 5 provides the distribution of distraction observed for the pedestrians and wheel user. The observations indicated that 62 percent of pedestrians and 86 percent of wheels using the intersection were not distracted in the before period. In the after period, a similar percentage of wheeled users were coded as not being distracted; however, a smaller proportion of the pedestrians in the after period were coded as having none for distraction (29 percent). In the after period, a greater proportion of the pedestrians were observed to be talking to others within their group or were paying attention to a dog.

Table 5. Distraction Distribution for Pedestrians and Wheeled Crosswalk Users.

Crosswalk User	Distraction Type	Before Count	Before Percent	After Count	After Percent
Pedestrian	None	45	62%	23	29%
	Phone/Music	19	26%	26	33%
	Texting	6	8%	0	0%
	Talking	2	3%	23	29%
	Other (Dog)	1	1%	6	8%
Pedestrian Total		**73**	**100%**	**78**	**100%**
Wheels	None	143	86%	54	82%
	Phone/Music	23	14%	7	11%
	Talking	**0**	0%	5	8%
Wheels Total		**166**	**100%**	**66**	**100%**

Table 6 presents if a pedestrian or wheel user glanced at traffic before entering the crosswalk. “Glances” were defined as noticeable movements of the head toward the left side or right side or both of the road. In most cases, the user did look at the traffic prior to entering the crosswalk. The percentages were somewhat smaller in the after period than the before period (64 percent versus 81 percent for pedestrians; 59 percent versus 78 percent for wheeled crosswalk users). A notable change was in pedestrians crossing within a group. In the before period, 78 percent of grouped pedestrians glanced at traffic, while only 52 percent did so in the after period. When crossing within a group, it may not be as critical for the user to glance at traffic as others within the group can help with searching for vehicles. For those pedestrians who crossed without a group, 70 percent of the pedestrians glanced at traffic in the after period as compared to 82 percent in the before period.

Table 6. Glanced at Traffic.

Crosswalk User	Group	Traffic Glances	Before Count	Before Percent	After Count	After Percent
Pedestrian	No	No	9	18%	16	30%
		Yes	41	82%	37	70%
		Total	**50**	**100%**	**53**	**100%**
	Yes	No	5	22%	12	48%
		Yes	18	78%	13	52%
		Total	**23**	**100%**	**25**	**100%**
	Both	No	14	19%	28	36%
		Yes	59	81%	50	64%
		Total	**73**	**100%**	**78**	**100%**
Wheel	No	No	26	22%	22	42%
		Yes	92	78%	31	58%
		Total	**118**	**100%**	**53**	**100%**
	Yes	No	11	23%	5	38%
		Yes	37	77%	8	62%
		Total	**48**	**100%**	**13**	**100%**
	Both	No	37	22%	27	41%
		Yes	129	78%	39	59%
		Total	**166**	**100%**	**66**	**100%**

Table 7 describes pedestrian behavior in terms of looking at the pedestrian signal head. In the before period, all pedestrians looked at the pedestrian signal, 25 percent for a long time. The percentage of pedestrians looking at the pedestrian and supplemental bus sign for a long time increased to 33 percent in the after period. The supplemental bus sign may have influenced this result.

Table 7. Pedestrians Looking at Pedestrian Signal Head Behavior.

Looked at Pedestrian Signal?	Before Count	Before Percent	After Count	After Percent
Long	18	25%	26	33%
Some	55	75%	50	64%
None	0	0%	2	3%
Grand Total	**73**	**100%**	**78**	**100%**

Table 8 describes pedestrian button-pressing behavior. The pedestrians pushed the button essentially the same amount in the two time periods (74 percent before, 73 percent after).

Table 8. Pedestrians Button-Pressing Behavior.

Pushed the Button?	Before Count	Before Percent	After Count	After Percent
No	19	26%	21	27%
Yes	54	74%	57	73%
Grand Total	**73**	**100%**	**78**	**100%**

Two variables were used to describe if the crosswalk user hurried during either the second half of the crossing movement or the entire movement. These two variables were used to account for situations where a crosswalk user increased pace to finish the crossing during the second half of the movement (to avoid running out of time at the end of the flashing DON'T WALK indication) or whether he or she was hurrying throughout the crossing (such as running or jogging, not in response to running out of time). In almost all the crossings, the user did not hurry at any point of the crossing (231 of 239 users in the before period, or 97 percent; 136 of 144 users in the after period, or 94 percent).

For the group variable, a group was classified as peer or mixed. If the group consisted of people who appeared to be of similar age such as friends or colleagues, it was classified as peer. If the age of individuals varied (e.g., a professor with students or family), the group was classified as mixed. In all cases, the groups consisted of people of similar age. In about half of the crossings (126), the user was the only person moving in his/her direction. The pedestrian grouping patterns did not change notably between the two time periods.

The timestamps were used to calculate the number of seconds between when the user entered the intersection and when the bus began the left turn. Figure 22 shows the cumulative distribution of the time difference between the crosswalk users entering the intersection and the bus starting the left turn. The graph separated the distribution for those starting from the northeast (NE) corner and those starting from the southeast (SE) corner, since people originating from the northeast corner can proceed halfway through the crossing before reaching the bus-ped/bike conflict zone, so an early start is less concerning for these people. Negative values (at the bottom portion of the graph) indicate that the pedestrian or bicyclist moved into the intersection before the bus began turning. In the before period, approximately 90 percent entered the intersection after the bus had initiated the left turn, with 10 percent entering the intersection before the bus turned. One notable change was observed in the after period. Specifically, only about 2 percent of the pedestrians originating from the southeast corner entered the intersection before the bus turned (see the red data series on the graph). Pedestrians originating from the southeast corner would be most likely to be exposed to a conflict with the left-turning bus, so it is desirable to reduce the number of early corner departures by these pedestrians.

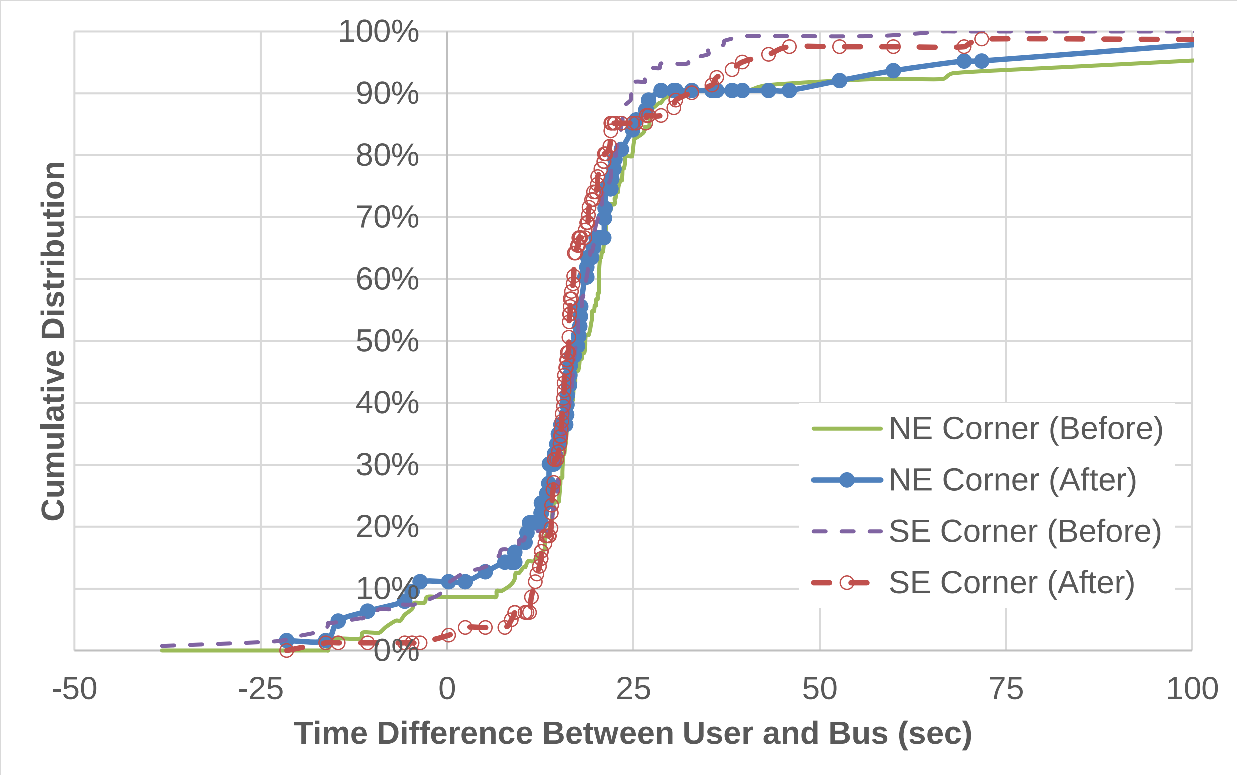


Figure 22. Cumulative Distribution of Time Difference Between User Entering the Intersection and Bus Starting Left Turn.

SURVEY OF BUS OPERATORS

An online survey of Texas A&M University bus operators was conducted to obtain their perspectives on the pedestrian and bicyclists visual and audio alerts at the GBD/PB intersection. The survey was included in the approved IRB application. Texas A&M University Transportation Services provided the link to the online survey to bus operators driving on Route 8. The survey was conducted the week on June 14, 2021.

A total of 45 bus operators completed the survey. Most respondents, 60 percent, reported driving on Route 8 for over 6 months; 36 percent reported driving on the route for 1 to 6 months, and 4 percent reported driving on the route for less than 1 month.

An overwhelming majority of responding bus operators, 93 percent, indicated that they were aware of the supplemental bus sign and the voice announcement. A majority of respondents (63 percent) responded that they system helps alert pedestrians and bicyclists to turning buses, while 21 percent were not sure, and 16 percent felt the system did not help. Many of the respondents noted ongoing issues with distracted pedestrians and bicyclists while driving through campus and the local area and suggested that continuing efforts to address these concerns was beneficial.

CRASH DATA AND BUS OPERATOR INCIDENT REPORTS

Crash data for the GBD/PB intersection were obtained from CRIS for a year before the demonstration and during the demonstration. There were three crashes at the intersection in the year before the supplemental BUS sign and verbal "caution bus turning" treatment was implemented and four crashes during the demonstration. None of the crashes in either period involved buses, bicyclists, or pedestrians. The four crashes occurring during the demonstration were angle crashes between cars and none involved buses, bicycles, or pedestrians.

Texas A&M University Transportation Services, Transit Operations, records incidents reported by bus operators daily by route. The Transportation Services Bus Operator Incident logs were also reviewed for the similar periods. No incidents were reported for the intersection in either the before year or during the demonstration year.

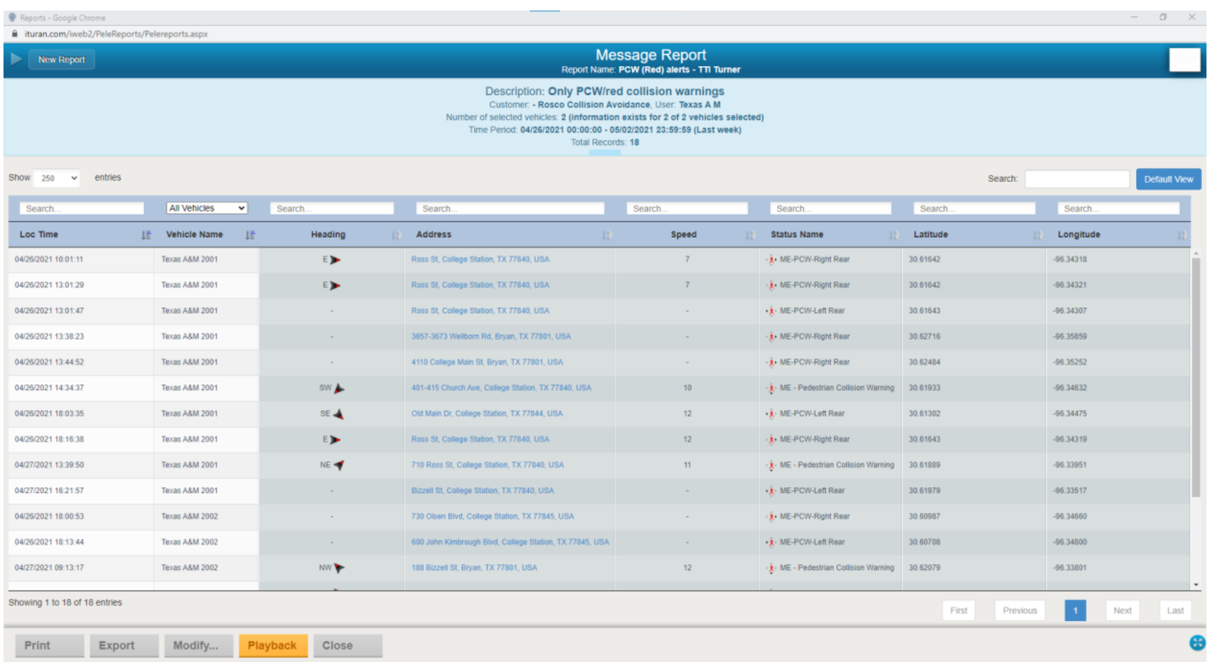
Based on these reviews, the supplemental BUS sign and verbal "caution bus turning" were not associated with any crashes at the intersection. Longer study periods or more locations may be needed to identify a change in crashes associated with this type of treatment.

IV. MOBILEYE® SHIELD+ VERSION 4™ COLLISION WARNING SYSTEM ASSESSMENT

As part of Phase I, TTI partnered with TxDOT, Texas A&M University Transportation Services, and the technology firms Mobileye and Roscoe to pilot the Mobileye® Shield+™ collision-warning system on one Texas A&M bus. TTI purchased the system, Texas A&M University Transportation Services provided the bus, and the TxDOT project supported the assessment of the pilot. The Phase I final report documents the operation of the Mobileye Shield+ Version 4™ (V4) and the pilot. The system continued to operate in regular service on bus 120 until the bus was retired from service in the fall of 2020.

As part of Phase III, TTI again partnered with TxDOT, Transportation Services, and Roscoe to pilot the new version of the Mobileye Shield+ on two new buses. In January 2021, an updated version of the system, Mobileye Shield+ V4, was installed by Rosco Collision Avoidance, an "Official Mobileye Partner," on two new Texas A&M university buses. The Mobileye systems were purchased by TTI as part of the Texas A&M Campus Technology Initiative. Transportation Services provided the two buses. TTI researchers assessed the Shield+ V4 system from February through April 2021 as part of Phase III. The assessment was undertaken shortly after installation of the systems as some initial adjustments were occurring. The results of this assessment are summarized in this section.

The assessment included review of the bus-based video associated with pedestrian collision warnings highlighted in Figures 23 and 24. Researchers reviewed the video to determine whether pedestrian, bicyclists, or other vulnerable road users were near the operating bus and presented an imminent collision risk.


Reports - Google Chrome
ituran.com/iweb2/PeleReports/Pelereports.aspx
New Report
Message Report
Report Name: PCW (Red) alerts - TTI Turner
Description: Only PCW/red collision warnings
Customer: - Rosco Collision Avoidance, User: Texas A M
Number of selected vehicles: 2 (information exists for 2 of 2 vehicles selected)
Time Period: 04/26/2021 00:00:00 - 05/02/2021 23:59:59 (Last week)
Total Records: 18
Show 250 entries
Search:
Default View

Loc Time	Vehicle Name	Heading	Address	Speed	Status Name	Latitude	Longitude
04/26/2021 10:01:11	Texas A&M 2001	E	Ross St, College Station, TX 77840, USA	7	ME-PCW-Right Rear	30.61642	-96.34318
04/26/2021 13:01:29	Texas A&M 2001	E	Ross St, College Station, TX 77840, USA	7	ME-PCW-Right Rear	30.61642	-96.34321
04/26/2021 13:01:47	Texas A&M 2001	-	Ross St, College Station, TX 77840, USA	-	ME-PCW-Left Rear	30.61643	-96.34307
04/26/2021 13:38:23	Texas A&M 2001	-	3657-3673 Wellborn Rd, Bryan, TX 77801, USA	-	ME-PCW-Right Rear	30.62716	-96.35859
04/26/2021 13:44:52	Texas A&M 2001	-	4110 College Main St, Bryan, TX 77801, USA	-	ME-PCW-Right Rear	30.62484	-96.35252
04/26/2021 14:34:37	Texas A&M 2001	SW	401-415 Church Ave, College Station, TX 77840, USA	10	ME - Pedestrian Collision Warning	30.61933	-96.34632
04/26/2021 18:03:35	Texas A&M 2001	SE	Old Main Dr, College Station, TX 77844, USA	12	ME-PCW-Left Rear	30.61302	-96.34475
04/26/2021 18:16:38	Texas A&M 2001	E	Ross St, College Station, TX 77840, USA	12	ME-PCW-Right Rear	30.61643	-96.34319
04/27/2021 13:39:50	Texas A&M 2001	NE	710 Ross St, College Station, TX 77840, USA	11	ME - Pedestrian Collision Warning	30.61889	-96.33951
04/27/2021 16:21:57	Texas A&M 2001	-	Bizzell St, College Station, TX 77840, USA	-	ME-PCW-Left Rear	30.61979	-96.33517
04/26/2021 18:00:53	Texas A&M 2002	-	730 Olsen Blvd, College Station, TX 77845, USA	-	ME-PCW-Right Rear	30.60987	-96.34660
04/26/2021 18:13:44	Texas A&M 2002	-	600 John Kimbrough Blvd, College Station, TX 77845, USA	-	ME-PCW-Left Rear	30.60708	-96.34800
04/27/2021 09:13:17	Texas A&M 2002	NW	188 Bizzell St, Bryan, TX 77801, USA	12	ME - Pedestrian Collision Warning	30.62079	-96.33801

Showing 1 to 18 of 18 entries
First Previous 1 Next Last
Print Export Modify... Playback Close

Figure 23. Screenshot of Telematics Subsystem That Recorded the Date and Time of All Red Collision Alerts.

When reviewing red collision alerts, TTI used the following attributes from the Ituran telematics subsystem:

- Collision alert date and time
- Vehicle name: Bus 2001, Bus 2002
- Bus speed at time of collision alert
- Bus location and address at time of alert
- Specific sensor triggering the collision alert: Front, Left Rear, or Right Rear

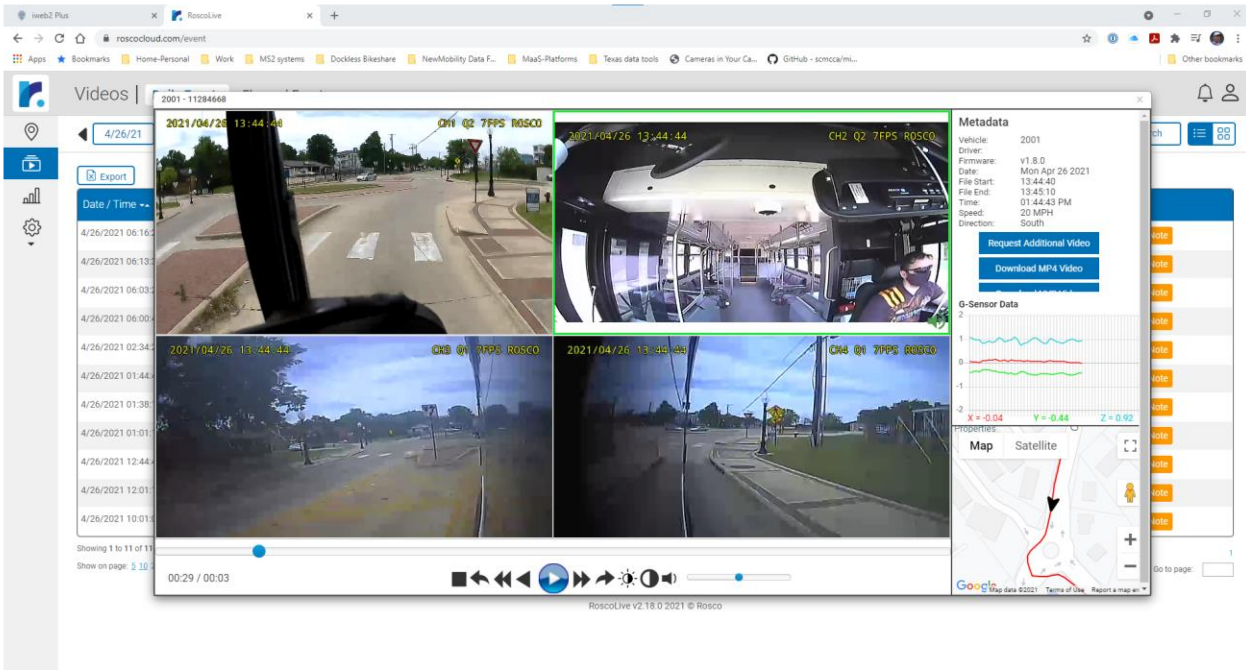


Figure 24. Screenshot of Video Review Subsystem Used to Verify Collision Alert Accuracy.

Researchers recorded the following attributes when reviewing the video associated with each red collision alert:

Was a pedestrian, bicyclist, or other vulnerable road user present?

1. Yes
2. No
3. Not Sure

What specific user type was present?

1. Pedestrian
2. Bicyclist
3. Other Wheels (includes motorcycles, one and two-wheeled scooters, skateboards, etc.)
4. No vulnerable road user present

If present, what was the estimated proximity of vulnerable road user to the bus?

1. 0 to 5 feet
2. 5 to 10 feet
3. 10 to 15 feet
4. 15 to 20 feet
5. More than 20 feet

What was bus movement at time of red collision alert?

1. Turning left
2. Turning right
3. Straight ahead
4. Passenger boarding

Researchers evaluated the 113 red collision alerts recorded during the three-month period from February through April 2021. Of the 113 collision alerts, a positive determination of accuracy could not be made on 4 alerts due to low ambient light in the bus-based video. As presented in Table 9, researchers positively identified a vulnerable road user in 100 of the remaining 109 alerts, which equates to an accuracy rate of 92 percent or a false alarm rate of 8 percent.

Table 9. Accuracy of Red Collision Alerts.

Was Vulnerable Road User Present?	**Location of Collision Sensor Alert**			**Total**
	Front	Left	Rear	
Yes	23	19	58	**100**
No		7	2	**9**
Not Sure		4		**4**

Table 10 shows that pedestrians accounted for 75 percent of the users detected by the system. The system also detected bicyclists, 17 percent, and other wheeled road users (i.e., motorcycles, scooters, and skateboards), 8 percent.

Table 10. Types of Vulnerable Road Users Detected.

Type of Vulnerable Road User	**Percent of Red Collision Alerts**
Pedestrian(s)	75
Bicyclist	17
Other wheels	8
Total	100%

A review of the video indicates that some of the red alerts were pedestrians and bicycles in the operator's blind spot and were beneficial to the operator. As presented in Table 11, 43 of the red alerts occurred when buses were traveling straight ahead and 42 occurred as the buses were stopped or nearly stopped for passenger boarding.

Table 11. Bus Movement During Accurate Red Collision Alert.

Bus Movement at Time of Collision Alert	Number of Valid Collision Alerts
Straight ahead	43
Passenger boarding	42
Turning left	3
Turning right	12
Total	100

By default, the Shield+ V4 collision avoidance system is configured to provide red collision alerts when the bus speed is between 0.6 and 43 mph (i.e., 1 to 70 km/hr). Table 12 shows that 27 or 64 percent of the 42 red collision alerts, during passenger boarding occurred when the bus was stopped or nearly stopped (less than 1 mph, indicated as "-" by the telematics subsystem). The remaining 15 or 36 percent of 42 red collision alerts occurred as the bus was approaching a bus stop and detected a pedestrian waiting at the stop or approaching the bus loading area.

Researchers provided this finding about red collision alerts during passenger boarding to the Rosco Systems team in early April. The Rosco team indicated that the minimum speed threshold for red collision alerts could be configured to a slightly higher bus movement speed in the 3 to 5 miles per hour range. Subsequent reviews of alerts in mid-to-late April continued to show red collision alerts occurring during stationary or near-stationary passenger boarding, however.

Table 12. Bus Speed and Movement During Red Collision Alerts.

Bus Speed at Time of Collision Alert	**Bus Movement at Time of Collision Alert**				**Total**
	Straight Ahead	**Passenger Boarding**	**Left Turn**	**Right Turn**	
- (0.6 to 1 mph)	**17**	**27**		2	46
1 mph					0
2 mph					0
3 mph					0
4 mph					0
5 mph	2	1			3
6 mph	4			2	6
7 mph	4	5		2	11
9 mph	3	3		1	7
10 mph	4	1			5
11 mph	3	2	3	3	11
12 mph	2	2		2	6
16 mph	2				2
19 mph		1			1
21 mph	1				1
25 mph	1				1
Total	**43**	**42**	**3**	**12**	**100**

Table 11 also shows that 43 of the valid red collision alerts occurred when the bus was traveling straight ahead, with no turning maneuvers. In reviewing the video, researchers noticed that the Shield+ V4 system provided red collision alerts when bicyclists or motorcyclists passed a "straight ahead" bus in an adjacent lane, either the inside travel lane (left side of "straight ahead" bus) or the bicycle lane (right side of "straight ahead" bus). In these cases, both the bus and the vulnerable road users were traveling straight ahead, with no intersecting collision course and no apparent collision risk. Although researchers cannot prove it conclusively, it seemed as though the red collision alerts were based on proximity to the bus, not on an imminent collision course with the bus.

Overall, the analysis indicated that the Mobileye Shield+ V4 collision avoidance system detected pedestrians, bicyclists, and other wheeled users in close proximity to the buses, improving the safety of vulnerable road users. One suggestion from the assessment is that fine-tuning the system to ensure that the red collision alerts occurring during passenger boarding and when vulnerable road users are in adjacent travel lanes when both the bus and the other road users are traveling straight ahead with no imminent collision course would be beneficial to help ensure that bus operators do not discount the warnings but respond properly.

V. ROUNDTABLE FORUM

This section summarizes the June 22, 2021, Virtual Roundtable Forum. Topics covered in the Roundtable Forum included an overview of all three phases of the project and a review of the development, operation, and evaluation of the GBD/PB smart intersection. The assessment of the Mobileye Shield+ V4 units on two new Texas A&M buses was also reviewed. The Roundtable Forum concluded with a discussion of possible future research, demonstrations, and deployments.

AGENDA AND PARTICIPANTS

Figure 25 presents the electronic invitation to the Roundtable Forum and the agenda. The electronic invitation was sent to project panel members and individuals participating in the workshops and Roundtable Forums held in 2015, 2016, and 2018 as part of Phases I and II of the project. The list was updated and expanded to account for changes in personnel and to reach out to additional organizations. Table 13 lists the participants at the Roundtable Forum, which included representatives from TxDOT, transit agencies, metropolitan planning organizations (MPOs), Texas A&M University Transportation Services, and TTI researchers.

The Texas A&M Transportation Institute
Invites You to the

Virtual Roundtable Forum
Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety

Details **Date: Tuesday, June 22, 2021**
Time: 9:30 AM – 11:00 AM

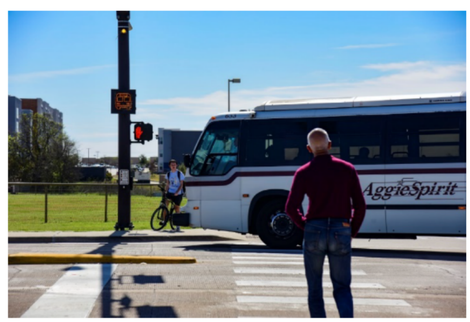
Background

As part of a research project sponsored by the Texas Department of Transportation (TxDOT), the Texas A&M Transportation Institute (TTI) is examining automated and connected vehicle (AV/CV) applications to improve transit, bicycle, and pedestrian safety.

Building on the meetings and workshops held in 2015 and the Roundtable Forums held in 2016 and 2018, this Roundtable Forum will highlight the development and operation of a Smart Intersection at George Bush Drive and Penberthy Boulevard on the Texas A&M University Campus. The Smart Intersection alerts pedestrians and bicyclists to buses turning left at the intersection. TTI researchers will highlight the operation of the intersection, surveys of pedestrians and bicyclists using the intersection, video of pedestrians and bicyclist crossing behavior, bus operator feedback, and crash and incident data. The use of the Mobileye® Shield+ V4 on two Texas A&M University buses will also be reviewed. Participants will have the opportunity to discuss future applications and pilots of these systems.

Virtual Roundtable Forum Agenda

- Welcome and Introductions
- Project Overview
- Smart Intersection Operation
- Smart Intersection Evaluation
    - Pedestrian and Bicyclist Surveys
    - Bus Operator Perspectives
    - Pedestrian and Bicyclists Crossing Behavior
    - Crash and Incident Data
- Assessment of the Mobileye® Shield+ V4 on Two Texas A&M University Buses
- Discussion of Future Applications and Pilots



Contact Information

Katie Turnbull
Executive Associate Director, Principal Investigator
Phone: (979) 317-2473
Email: k-turnbull@tti.tamu.edu

Please RSVP by June 18 to:
Rachael Sears
Phone: (979) 317-2120
RSVP Link: RSVP HERE

Texas A&M Transportation Institute

Figure 25. Roundtable Forum Invitation.

Table 13. Participants in the June 22, 2021, Roundtable Forum.

Name	Agency/Organization
Albert, Debbie	TTI
Brydia, Bob	TTI
Cearley, Mary	TTI
Charrara, Hassan	TTI
Copley, Stephen	TxDOT
Dillard, Madeline	TAMU Transportation Services
Fitzpatrick, Kay	TTI
Flores, Jorge	Capital Metro
Flores, Yvette	TxDOT
Garcia, Ted	Capital Metro
Gick, Brittney	TTI
Hoffmann, Debbie	TAMU Transportation Services
Khandaker, Taslima	Brazos Transit District
Kram, Mike	Capital Metro
Kuhr, James	TxDOT
Lange, Peter	TAMU Transportation Services
Lomax, Tim	TTI
Malnar, Justin	TTI
Odell, Wade	TxDOT
Pratt, Mike	TTI
Ramirez, Christopher	TxDOT
Rudge, Daniel	B/CS MPO
Sherman, Bonnie	TxDOT
Sunkari, Srinivasa	TTI
Tobin, Bill	TxDOT
Turnbull, Katie	TTI
Turner, Shawn	TTI
Williams, Kimberly	Houston METRO

SUMMARY OF PRESENTATIONS

The topics covered in the presentations are summarized below.

- Wade Odell, TxDOT, welcomed participants to the roundtable form. He reviewed the project background summarizing key activities in the three phases. Wade thanked the panel members for their assistance throughout the project.
- Katie Turnbull and Srinivasa Sunkari, both TTI, described the development and operation of the GBD/PB smart intersection highlighted in Section II.
- Katie Turnbull and Kay Fitzpatrick, TTI, summarized the results of the survey of pedestrians and bicyclists, crossing behavior before and during the demonstration, and the survey of bus operators described in Section III.

- Shawn Turner, TTI, presented the results of the assessment of the Mobileye Shield+ V4 installed by Rosco Collision Avoidance on two new Texas A&M buses summarized in Section IV.

DISCUSSION OF POSSIBLE FUTURE RESEARCH, DEMONSTRATIONS, AND DEPLOYMENTS

The Roundtable Forum concluded with participants asking questions on the project and discussing possible future research, demonstrations, and deployments to advance AV/CV applications to improve transit, pedestrian, and bicycle safety.

The following topics and suggestions were made by Roundtable Forum participants.

- Participants discussed situations where non-equipped buses turn left at the GBD/PB intersection. This situation could occur if non-equipped buses are assigned to Route 8, if Texas A&M buses are operating as charters, or if non-Texas A&M University buses make a left turn at the intersection. Researchers noted that there were only a few instances of non-equipped buses making left turns at the intersection during the 14-month demonstration, however with the advent of summer sports camps and other activities more non-equipped Texas A&M University buses operating as charters have been recorded making left turns at the intersection. Participants discussed the potential perceptions of pedestrians and bicyclists to situations when the system does not operate when buses turn left and if the situations would result in a loss of confidence of the system.
- Participants from transit agencies expressed interest in exploring additional applications of the smart intersection to reduce potential negative interaction of pedestrians and bicyclists around buses and light rail transit (LRT) vehicles.
- Participants discussed demonstrating the smart intersection at locations in other areas and in different applications. There was agreement that additional lessons can be learned from other applications.
- Participants discussed the advantages and limitations of the different approaches to addressing safety concerns. The smart intersection warns pedestrians and bicyclists, while the Mobileye Shield+ V4 warns bus operators. Participants suggested that all types of approaches are needed and that ongoing research, demonstrations, and deployments are beneficial. Participants discussed ensuring that all user groups are also considered, including individuals with disabilities and those using wheelchairs.

VI. UPDATED TEST BED VISION, GOALS, AND APPLICATIONS

Phase I included the development of a concept of operations (ConOps) plan for the AV/CV Test Bed to Improve Transit, Bicycle, and Pedestrian Safety. The ConOps plan included the test bed vision, goals, and candidate applications. These have been updated in this section to reflect the results of Phase II and Phase III, and the comments from panel members and participants in the 2021 Roundtable Forum. The updated candidate applications provide a road map for further research, demonstrations, and deployments.

OVERARCHING TEST BED VISION AND GOALS

The overarching vision is to maintain a test bed to research, develop, test, pilot, and deploy AV/CV technologies to improve transit, bicyclists, and pedestrian safety. The test bed consists of several facilities in different operating environments, including the Texas A&M University System RELLIS Campus, The Texas A&M University Campus, and transit systems and communities in rural, small urban, and large metropolitan areas throughout the state. The vision is realized with the participation of TxDOT, TTI, Texas A&M University, and numerous public and private partners.

The following four goals help guide the test bed research, demonstrations, and deployments.

- Goal 1 – Reduce crashes involving transit vehicles, bicyclists, and pedestrians.
- Goal 2 – Leverage public and private resources to conduct the test bed activities.
- Goal 3 – Provide objective and unbiased assessments of technologies and techniques.
- Goal 4 – Provide transferable lessons learned to other prospective deployers in Texas and the nation.

TEST BED APPLICATIONS

The initial ConOps plan included candidate applications focusing on smart buses, smart intersections, and smart bike racks. The pilot and assessment of the Mobileye Shield+ collision warning system on one Texas A&M University bus in Phase I and the assessment of the Mobileye Shield+ V4 collision warning system on two new Texas A&M University buses in Phase III helped advance the smart bus application. The development and pilot testing of the smart intersection at the RELLIS campus in Phase II and deployment at the GBD/PB intersection in Phase III advanced the smart intersection application. These projects and the other applications are expanded in this section to help focus future research, demonstrations, and deployments. A new candidate application on smart transit stops has been added to address suggestions from participants at the 2021 Roundtable Forum.

- **Candidate Application 1 — Smart Buses: Vehicle-Based Collision-Warning System.** The first candidate application focuses on avoiding crashes involving buses, bicyclists, and pedestrians using collision-warning systems on buses. These warning systems may use cameras, sensors, and other technologies to detect bicyclists and pedestrians close to transit vehicles and alert the bus driver of their presence.
    - Continue to build on the pilots and assessments of the Mobileye Shield+ in Phase I and the Mobileye Shield+ V4 in Phase II. The Mobileye Shield+ V4 continues

in operation on the two Texas A&M University buses. Ongoing research focusing on identifying hots spots for potential crashes and possible counter measures, reviewing system performance, and identifying methods to coordinate with other technologies would be beneficial.
    - Research, monitor, and evaluate other on-vehicle crash warning technologies. Capital Metro has installed a camera on several buses to monitor the blind spot behind the A-pillar. The product line also includes a B-pillar camera sensing system. Assessing the use of the A-pillar camera, as well as other applications, would be beneficial.
    - Research the impact of collision warning systems on driver workload to ensure bus operators aren't being overburdened.
    - Research the effectiveness of curve-adaptive headlights that pivot toward the bus's direction to see pedestrians and bicyclists.
- **Candidate Application 2 — Smart Intersections: Collision Avoidance with Intersection-Based Warning Systems.** The second candidate application focuses on avoiding crashes involving buses, bicyclists, and pedestrians at signalized intersections using on-vehicle technologies automatically communicating with visual and/or audible technologies at the signal. This application may use cameras, sensors, infrared, DSRC, and other technologies to communicate the presence of a turning bus to the traffic signal and activate a visual or audio warning to bicyclists and pedestrians.
    - Continue to demonstrate and upgrade the smart intersection system developed in Phase II and demonstrated in Phase III. Pursue opportunities for additional deployments in different settings throughout the state.
    - Build on the smart intersection by adding additional features, such as bus priority, links to smartphone apps, and test in different settings.
- **Candidate Application 3 — Smart Bicycles and Sensors on Bicycles.** The third candidate application focuses on providing warnings to bicyclists about vehicles, including buses, in close proximity and imminent bicycle-vehicle crashes. One approach is to equip bicycles with sensors and other technologies to detect vehicles in the path of the bicycle or approaching the bicycle. Collision-prediction algorithms would be developed and included in the bicycle technology to warn bicyclists through tactile or haptic feedback means in the seat and handlebars and/or through sounds. The sounds could also be used to alert the driver of approaching vehicle.
- **Candidate Application 4 — Smart Pedestrians: Smartphone Applications.** The fourth candidate application uses a smartphone app to warn pedestrians of approaching buses and other vehicles. Path prediction algorithms would be developed and used to warn pedestrians of approaching buses. A beta Android smartphone app was developed in Phase II as part of the smart intersection at the RELLIS campus. Additional research and development of an app to alert pedestrians to buses and LRT vehicles would be beneficial. In addition, human factors research focusing on how best to communicate with pedestrians, their reactions to different methods, and their preferences is needed.
- **Candidate Application 5 — Smart Bike Racks: Automated Alerts for Bus Operators.** The fifth candidate application addresses improving the safe operation of bike racks on buses. Technologies and techniques focus on enhancing the safety of bicyclists using front-mounted bike racks. Possible technologies and approaches include sensors, cameras, infrared, and networked wireless communication devices on buses and

bicycles. In addition, research and development of an app to communicate in real-time on the availability of a bike rack space would be beneficial.

- **Candidate Application 6 — Smart Transit Stops.** The sixth candidate application addresses combining numerous technologies and some of the previous applications to create a smart transit stop that improves safety for all users. Elements that could be considered include visual and verbal warning of approaching vehicles, next vehicle arrival information, apps, and other technologies.

VII. VALUE OF RESEARCH

The research team completed a Value of Research (VoR) assessment as part of the project. The VoR was based on the benefits areas selected at the beginning of the project presented in Table 14.

Table 14. Project VoR Selected Benefit Areas.

Qualitative Value	
Benefit Area	**Value**
Level of Knowledge	Increasing the level of knowledge of TxDOT personnel, Texas residents, and visitors related to the safe interaction of buses, bicyclists, and pedestrians raises the awareness of possible safety issues and will help reduce conflicts, crashes, and injuries.
Management and Policy	Enhancing TxDOT's ability to allocate resources to bus purchases and operations, bicycle facilities, and intersection and roadway projects provides additional tools for TxDOT to manage the operation of intersections to ensure the safe use by buses, bicyclists, and pedestrians.
Quality of Life	Reducing crashing involving buses, bicyclists, and pedestrians has a direct relationship to the quality of life in Texas. Improving the interaction of buses, bicyclist, and pedestrians makes residents and visitors more likely to use these modes and to engage in more active lifestyles.
Customer Satisfaction	Every person begins and ends their trip as a pedestrian. Enhancing safety for pedestrians helps everyone. The project also enhances the safety of bus riders, bicyclists, and pedestrians by making all three safer.
Environmental Sustainability	The use of transit, bicycling, and walking offers alternatives to single occupancy vehicle use. By supporting the safer operation and use of these modes, TxDOT may help reduce traffic congestion and improves air quality.
System Reliability	Crashes involve buses, bicyclists, and pedestrians disrupt normal traffic, roadway, and transit operations. These crashes reduce the reliability of the roadway and transit system for other users.
Safety	Reducing crashes involving buses, bicyclists, and pedestrians has the potential to save lives, reduce injuries, and reduce property damage.

The research team used the TxDOT VoR assessment spreadsheet to calculate the project's estimated VoR. The results of this assessment are presented in Figure 26. The VoR calculations are based on the following assumptions. By reducing crashes, traffic delays are reduced (saving people time) and injuries/fatalities are avoided (preserving productivity and limiting health/emergency expenses). Based on these assumptions, data documenting the value of one hour of time per person, traffic volumes in Texas, and the cost of a statistically equivalent human life were collected and used in the assessment.

	Project #	0-6875-03			
	Project Name:	Automated and Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, and Pedestrian Safety - Phase III			
	Agency:	TTI	Project Budget	$	586,214
	Project Duration (Yrs)	2	Exp. Value (per Yr)	$	23,944,476
Expected Value Duration (Yrs)		10	Discount Rate		3%
Economic Value					
Total Savings:	$	238,858,551	Net Present Value (NPV):	$	195,554,988
Payback Period (Yrs):		0.024482	Cost Benefit Ratio (CBR, $1 : $___):	$	334

Years	Expected Value
0	-$1,172,428
1	$15,283,708
2	$20,378,278
3	$25,472,847
4	$25,472,847
5	$25,472,847
6	$25,472,847
7	$25,472,847
8	$25,472,847
9	$25,472,847
10	$25,472,847

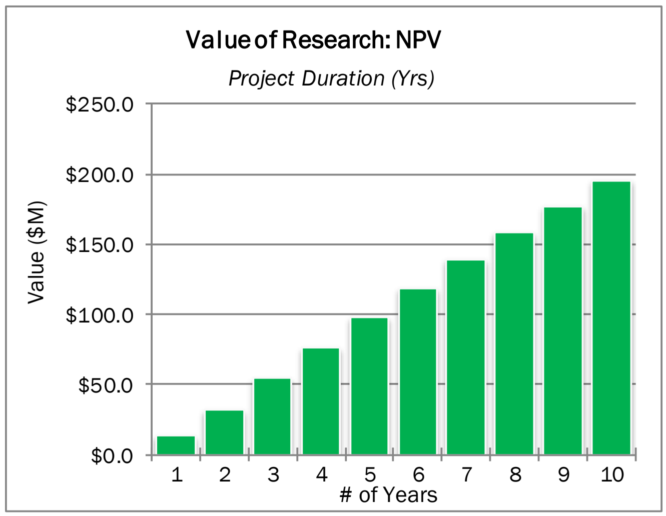


Figure 26. VoR Estimate.

APPENDIX: AUTOMATED AND CONNECTED VEHICLE (AV/CV) TEST BED TO IMPROVE TRANSIT, BICYCLE, AND PEDESTRIAN SAFETY − PHASE III: PEDESTRIAN/BICYCLIST INTERCEPT SURVEY

Approach potential survey participants who had arrived or were waiting at the SE or NE corners when a bus on the east leg approaches the intersection after they finish crossing the intersection. Ask if they would be willing to participate in a short survey and if they are 18 years old or older. If they are old enough and agree to participate, proceed with the questions.

1. Did you notice the illuminated "BUS" sign or announcement of the bus turning or both?
   - Yes (continue to #2)
   - No (skip to #7)
   - Not sure (skip to #7)

2. What did you notice first?
   - Saw the sign
   - Heard the announcement
   - Both at same time

3. After you noticed the message, did you:
   - Stop and look for the bus before you continued crossing?
   - Continue crossing without stopping, while looking for the bus?
   - Continue crossing without stopping, without looking for the bus?
   - Other (specify):

4. Was the announcement helpful for you?
   - Yes
   - No

5. Do you think that the "bus arriving" message is helpful for all people crossing this intersection, helpful for some people crossing this intersection, or not helpful?
   - Helpful for all (skip to #8)
   - Helpful for some (continue to #6)
   - Not helpful (skip to #8)

6. Who do you think would find the "bus arriving message" to be helpful? (fill in)

7. Did you notice the bus approaching?
   - Yes (continue to #8)
   - No (skip to 9)
   - Unsure (skip to 9)

8. When you noticed the bus, did you:
    - Stop and look to see what the bus was doing before you continued crossing?
    - Continue crossing while watching the bus?
    - Continue crossing without watching the bus?
    - Other (specify):

9. How frequently do you cross this intersection?
    - Multiple times a day
    - At least daily
    - At least once a week
    - Less than once a week

[remainder of questions are not asked, but filled in by data collector]

10. Gender
    - Male
    - Female
    - Unsure

11. Approximate age
    - 18–30
    - 31–50
    - 50+
    - Unsure

12. Phone/tablet visible?
    - Yes, talking on phone
    - Yes, texting or reading phone/tablet
    - Yes, in hand but not apparently using
    - No
    - Unsure

13. Headphones visible?
    - Yes
    - No
    - Unsure

14. Participant is a:
    - Pedestrian
    - Cyclist riding bike
    - Cyclist walking bike
    - E-scooter
    - Other (fill in)

15. Pedestrian entered the crosswalk:
    - During Walk Indication
    - During Do Not Walk Indication
    - Did Not Observe

16. Participant crossed street within or outside of the crosswalk or the bike lane?
    - Within the painted crosswalk
    - Outside of the painted crosswalk
    - Within the logical extension of the bike lane through the intersection
    - Outside the logical extension of the bike lane through the intersection

17. Looked both ways before entering the crosswalk?
    - Yes
    - No
    - Did Not Observe

[Alternate survey questions, if additional surveys are conducted of pedestrians crossing when a turning bus is not present]

1. How frequently do you cross this intersection?
    - Multiple times a day
    - At least daily
    - At least once a week
    - Less than once a week

2. Have you ever noticed the illuminated "BUS" sign or an announcement of a bus turning or both at this intersection?
    - Yes
    - No *(thank participant for their time, skip to 5)*
    - Not sure *(thank participant for their time, skip to 5)*

3. Was the announcement helpful for you?
    - Yes
    - No

4. Do you think that the "bus arriving" message is helpful for all people crossing this intersection, helpful for some people crossing this intersection, or not helpful?
    - Helpful for all
    - Helpful for some
    - Not helpful

[remainder of questions are not asked, but filled in by data collector]

5. Gender
    - Male
    - Female
    - Unsure

6. Approximate age
    - 18–30
    - 31–50
    - 50+
    - Unsure

7. Phone/tablet visible?
    - Yes, talking on phone
    - Yes, texting or reading phone/tablet
    - Yes, in hand but not apparently using
    - No
    - Unsure

8. Headphones visible?
    - Yes
    - No
    - Unsure

9. Participant is a:
    - Pedestrian
    - Cyclist riding bike
    - Cyclist walking bike
    - E-scooter
    - Other (fill in)

10. Pedestrian entered the crosswalk:
    - During Walk Indication
    - During Do Not Walk Indication
    - Did Not Observe

11. Participant crossed street within or outside of the crosswalk or the bike lane?
    - Within the painted crosswalk
    - Outside of the painted crosswalk
    - Within the logical extension of the bike lane through the intersection
    - Outside the logical extension of the bike lane through the intersection

12. Looked both ways before entering the crosswalk?
- Yes
- No
- Did Not Observe