Reducing School Bus/Light-Vehicle Conflicts Through Connected Vehicle Communications

CVI UTC

CONNECTED VEHICLE/INFRASTRUCTURE UNIVERSITY TRANSPORTATION CENTER (CVI-UTC)

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Reducing School Bus/Light-Vehicle Conflicts Through Connected Vehicle Communications

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Connected Vehicle/Infrastructure UTC

The mission statement of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) is to conduct research that will advance surface transportation through the application of innovative research and using connected-vehicle and infrastructure technologies to improve safety, state of good repair, economic competitiveness, livable communities, and environmental sustainability.

The goals of the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) are:

- Increased understanding and awareness of transportation issues
- Improved body of knowledge
- Improved processes, techniques and skills in addressing transportation issues
- Enlarged pool of trained transportation professionals
- Greater adoption of new technology

Abstract

This project aimed to develop and test a concept for improving the safety of school bus transportation using connected vehicle technology. The project consisted of three key steps that led to a final road study: 1) conducting focus groups with light vehicle drivers and school bus drivers to determine what type of in-vehicle school-bus related information they would like to receive/send; 2) developing a concept of operations to accommodate driver desires; and 3) evaluating the effect of an in-vehicle message that warns of a stopped school bus ahead. In the road study, researchers evaluated each driver's response through analysis of vehicle kinematics (speed, longitudinal acceleration, and jerk) when a bus was staged either beyond a "School Bus Stop Ahead" roadside sign or beyond the point at which a similar in-vehicle message was presented. Driver responses for each condition were compared to a baseline condition that described their driving behavior when no bus was present on the roadway. The results showed a nearly immediate response to in-vehicle messages, whereas the corresponding roadside sign messages provided little evidence of modifying driver behavior prior to visually observing a stopped school bus in the roadway.

Acknowledgements

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Background

Motivation

In 2013, 114 school buses were involved in crashes that resulted in 130 fatalities [1]. Approximately 24,000 more individuals were injured in non-fatal school bus related crashes in the United States [1]. Buses are particularly susceptible to rear-end conflicts due to their frequent decelerating and stopping behavior in traffic, and statistics indicate that the rear of the bus is a frequent initial point of impact during a crash (approximately 22% of crashes) [1]. Fatalities resulting from collisions with passenger buses often involve light vehicles and pedestrians [2], [3] and, when analyzing Buses Involved in Fatal Accidents (BIFA) data, Blower et al. (4) found that driver error leading to the crash was more likely to have occurred in the striking vehicle than the vehicle being struck. As this evidence indicates, rear-end collisions with buses are, therefore, a concern for the entire motoring public. Blower et al. (4) also stated that the high proportion of rear-end crashes during which the bus was struck suggests that improved conspicuity and increased awareness of the stopped bus could enhance safety in stopped bus situations. While there are safety technologies (e.g., collision warning systems, adaptive cruise control) installed in today's vehicles, it is recognized that these systems currently have limitations when vehicles are traveling around curves and over hills due to restricted field-of-view [5], [6]. For instance, when a forward collision warning (FCW)-equipped vehicle is traversing a sharp curve, the stopped vehicle may not lie within the system's sensor range due to its limited lateral coverage. The same is true in situations where an FCW-equipped vehicle is cresting the top of a hill and the FCW sensor's coverage is aimed above the descending roadway on the other side.

CV communication, particularly local dedicated short-range communication (DSRC) technology, could be used to provide following traffic with in-vehicle notifications of a stopped bus, which may be especially useful when the bus is stopped over a hill or around a blind curve. The CV-DSRC system provides an "extended information horizon" and lets drivers "see over hills and around curves" [7]. This project focuses on a novel approach to applying this enhanced capability in order to increase awareness of stopped buses during the aforementioned situations. Although CV technology (e.g., DSRC, cellular, Wi-Fi) could be applied to all passenger bus types (e.g., transit, school, motor coach), this work focuses on school buses engaged in student transportation.

School bus drivers face unique safety concerns as they transport our children to and from school and on school-related activities. Every school day, more than 25 million school-aged children are transported to and from school on nearly 480,000 school buses. This equates to approximately 20 billion annual school bus boardings and alightings throughout the United States [2]. Many of these boardings and alightings occur when school buses are stopped in the roadway. This scenario is considered one of the most dangerous situations for a school bus and its student riders. CV technology offers a potential solution for improving bus conspicuity and increasing other drivers' awareness of stopped school buses.

Current State of the Practice

The current state of practice for dealing with obscured bus stops involves placing a fluorescent yellow-green “School Bus Stop Ahead” (SBSA) sign (S3-1 in Figure 1) according to the following guidance from the Manual on Uniform Traffic Control Devices (MUTCD):

> *The School Bus Stop Ahead sign should be installed in advance of locations where a school bus, when stopped to pick up or discharge passengers, is not visible to road users for an adequate distance and where there is no opportunity to relocate the school bus stop to provide adequate sight distance. [8]*

Figure 1. Sign S3-1 in the MUTCD – SBSA.

While the MUTCD provides some direction as to when school bus stop signs are to be used, these are simply recommendations, not requirements. Additionally, these signs, as described, provide no indication of a school bus’s actual presence or its loading/unloading schedule, which leaves drivers uncertain as to whether or not they may actually encounter a school bus.

Previous versions of the SBSA sign, seen in Figure 2, may still exist at some locations as text on a yellow background [9]. These legacy signs often exist along the same roads as newer signs, and the presence of both signs could confuse drivers about their validity, creating a potential safety concern if the signs are ignored because one or both are believed to be invalid and therefore irrelevant.

Figure 2. Previous version of the SBSA. (Replaced by the sign in Figure 1 in the 2009 MUTCD, although many road signs have not been upgraded.)

Research Objectives

The research objectives of this project were to develop and evaluate a system for improving driver awareness around school buses and school bus stops within a connected vehicle (CV) environment. The proposed system was evaluated through an on-road study that assessed driver responses to an in-vehicle School Bus Stopped Ahead message and similar roadside signage.

Method

The following sections summarize the data collection and analysis methods used in this project. The project kicked off with two in-person focus groups to identify information that drivers would like to send or receive as part of a CV system. Those focus groups were one of several inputs used to develop a Concept of Operations (ConOps) that was subsequently used to develop the on-road study to quantify the effects of an in-vehicle message that alerts drivers of a stopped school bus ahead.

Focus Groups

The research team conducted two focus groups of six participants each at the Virginia Tech Transportation Institute (VTTI) in late July/early August 2014. One focus group included light vehicle drivers and one included school bus drivers. Each focus group session lasted two hours and included a brief entrance questionnaire followed by a moderated group discussion.

To participate in the light-vehicle focus group, individuals had to be at least 18 years old, hold a valid driver's license, currently drive, and approach a school bus at a bus stop at least once a month during their normal driving during the school year. During participant recruiting, researchers attempted to balance the gender of the light vehicle focus group participants across several age brackets. To participate in the school bus driver focus group, individuals had to be at least 18 years old, hold a valid Commercial Driver's License with school bus and passenger bus endorsements, and currently drive a school bus for a public school on at least a monthly basis during the school year.

Focus groups sessions lasted two hours and covered a variety of topics. During the light-vehicle focus group, participants were shown a video on how CV technology works and then asked to discuss the information they would want a school bus to relay to them via CV when the bus is stopping at a bus stop or railroad crossing. The group was also asked when they would like to receive the information (i.e., at what distance) and how they would like to receive the information (i.e., audible alert, visual alert, haptic alert, combination alert). Focus group participants were also shown a school bus stop sign and asked to comment on how effective they thought the sign was at alerting them to a bus stop ahead.

The school bus driver focus group session also lasted two hours and covered topics similar to those covered in the light-vehicle focus group. School bus drivers also watched the CV technology video and discussed the information they would want to receive from other vehicles as well as the information they would like to relay to other vehicles when they are coming to a stop at a bus stop or railroad crossing. The focus group facilitator also asked the school bus drivers under what circumstances a bus must stop and the procedures they follow to perform a stop.

A report on the focus groups was used as input for the development of the School Bus Stop Ahead Connected Vehicle ConOps and the subsequent road study. However, there were only two focus groups and, therefore, the analyst only had two focus group transcripts to work with for the results section of the report. Readers should bear in mind that findings were based on a small pool of participant comments. Findings from relevant literature and researcher expertise were used in conjunction with participant comments to guide the development of the ConOps and prototype, in-vehicle message display. The full focus group report is presented at http://www.apps.vtti.vt.edu/appendices/schoolbus/Palframan_SBSA Focus Group Findings.pdf.

The conclusions relevant to this final report indicate that light vehicle drivers and school bus drivers alike are interested in sending and receiving alerts about stopped school buses. The participants also discussed how this information would be especially important when a bus stop is located over a hill or on a blind curve when views may be obstructed.

Concept of Operations

Input for the ConOps and prototype in-vehicle message display was gathered via the focus group sessions. Researchers brainstormed the "who, what, when, where, why, and how" of the SBSA system as well as the potential algorithms it could use to determine when to display the in-vehicle messages.

The proposed SBSA system consisted of five operational scenarios that could be addressed by CV technology. These scenarios included the following:

1. Informational and regulatory messages that could be sent from an occupied bus stop to other vehicles in the vicinity.
2. Informational messages that a school bus could send to other vehicles near their route.
3. Informational and safety-critical messages that a stopped or stopping school bus could send to other approaching vehicles.
4. Safety-critical messages that other vehicles could relay to a stopped school bus.
5. Informational and safety-critical messages that could be sent from a stopped or stopping school bus at a railroad crossing to vehicles approaching from behind.

The full ConOps is presented at http://www.apps.vtti.vt.edu/appendices/schoolbus/Palframan_SBSA - ConOps.pdf. The road study was developed to test the third operational scenario where informational and safety-critical messages are shared directly between the stopped school bus and approaching drivers.

Road Study

Twenty-nine naïve subjects, counterbalanced by age and gender, participated in an on-road study to investigate drivers' response to two types of school bus stop indicators. Along the route, each driver encountered two experimental conditions that were intermixed with a variety of other roadside signs and in-vehicle messages. The experimental conditions included the following:

1. Encountering a stopped school bus after passing a static roadside SBSA sign.

2. Encountering a stopped school bus after receiving an in-vehicle School Bus Stopped Ahead message.

Researchers recorded drivers' responses to the experimental conditions using an in-vehicle data acquisition system (DAS) [11]. The DAS allowed researchers to track when the in-vehicle message was displayed synchronously with the drivers' behaviors and vehicle speed profiles. Researchers estimated that the legibility of a SBSA roadside sign was sufficient at 100 feet prior to the sign while traveling at 25 mph (according to Table 2C-4 in the MUTCD) [8]. Researchers used recorded video to identify landmarks as visual references for locating the initial point of driver recognition of the roadside sign. The video also provided evidence to identify the time at which drivers first observed the bus. Researchers used these time-based inputs in combination with the collected vehicle speed and acceleration to evaluate drivers' driving behaviors during the encounters with the experimental conditions. Researchers determined vehicle jerk by calculating the rate of change of acceleration with respect to time.

Test Route

Prior to driving the test route, researchers displayed three example in-vehicle messages for the participants to view: a trail crossing sign, a 35 mph speed limit sign, and the in-vehicle School Bus Stopped Ahead message with associated audio tone. The intent of this exercise was to reduce the anticipated novelty effect of exposure to the messaging system and to minimize potential unintended consequences caused by startling participants with messages or tones.

The test route consisted of two laps around a 14.8 mile (23.8 km) circuit through residential and commercial areas with a variety of speed zones, several blind curves, and a school zone. The drivers were instructed to operate at the posted speed limit, abide by all traffic laws, and only view the in-vehicle message screen when they felt it was safe to do so.

As the drivers followed the route, their in-vehicle display emulated various features of a CV system by presenting posted speed limits, trail crossing warnings, and road narrowing warnings. In cases where drivers were required to come to a complete stop in accordance with the message, the message was displayed sufficiently in advance to allow the driver to come to a safe and controlled stop based on the assumptions of the American Association of State Highway and Transportation Officials' stopping distance equation [12].

During each lap, drivers encountered both experimental conditions twice, although the bus was only present at two of the four bus stop locations. Figure 3 shows the locations of the four bus stops. The yellow (lighter) shapes indicate the bus stops on lap one and the blue (darker) shapes indicate the bus stops on lap two. Participants were randomly assigned to experience one of the two experimental scenarios (Lap 1 or Lap 2) first. Bus stops one and four (diamond shapes) had existing text-based roadside SBSA signs (Figure 2), whereas drivers received an in-vehicle message (Figure 4) at bus stops 2 and 3.

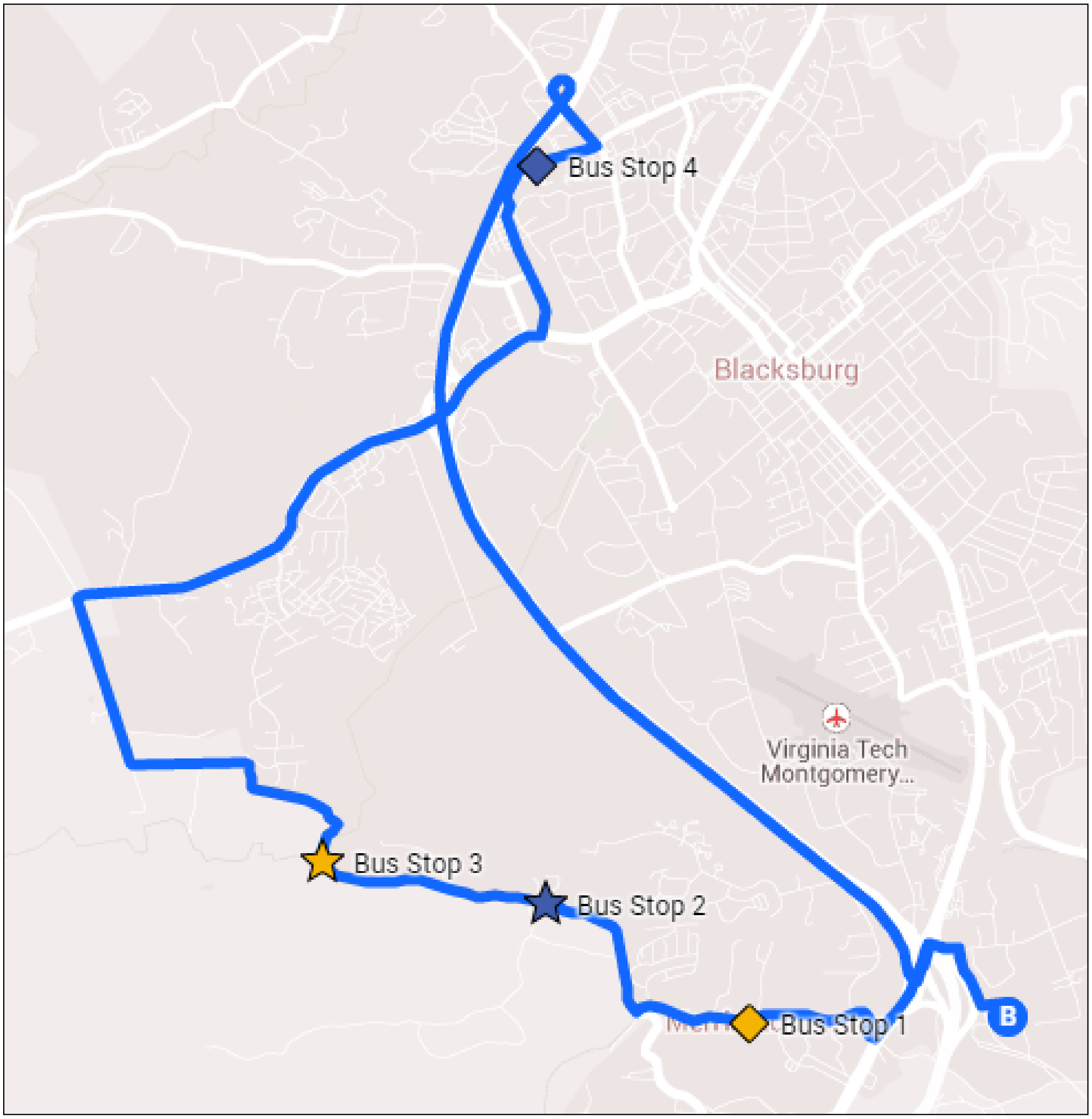

Figure 3. Experimental test route showing the locations of bus stops.

Table 1. Summary of Test Route and Bus Stop Characteristics

Experimental Condition	Bus Stop	Posted Speed Limit	Curve Advisory or Delineation	Number of Lanes	Type of Curve	Approximate Curve Radius
Roadside Sign	1	Not posted (55 mph)	25 mph curve advisory speed	2	Spiral horizontal curve	335 feet
	4	25 mph	"Curve Ahead" pavement marking	2	Spiral horizontal curve	225 feet
In-vehicle Message	2	35 mph	30 mph curve advisory speed	2	Compound curve	250 feet
	3	55 mph	Chevron curve delineators	2	Spiral horizontal curve	600 feet

Static School Bus Stop Ahead Roadside Sign

Along the test route, drivers passed existing SBSA road signs placed along a horizontal curve that preceded a school bus stop location. Researchers reviewed participants' driving behavior to determine if the existing signage led to increased driver awareness of the potential presence of a bus ahead. During this experimental condition, drivers encountered a confederate school bus once they traversed the curve. This was intended to replicate the conditions under which these signs were designed to operate.

For comparison purposes, researchers also reviewed drivers' behaviors as the drivers passed through the same area of interest when a bus was not present. This allowed the researchers to determine how participants behaved when traveling these curves in the absence of a stopped school bus.

In-vehicle School Bus Stop Ahead Warning Message

Drivers received in-vehicle messages that indicated that there was a school bus stopped ahead when they approached a curve with a visual obstruction. These messages began with an auditory alert tone, which was subsequently accompanied by an image of the current MUTCD-approved SBSA sign with the message "Stopped Ahead" displayed below the image (Figure 4). The locations where drivers were presented with the in-vehicle message were separate from existing roadside SBSA signage.

Figure 4. In-vehicle message indicating a stopped school bus ahead.

Researchers monitored driving behavior each time a participant passed through the curves associated with this experimental condition regardless of whether an in-vehicle message was displayed or not. Since many of the curves along this route had curve advisory speed warnings, monitoring driving behavior allowed researchers to establish a baseline behavior around each curve to compare against driving behavior when the in-vehicle message was presented.

Participant Recruitment

Researchers recruited participants using VTTI's extensive participant database, which includes individuals who have either participated or expressed interest in participating in driving research studies. Drivers were pre-screened and had to meet the following criteria[1]:

1. Must possess a valid U.S. Driver's license and have at least two years of driving experience.
2. Must drive regularly (at least three times per week).
3. Must be within the ages of 20–35 or 50–65 to fit within the study design.
4. Must be a U.S. citizen or permanent resident (green card holder).
5. Must not have driven a school bus (never licensed as a school bus driver).
6. Cannot drive the study route more than five days per week.
7. Must be comfortable reading, writing, and speaking English.
8. Must have normal or corrected to normal vision and hearing.
9. Must not have a medical history that affects the ability to drive.

[1] Other criteria were included in the pre-screening process (such as, "must be available between 6:30–9:30 a.m. or 2:00–5:00 p.m."); however, only relevant participant and driving-related criteria are provided in this section.

10. Must not have been convicted of more than two driving violations in the past three years or convicted of an injurious crash (driving violation) in the past three years.

11. Must be able to drive a vehicle with an automatic transmission without assistive devices.

Researchers used a statistical power analysis to estimate that 27 participants would be needed to achieve statistical data significance (assuming one-tailed t-tests with a medium effect size of 0.5, alpha of 0.05, and a power of 0.8). The participants recruited for this study were counterbalanced by age group and gender.

Data Collection

Vehicle Instrumentation

The experimental test vehicle, a Buick LaCrosse, was equipped with a Savari MobiWAVE S102 CV transceiver, a VTTI NEXTgen DAS, and an ASUS wireless transceiver. The DAS collected a variety of vehicle dynamic data including, but not limited to: vehicle global positioning system (GPS) location, speed, 3-axis acceleration, and throttle position. Associated timestamps and continuous audio and video were also recorded.

The test vehicle was also equipped with an in-vehicle information system that was capable of displaying visual messages and corresponding audible tones during driving events. The display system was mounted above the center instrument stack, obscuring the vehicle's built-in infotainment system screen (Figure 5).

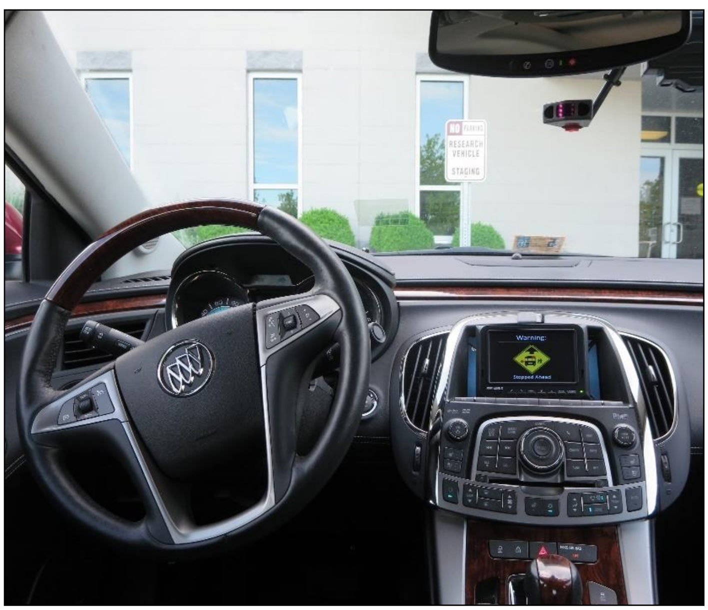

Figure 5. View of the test vehicle message display system.

The experimental test vehicle was equipped with five cameras (shown in Figure 6), which provided views as described below:

1. **Over-the-shoulder camera** – showed the driver’s hand position on the steering wheel and the message presentation on the in-vehicle display.
2. **Forward-facing camera** – provided the driver’s view of the forward roadway while driving. In this experiment, this view was used to identify when the driver first saw the school bus or when the roadside school bus sign was visible.
3. **Face camera** – showed the driver’s initial reaction to the SBSA in-vehicle message. This view was used to confirm that the driver looked at the display and to determine the amount of time it took the driver to view the in-vehicle message.
4. **Rear-facing camera** – provided a view of any drivers who may have been following the test vehicle. Vehicles following closely may have affected the driver’s behavior.
5. **Foot camera** – provided an indication of when the driver began to react to the information they received.

Figure 6. Camera views on the test vehicle (over the shoulder camera [top left], forward-facing camera [bottom left], face camera [top right], rear-facing camera [middle right], and foot/brake pedal camera [bottom right]).

The school bus was also equipped with Savari MobiWAVE S102 on-board equipment, a NEXTGen DAS as seen in Figure 7. The on-board equipment in the test vehicle received the school bus signal when the test vehicle was within a range of approximately 300 meters.

However, the devices' ranges were contingent on having a clear line of sight, so the effective range along the test route was often around 100–150 meters.

Figure 7. Image of school bus instrumentation.

Researcher Communication Devices

Researchers communicated with each other through the use of two-way radio communication devices equipped with headsets. Since participants were not informed as to the main purpose of the study, the researchers in the test vehicle communicated with the bus driver using code phrases that informed the bus driver of their current location. These code phrases included the following:

- "Just keep driving, I'll tell you when you need to turn next."
- "You're doing great!"
- "At the next stop sign, please turn right."
- "Keep following this road until you reach the next traffic light."

Figure 8. Image of radio communicators.

Driving Data Collection

During this experiment, two VTTI researchers accompanied the driver in the test vehicle. The first researcher facilitated the experiment from the front passenger seat, providing route guidance as needed. The second researcher, located in the back seat of the vehicle, monitored the DAS and displayed the in-vehicle messages via a laptop.

Once drivers were brought out to the car, they received an introduction to the vehicle and in-vehicle display. Researchers introduced potential messages by showing drivers the messages in Figure 9.

Figure 9. Sample messages provided to introduce the driver to the in-vehicle display and to demonstrate the types of messages they would receive during the experiment.

For the driving part of the experiment, participants were randomly assigned to receive Trial A or Trial B first. The trial designation only affected the order in which drivers encountered the confederate school bus. In Trial A, the confederate bus was present at the first and second bus stops and absent at the third. In Trial B, the confederate bus was absent at the first bus stop and present at the second and third stops. In both Trials, in-vehicle messages were presented only at the second bus stop. The test conditions, including full descriptions of the two Trial types, are included in Appendix A of the Test Plan which is available at http://www.apps.vtti.vt.edu/appendices/schoolbus/Palframan_SBSA - Test Plan.pdf. This Appendix includes a matrix of the experiment trials and key events.

Along the route, the drivers encountered nine key events that represented a variety of existing road signs and CV events. The locations of these key events are shown in Figure 10 and each event is described in the following subsections.

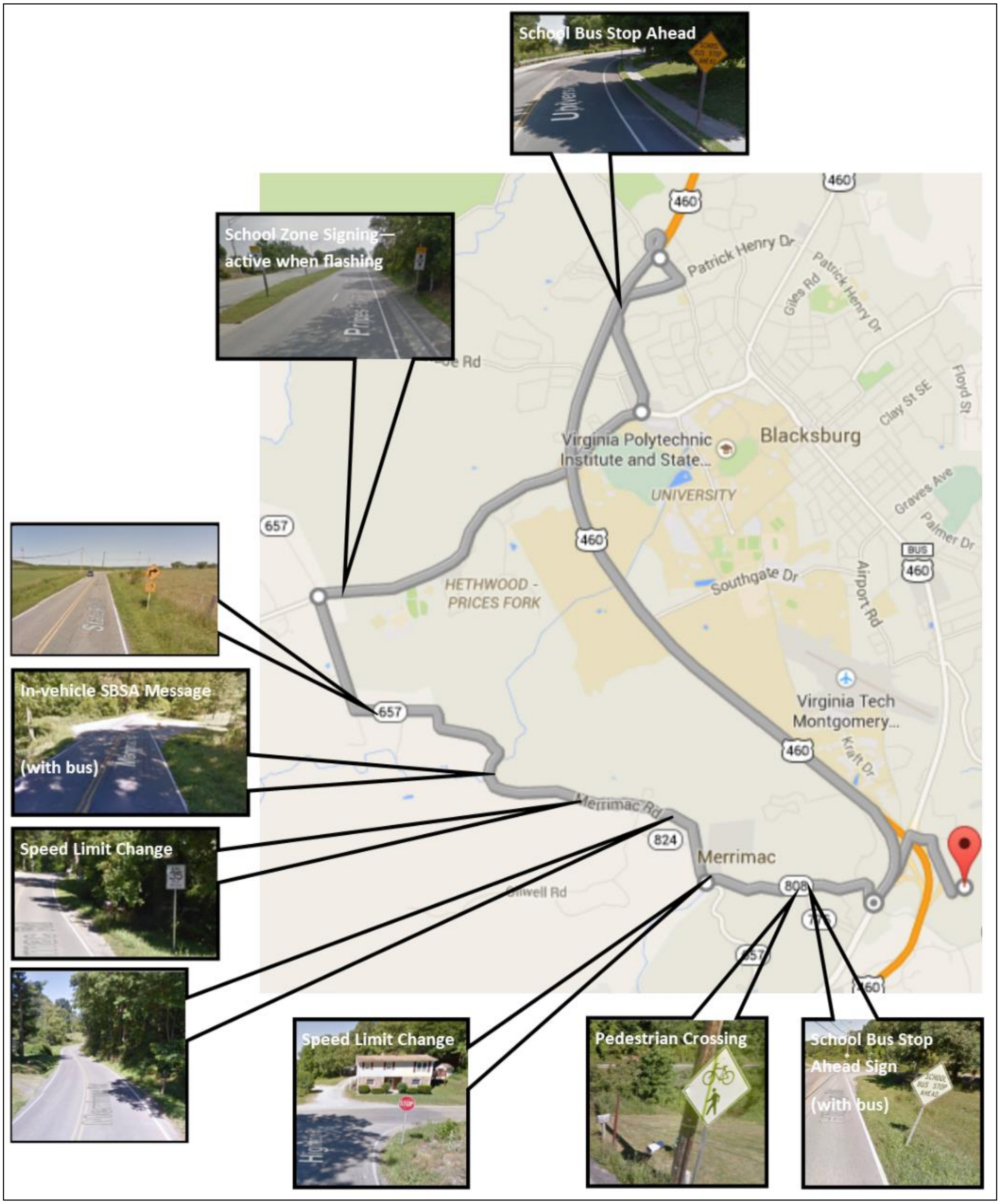

Figure 10. Map of the test route showing the types and locations of key events.

Key Event #1 – Roadside SBSA Sign

Drivers encountered a SBSA sign approximately 1.2 miles into the test route (Figure 11). During Trial A, drivers encountered a school bus around the curve, while during Trial B drivers did not encounter a school bus.

Figure 11. Location of the first roadside SBSA sign. No in-vehicle messages were displayed during this event.

Key Event #2 – Trail Crossing

Along Hightop Road, approximately 1.6 miles into the test route, drivers crossed over the Huckleberry Trail (Figure 12a). As they approached this multi-use trail crossing, they were presented with an in-vehicle message displaying the MUTCD trail crossing sign (Figure 12b). This event occurred during both trials.

Figure 12. Location of (a) trail crossing warning and (b) in-vehicle display of trail crossing warning.

Key Event #3 – Speed Limit Display

As drivers turned right at the stop-controlled intersection of Hightop Road and Merrimac Road (Figure 13a), they were presented with an in-vehicle speed limit sign displaying a driving speed of 35 mph (Figure 13b). The speed limit along this portion of the test circuit was 35 mph (as posted upstream of the intersection); however, the driver did not encounter any roadside speed limit signs during their drive. This event occurred during both trials.

Figure 13. Location of (a) in-vehicle speed limit message and(b) in-vehicle display of the speed limit message.

Key Event #4 – In-vehicle SBSA Message

Drivers were presented with the first in-vehicle experimental condition at 2.7 miles along the course. As they approached a blind curve (Figure 14a), they were presented with an on-screen SBSA warning that indicated a stopped bus ahead (Figure 14b).

This in-vehicle message was only displayed during Trial B when drivers were scheduled to encounter a school bus around the curve. Researchers tracked the drivers' speed and acceleration/deceleration data during Trial A to compare against the driving behavior at this location in Trial B.

Figure 14. Location of (a) SBSA message and (b) in-vehicle display of SBSA.

Key Event #5 – Speed Limit Display

As drivers continued along Merrimac Road, they encountered an "END 35 MILE SPEED" on the right side of the road (Figure 15a). According to the Virginia Department of Transportation[2], a speed limit of 55 mph was assumed along this segment. At this point, researchers displayed a

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[2] http://www.virginiadot.org/info/faq-speedlimits.asp

55 mph speed limit sign on the in-vehicle display (Figure 15b). This event occurred during both trials.

Figure 15. Location of speed limit display (a) and speed limit message(b).

Key Event #6 – In-vehicle SBSA message

Drivers were presented with an in-vehicle experimental condition at 2.7 miles along the course as they approached a blind curve (Figure 16a). At this time they received an on-screen SBSA message that indicated a stopped bus ahead (Figure 16b).

This in-vehicle message was only displayed during Trial B when drivers encountered a school bus around the curve. Researchers tracked drivers' speed and acceleration/deceleration data during Trial B to compare against the driving behavior at this location in Trial A.

Figure 16. Location of (a) SBSA warning and(b) SBSA warning message.

Key Event #7 – Curve Advisory Speed

Drivers were presented with an in-vehicle curve advisory speed message as they approached a sharp turn along Merrimac Road (Figure 17a) in the form of an on-screen warning that duplicated the existing road signs (Figure 17a).

Figure 17. Location of (a) curve advisory warning and (b) in-vehicle display of curve advisory speed sign.

Key Event #8 – School Zone

As drivers continued on Prices Fork Road, they passed through an active school zone (Figure 18). Drivers encountered this active school zone during both trials; however, they did not receive this message on their in-vehicle displays.

Figure 18. School zone signs (active when flashing).

Key Event #9 – Roadside SBSA Sign

Drivers encountered their last roadside SBSA sign approximately 8.9 miles into the test circuit (Figure 19). During Trial B, drivers encountered a school bus stopped around the curve; drivers did not encounter a school bus during Trial A.

Figure 19. Location of the first roadside SBSA sign. No in-vehicle messages were displayed during this event.

Unscheduled Events

The experiment was designed to take place during typical school bus operation times in order for drivers to believe that the school bus encounters were realistic. As a result, some participants experienced additional encounters with stopped school buses that were not a planned part of the experiment. In those cases, the researchers deployed an unscheduled SBSA message on the in-vehicle display to provide continuity to participant exposure to experimental conditions. The activation of this message automatically flagged the position of the event in the dataset for potential subsequent analysis. However, this information was not included in the data analysis because differing experimental conditions between locations of occurrence, such as driver sightline and respective views of signs and bus stops, created unacceptable confounds.

Post-Drive Surveys

After completing the driving portion of the experiment, drivers were asked to fill out a survey on their experience with the CV system. Additionally, drivers were asked about their interpretations and preferences regarding SBSA warnings (both in-vehicle messages and roadside signs).

Data Analysis

Researchers reviewed data acquired at 10 Hz corresponding to vehicle speed, longitudinal acceleration, and jerk during the 30 seconds before and the 60 seconds after an experimental condition or baseline condition. To reduce noise in the data, each data array (epic) was smoothed using a Savitzky-Golay filter [13].

Since researchers aimed to record participants' uninhibited responses, results that were obviously influenced by the presence of other vehicles on the roadway while within the area of interest (e.g., following another vehicle) were not evaluated. As a result, each bus stop had a unique combination of usable data epochs across varying participants. For example, a participant may have had an acceptable bus-present and baseline pairing for the first three bus stops, but may have been following a slow-moving vehicle during the baseline condition at the fourth bus stop. In this case, the participant's records were included in the analysis of Bus Stops 1, 2, and 3, but not Bus Stop 4.

Researchers used the forward video camera recording to determine the time at which each driver was first able to see the stopped school bus. Any driver whose time-to-bus-observation was outside of two standard deviations from the mean bus observation time was removed from the dataset as an outlier. This accounted for elimination of only one participant's school bus encounter.

The data for each bus stop were then compared between the bus-present condition and the baseline condition. The data were evaluated for statistical significance using a paired Student's t-test ($\alpha = 0.05$) before and after each bus stop sign or message.

Results of the Road Study

The results section of this report is broken down into three sections: participant demographics, driving study results, and post-drive survey results.

Participant Demographics

Altogether, 34 participants were recruited to participate in this study. Twenty-nine participants successfully completed the study and are included within the analysis portion of the report. The remaining five participants were unable to complete the study due to unforeseen circumstances. Three participant sessions were canceled due to technical difficulties with equipment, two due to bus wiring issues with the stop arm, and one due to DAS power issues. One participant session was canceled due to rain. The participants were nearly equally split between age and gender groups, as shown in Table 2.

Table 2. Participant Age/Gender Matrix

Gender/Age	Male	Female	TOTAL
Younger (20-35 years old)	8	7	15
Older (50-65 years old)	7	7	14
TOTAL	15	14	29

The younger age group indicated an average of 10.13 years ($\sigma = 4.63$) of driving experience, whereas the older age group indicated an average of 40.86 years ($\sigma = 4.45$) of driving experience. Two of the participants had international driving experience; however, this international experience comprised less than half of their total driving experience.

Most participants indicated that they had experience using navigation systems while driving (26 out of 29 participants). Nine of those participants also indicated experience using a crowd-sourced traffic data application (e.g., Waze). Twenty-five participants indicated they had experience using a smart phone either in general or while driving.

Driving Study Results

In general, drivers exhibited statistically significant responses when they received in-vehicle messages warning of a bus ahead, whereas there were no discernable responses to the roadside sign condition during the bus-present or baseline conditions. Comparisons of bus-present and baseline condition results are presented in order by variation in speed, longitudinal acceleration, and jerk (i.e., change in acceleration). Due to the differences in curve characteristics and approach speeds, the authors did not perform direct quantitative comparison of the responses to in-vehicle messages versus roadside signs, believing the results would be inconclusive and potentially misleading. (Note: Expanded Data Results are included in the appendix.)

Comparing Average Vehicle Speed

Data trends indicate that drivers reduced their speeds at a much greater rate and magnitude after receiving a school bus related in-vehicle message versus after exposure to a roadside sign.

Roadside Signs

As expected, vehicle approach speeds between the bus-present and baseline roadside sign conditions were statistically similar within five seconds before and after the SBSA sign. This indicates that there was little variation in vehicle speeds regardless of whether a bus was present after the sign or not, as, until drivers see the bus, the conditions are exactly the same. Slight speed reductions are exhibited near both bus stop signs; however, these reductions appear to be consistent with curve-related speed reductions corresponding to the 25 mph (11.2 m/s) design speed of the curves rather than related to signage.

At Bus Stop 1, the speed profiles begin to diverge approximately 2.5 seconds after the first bus observation ($t_{22}\ at\ 6.3\ seconds = -1.966, p = 0.031$).

Similarly, speeds at Bus Stop 4 began to diverge approximately 1.8 seconds after the bus observation ($t_{16}\ at\ 5.5\ seconds = -0.804, p = 0.048$).

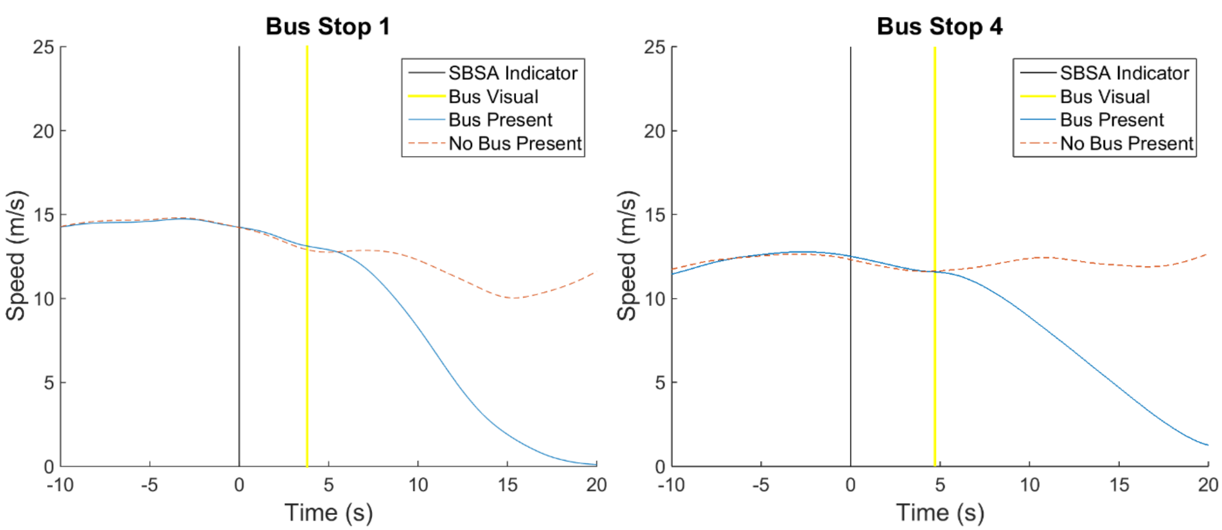

Figure 20. Comparison of vehicle speeds approaching the bus stops indicated via roadside sign. (Bus Stop 1 on left, Bus Stop 4 on right).

In-vehicle Messages

Overall, average driver behavior indicates a statistical difference in speeds within 3.5 seconds after the deployment of an in-vehicle message indicating a school bus is stopped ahead.

At Bus Stop 2, vehicle speeds prior to the message deployment were slightly higher than the baseline condition by approximately 0.3 m/s. However, this difference was not statistically significant. The t-tests indicated statistical divergence in speeds between the bus-present and baseline conditions starting at 3.4 seconds after the message deployment ($t_{21}\ at\ 3.4\ seconds = -1.764, p = 0.046$).

Vehicle speeds at Bus Stop 3 began to statistically diverge between the bus-present and baseline conditions starting at 3.2 seconds after participants received the in-vehicle message ($t_{17}\ at\ 3.2\ seconds = -1.740, p = 0.050$).

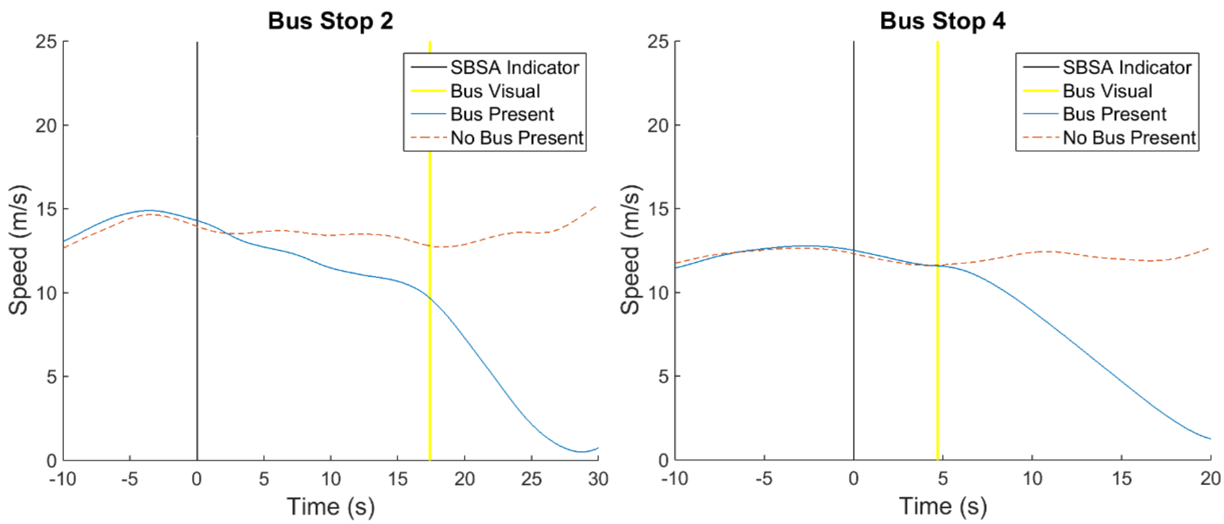

Figure 21. Comparison of vehicle speeds approaching the bus stops indicated via in-vehicle message. (Bus Stop 2 on left, Bus Stop 3 on right).

While the in-vehicle messages appear to have had a delayed effect on average vehicle speed, the statistical difference of average acceleration and jerk (in the next two subsections) provides evidence that drivers reacted to the in-vehicle messages quickly, even though the overall effect in the change of speed is not immediately evident.

Comparing Average Longitudinal Acceleration

The data trends in the following sections show that drivers noticeably decelerated after receiving an in-vehicle message. There is little evidence of similar behavior after passing a roadside SBSA sign.

Roadside Signs

As expected, average longitudinal acceleration was statistically similar during the bus-present and baseline conditions at roadside signs until after drivers observed the bus. In both roadside sign conditions, average longitudinal acceleration became statistically different approximately one second after the participants observed the school bus.

Average acceleration at Bus Stop 1 was statistically insignificant until 0.9 seconds after the driver observed the bus ($t_{22}\ at\ 4.7\ seconds = -2.063, p = 0.026$).

At Bus Stop 4, the average acceleration profiles between the bus-present and baseline conditions began to diverge approximately 0.3 seconds after the first bus observation ($t_{16}\ at\ 5.0\ seconds = -2.557, p = 0.005$). While the acceleration data demonstrated statistical significance starting at 3.0 seconds after the SBSA sign ($t_{16}\ at\ 3.0\ seconds = -1.894, p = 0.038$), it should be noted that in both cases the drivers were accelerating along the roadway and the magnitude of the acceleration is not practically relevant.

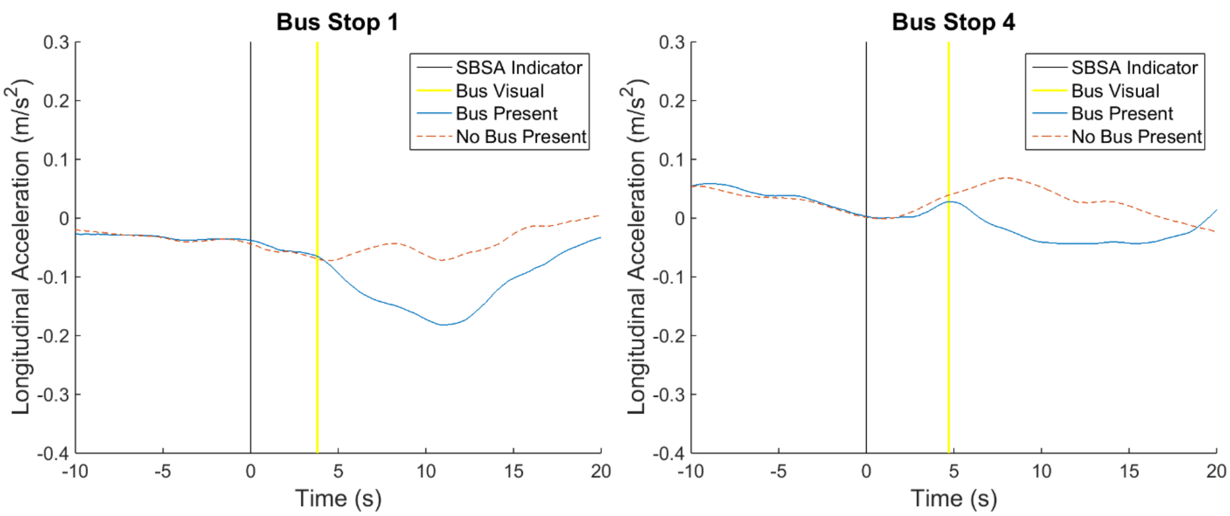

Figure 22. Comparison of vehicle longitudinal accelerations approaching the bus stops indicated via roadside sign. (Bus Stop 1 on left, Bus Stop 4 on right).

In-vehicle Messages

In general, the average driver demonstrated statistically higher decelerations less than 1.5 seconds after receiving the in-vehicle message. While the general shape of the acceleration profile mimics the accelerations and decelerations of the baseline conditions, the average driver behaved more conservatively after receiving the in-vehicle message.

At Bus Stop 2, the t-tests indicated statistical difference between the bus-present and baseline conditions starting at 1.0 seconds after the message deployment ($t_{21}\ at\ 1.0\ seconds = -1.728, p = 0.049 < 0.05[\alpha]$). Using the acceleration profile as a surrogate measure of driver caution as participants progressed along this curvy section of the route, results showed that drivers displayed increased caution approaching each curve preceding the curve with the staged bus encounter.

Similarly, the t-tests indicated statistical difference between the bus-present and baseline conditions at Bus Stop 3 starting at 1.3 seconds after the message deployment ($t_{17}\ at\ 1.3\ seconds = -1.776, p = 0.047[< 0.05]$). Since Bus Stop 3 was a high-speed bus stop in a non-posted speed zone (maximum speed limit of 55 mph [24.6 m/s]), drivers decelerated during the bus-present and baseline conditions as they approached the upcoming curve; however, drivers decelerated at a higher rate when they received the in-vehicle message (Figure 23).

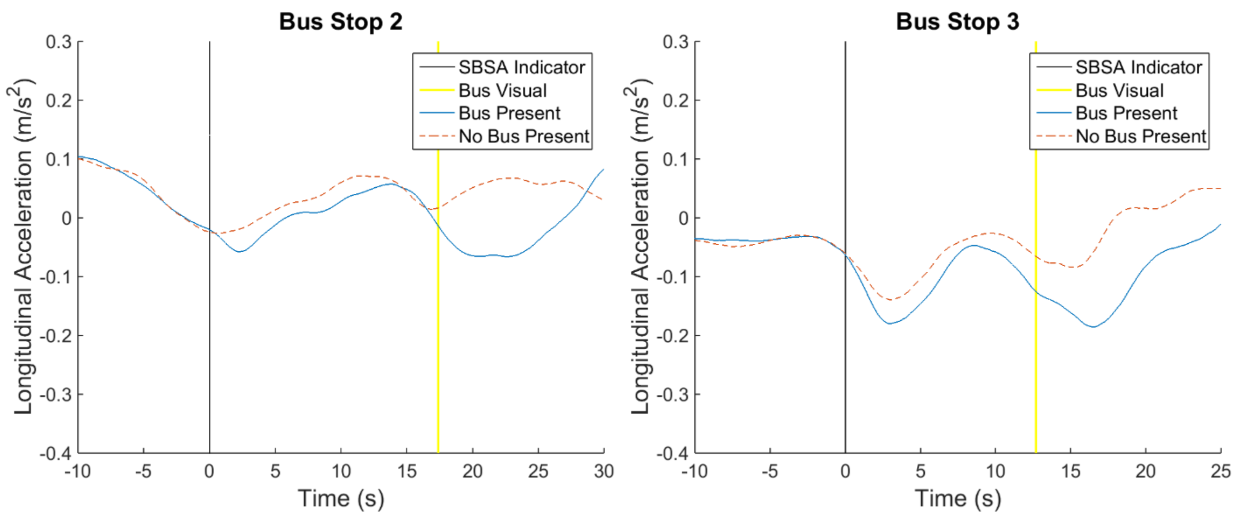

Figure 23. Comparison of driver longitudinal accelerations approaching the bus stops indicated via in-vehicle message. (Bus Stop 2 on left, Bus Stop 3 on right).

Comparing Average Jerk

The data trends indicate that drivers' rate of change of acceleration (i.e., vehicle jerk) was different from the baseline condition immediately after receiving an in-vehicle message. As expected, the roadside sign condition remained very similar to the baseline condition until drivers viewed the stopped school bus.

Roadside Signs

As expected, the data indicate that there is very little difference in jerk between bus-present and baseline conditions prior to observing the stopped school bus. (See Figure 24.) Once the drivers observed the bus, their average jerk value became statistically significant within one second. The minimum jerk value, indicating an increasingly negative acceleration, occurred approximately one second after observing the stopped bus.

At Bus Stop 1, the t-tests indicated statistical difference between the bus-present and baseline conditions starting at 0.1 seconds after the average time of the first bus observation at this bus stop ($t_{22}\ at\ 3.9\ seconds = -1.133, p = 0.037$). The minimum average jerk (-0.0304 m/s^3) occurred 1.1 seconds after observing the bus.

At Bus Stop 4, the t-tests indicated statistical difference between the bus-present and baseline conditions starting at 0.1 seconds after the average time of the first bus observation at this bus stop ($t_{16}\ at\ 4.8\ seconds = -1.828, p = 0.043$). The minimum average jerk (-0.0244 m/s^3) occurred 1.0 seconds after observing the bus.

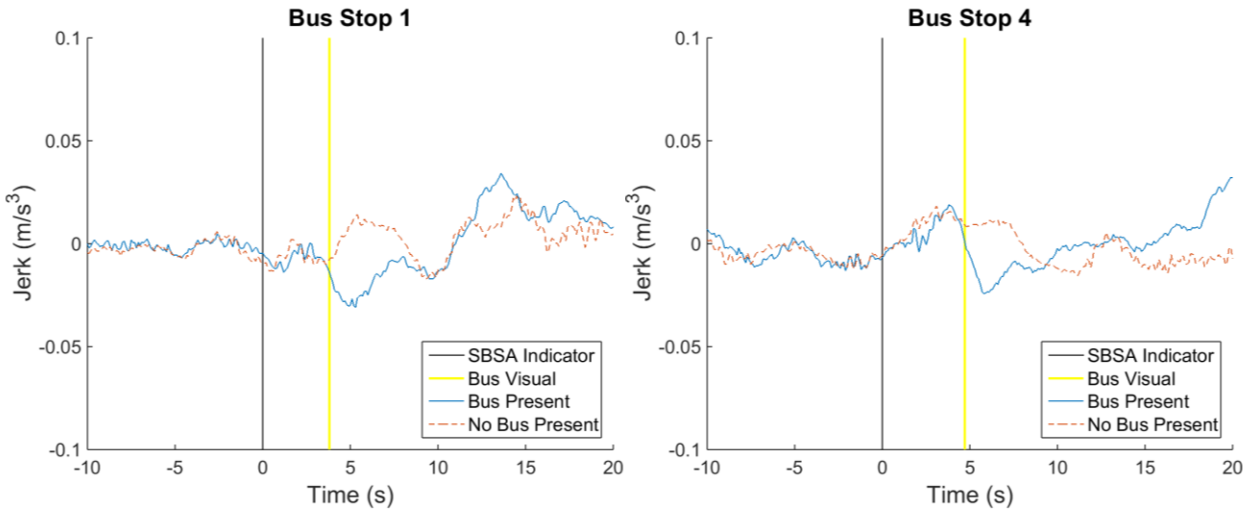

Figure 24. Comparison of driver jerk approaching the bus stops indicated via roadside sign. (Bus Stop 1 on left, Bus Stop 4 on right)

At both bus stops, there was evidence of statistically lower rates of acceleration prior to observing the bus; however, these variations in jerk were numerically small (less than 0.01 m/s^3) and likely not of practical significance.

In-vehicle Messages

After receiving an in-vehicle message that indicated a stopped school bus ahead, drivers demonstrated a nearly immediate reduction in jerk, indicating a higher rate of deceleration compared against the baseline conditions. (See Figure 25.)

At Bus Stop 2, the t-tests indicated statistical difference in jerk between the bus-present and baseline conditions starting at 0.1 seconds after the message deployment ($t_{21}\ at\ 0.1\ seconds = -1.810, p = 0.042$). This statistical difference in jerk lasted approximately 2 seconds ($t_{21}\ at\ 2.1\ seconds = -2.695, p = 0.007$). The average minimum jerk value (-0.024 m/s^3) occurred 0.8 seconds after the message deployment, at which point the rate of change of acceleration became positive again.

At Bus Stop 3, the t-tests indicated statistical difference between the bus-present and baseline conditions starting at 0.6 seconds after the message deployment ($t_{18}\ at\ 0.6\ seconds = -1.892, p = 0.038$) and lasting approximately 0.3 seconds ($t_{18}\ at\ 0.9\ seconds = -1.784, p = 0.046$). The average minimum jerk value (-0.05 m/s^3) occurred 0.8 seconds after the message deployment.

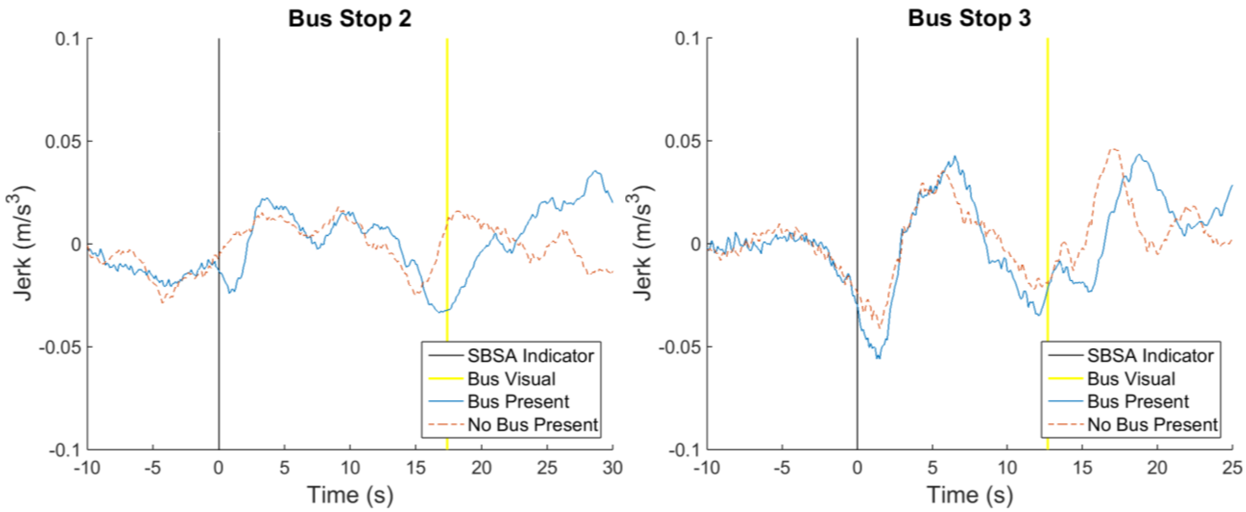

Figure 25. Comparison of vehicle jerk when approaching the bus stops indicated via in-vehicle message. (Bus Stop 2 on left, Bus Stop 3 on right).

The research team believes that the higher magnitude of the minimum jerk value at Bus Stop 3 can be attributed to a difference in average approach speeds (i.e., drivers decelerated at a higher rate when their approach speed was higher).

Both bus stops also demonstrate a statistical difference in jerk prior to observing the stopped school bus. This propagates the inference that drivers operated the vehicle with increased caution when rounding a curve after they received a warning about a stopped school bus ahead.

Summary of Results

Table 3 provides a summary of the results comparing average reduction of speed, longitudinal acceleration, and jerk between the bus-present and baseline conditions.

Table 3. Summary of Results Comparing Differences in Driver Behaviors in Bus-present versus Baseline Conditions

Condition	Bus Stop	Average Driving Speed at Sign/Message	Time of Bus Observation	Speed	Acceleration	Jerk (before bus observation)	Jerk (after bus observation)
Roadside Sign	1	14.25 m/s $\sigma = 1.82$	3.8 seconds after sign $\sigma = 0.41$	Statistically significant starting at 2.5 seconds after bus observation	Statistically significant starting at 0.9 seconds after bus observation	Not relevant before bus observation	Statistically significant 0.1-3.3 seconds after bus observation
	4	12.52 m/s $\sigma = 0.77$	4.7 seconds after sign $\sigma = 0.25$	Statistically significant starting at 1.8 seconds after bus observation	Statistically divergent behaviors starting at 0.3 seconds after bus observation[3]	Not relevant before bus observation[1]	Statistically significant 0.1-3.4 seconds after bus observation
In-vehicle Message	2	14.30 m/s $\sigma = 1.41$	17.4 seconds after sign $\sigma = 2.25$	Statistically significant starting at 3.2 seconds after message	Statistically significant starting at 1.0 seconds after message	Statistically significant 0.1-2.0 seconds after message	Statistically significant 0.0-2.9 seconds after bus observation
	3	18.35 m/s $\sigma = 2.42$	12.7 seconds after sign $\sigma = 2.52$	Statistically significant starting at 3.3 seconds after message	Statistically significant starting at 1.3 seconds after message	Statistically significant 0.6-0.9 seconds after message	Statistically significant 15.7-17.2 seconds after bus observation

[3] Statistical significance between the bus observed and baseline conditions was found prior to this time; however, it was not deemed to be of practical relevance.

Unanticipated Consequences

Upon hearing the automated tone, one driver abruptly steered to the left towards an opposing lane of traffic, though the vehicle did not cross the double yellow line.

Post-Drive Survey

Sign Familiarity

As part of the post-drive survey, drivers were asked to identify whether they noted specific signs on the roadside, in the vehicle, or did not notice specific signs at all.

Table 4. Summary of the Drivers' Familiarity with Signs Along the Test Route

Sign	Expected Answer	Saw on Roadside	Saw on in-vehicle display	Did Not Notice
	Saw on Roadside	**22**	11	7
	Saw on Roadside	**22**	0	6
	Did Not Notice	1	4	**22**
	Saw on Roadside and on In-vehicle Display	**22**	**29**	0
	Saw on Roadside and on In-vehicle Display	**23**	**22**	4
	Saw on Roadside	**29**	1	0
	Saw on Roadside	**29**	1	0
	Saw on Roadside and on In-vehicle Display	**28**	**16**	0
	Saw on Roadside and on In-vehicle Display	**16**	**26**	0

Sign	Expected Answer	Saw on Roadside	Saw on in-vehicle display	Did Not Notice
	Saw on In-vehicle Display	8	**27**	2
	Did not Notice	11	0	**18**
	Saw on Roadside	**21**	0	8

Despite passing the roadside SBSA four separate times (twice per test lap), 24% of drivers did not remember passing the text-based sign. However, 93% of drivers remembered seeing the SBSA message on the in-vehicle display. It is difficult to discern if the difference in recalling whether or not they saw the signs/messages was due to complacency about sign content or relevancy, or due to a quick dismissal of seeing the sign after passing it.

School Bus Sign Interpretation

This survey asked participants about their interpretation of the text-based SBSA sign (Figure 26). Participants were instructed to select all answers that applied. The most common answers included the following: there is a designated school bus stop ahead (26 participants); children may be waiting on the roadside ahead (22 participants); and there may be a bus stopped ahead (23 participants). Although the participants selected answers that indicated the children or school bus *may* be ahead, 19 participants still indicated that the sign effectively communicated the road conditions.

Figure 26. Text-based SBSA sign

Each participant was asked to provide a free-response answer to explain why they thought the sign was effective or ineffective at communicating the road condition. Most participants who considered the sign to be effective indicted that the sign made them more aware that there could be a bus and that they may need to slow down. Some participants also indicated that the sign's effectiveness was dependent on the time of day (i.e., not effective at night, but possibly effective during morning or afternoon hours). Participants who did not think the sign was effective mentioned that it did not accurately represent the current road conditions (e.g., "It does not tell me the current state of the vehicle/pedestrian on the road/roadside. Could mean a number of possible situations.”). Participants also commented that the sign was vague, as it did not provide information on when the bus would be there, how far away the bus stop was, and/or if any children were at the bus stop.

The survey then asked about the graphic-based in-vehicle SBSA message (Figure 27). Participant responses were split between certain responses (i.e., “Children *are* waiting on the roadside”) and possible responses (i.e., “Children *may be* waiting on the roadside”). Most notably, 26 of the participants answered that this message indicated that the bus *is* stopped ahead.

Figure 27. Graphic-based SBSA message

Most participants freely expressed that the in-vehicle message was more effective than the roadside sign because it clearly demonstrated that there was a stopped bus and that children could be on the roadside or crossing in front of the bus. Participant comments also indicated that they found this sign to be beneficial when displayed prior to a blind curve, “so that they can start planning on slowing down and do not run up on the bus.” Many of the comments also indicated that the audible tone helped them notice the message and react to it immediately. One participant who expressed that the message was not effective indicated that the message would be more helpful with a distance measurement (i.e., “Stopped 250 feet ahead”).

Participant Ratings on the Connected Vehicle Display

Participants used a Likert-type scale to rate their awareness of the in-vehicle display while they were driving the test route. The scale ranged from one (“not at all aware”) to seven (“very aware”), where four was considered “neutral.” On average, participants indicated that their awareness of the display was slightly above neutral (see Table 5).

Table 5. Descriptive Statistics of the Awareness of the In-vehicle Display

Awareness of the in-vehicle display	
Mean	5.41
Standard Error	0.20
Median	6
Mode	6
Minimum	3
Maximum	7
Standard Deviation	1.09
95% Confidence Level	0.41

Participants used a similar seven-point Likert-type scale to rate the usefulness of the in-vehicle display, of the informational messages, and of the SBSA message. The scale was labeled from one ("not at all useful") to seven ("very useful"). While Table 6 shows that the average response for each question was greater than neutral, the usefulness of the SBSA message was statistically greater than the other topics ($p < 0.001$ in both comparisons).

Table 6. Descriptive Statistics of the Usefulness of the In-vehicle Messages and Display

Usefulness of the in-vehicle display		**Usefulness of informational messages** (such as curve advisory signs, speed limit signs, and trail crossing signs)		**Usefulness of school bus message**	
Mean	5.48	Mean	5.76	Mean	6.76
Standard Error	0.19	Standard Error	0.18	Standard Error	0.09
Median	5	Median	6	Median	7
Mode	5	Mode	6	Mode	7
Minimum	3	Minimum	4	Minimum	5
Maximum	7	Maximum	7	Maximum	7
Standard Deviation	1.02	Standard Deviation	0.95	Standard Deviation	0.51
95% Confidence Level	0.39	95% Confidence Level	0.36	95% Confidence Level	0.19

Participants were asked to rate the likeliness of seeing a stopped school bus after each experimental condition. Results are presented in Figure 28. Nearly one-third of the participants indicated that the likeliness of encountering a stopped bus after a roadside sign was between 1%–40%, whereas almost all participants indicated an 80-100% likelihood of encountering a stopped bus after receiving an in-vehicle message.

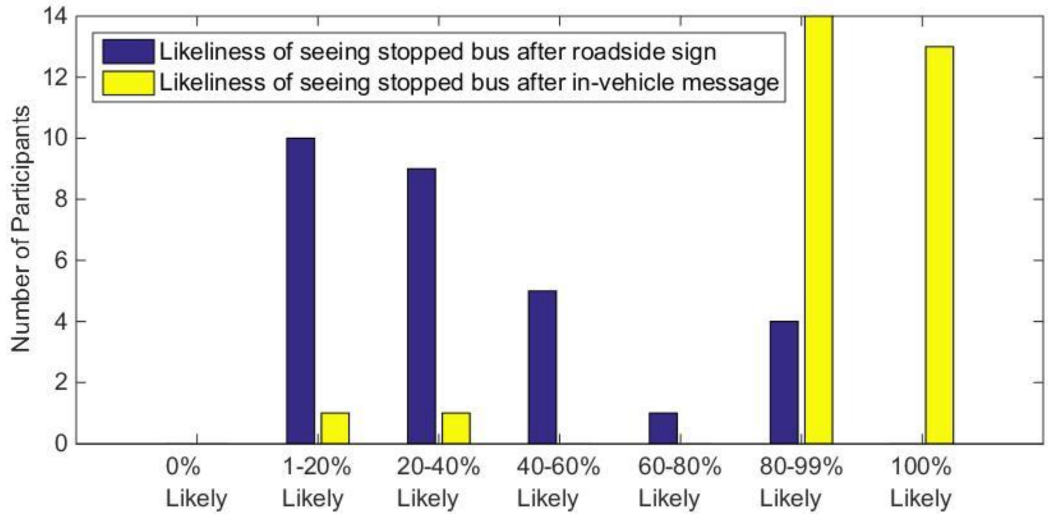

Figure 28. Likeliness of seeing a stopped school bus after a roadside SBSA sign or an in-vehicle message.

Participants were also asked how likely they were to change their driving behavior after passing a roadside sign or receiving an in-vehicle message about a stopped bus. As shown in Figure 29, drivers expressed a much higher likelihood of changing their driving behavior after receiving an in-vehicle message compared to changing their behavior after passing a roadside sign.

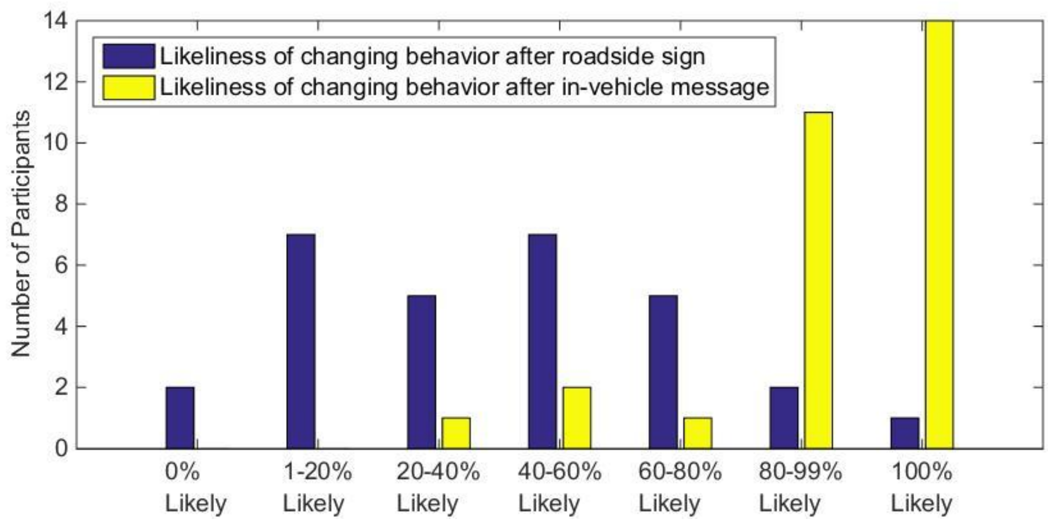

Figure 29. Likeliness of changing driving behavior after a roadside SBSA sign or an in-vehicle message.

Participant Preferences for Receiving Information about Stopped School Buses

Overall, participants expressed positive comments regarding the in-vehicle message deployment. When asked which method of message presentation they preferred (in-vehicle message, roadside sign, both, or neither), seven participants preferred the in-vehicle message, one preferred the roadside sign, and 21 preferred both methods.

In their space for a free-response answer, most participants explained that they actually preferred the in-vehicle message due to its ability to provide accurate real-time information, but that they did not want to completely eliminate roadside signs. Some participants expressed that the roadside sign was beneficial because it informed them that there could be children on the roadside as opposed to receiving a message only when there is a stopped bus. The participant who preferred the roadside sign expressed concern that the in-vehicle message caused him to look away from the road, thus distracting from the actual on-road hazard.

Discussion

The research objectives of this project were to develop and evaluate a system for improving driver awareness around school buses and school bus stops within a CV environment. The research team hypothesized that drivers would exhibit a noticeable response upon receiving an in-vehicle message, whereas drivers would react to a SBSA roadside sign only after passing the sign and seeing a stopped school bus.

Roadside Signs

Differences in driver behavior after passing a SBSA sign were statistically indiscernible when comparing the bus-present condition and baseline condition. Once drivers observed a stopped bus, they experienced statistically significant changes in jerk within one second. This propagated to a statistically significant difference in longitudinal acceleration approximately one second after seeing the bus and statistically different speeds approximately 1.5 to 2.5 seconds after seeing the bus. There was no clear evidence that indicated significant driver response to the actual presence of the roadside sign.

When asked about their interpretation of the roadside SBSA sign, participants expressed uncertainty about the actual presence of a school bus or children on the road. One third of all participants indicated that there was less than a 40% chance of encountering a stopped school bus after passing the sign. This was an expected result, as these signs are generally time-dependent even though they give no indication of when children are expected on the roadside.

In-vehicle Messages

Driver behavior was statistically different almost immediately after the deployment of an in-vehicle message indicating a stopped school bus ahead when compared against the baseline driving condition. Data indicated a significant reduction in vehicle jerk within 0.1 seconds of deploying the message, leading to a statistically higher deceleration within 1.5 seconds of message deployment. Vehicle speeds were also statistically different within 3.5 seconds of the message deployment. Plotting vehicle dynamics during the bus-present and baseline conditions led to the discovery that drivers not only had an immediate response to the message, but were also driving more conservatively as they navigated around blind curves when the message was displayed.

Participants expressed that the in-vehicle messages provided much more reliable information that was effective at reducing their speed and increasing their awareness. Their written responses regarding the in-vehicle message were overwhelmingly positive, with only one participant suggesting that the message could be improved by adding a measurement of distance between their vehicle and the school bus. Nearly all participants indicated an 80-100% chance of encountering a stopped school bus after receiving an in-vehicle message.

When asked about the usefulness of the CV system as a whole, participants indicated that the system and informational messages were useful; however, the school bus message was deemed to be statically more useful than the general informational messages such as speed limits and curve advisory signs.

Limitations

This experiment was limited by the researchers' ability to create a road test route that contained two existing roadside signs and could support the staging of two additional school bus stops along a curvy roadway for in-vehicle message presentation. As a result of this limitation, the roadside sign locations and in-vehicle message locations were not perfect matches in terms of curve characteristics and approach speeds. For example, the average approach speed of the roadside sign locations was 13.5 m/s whereas the average approach speed for the in-vehicle message deployments was 16.2 m/s.

To minimize driver risk, researchers deployed the in-vehicle message along a straight segment of the roadway, allowing for a conservative 3.0 seconds reaction time before the driver entered the next curved roadway segment. This led to a much higher interval between the message deployment and first observation of the stopped bus. The findings presented herein indicate that drivers reacted almost immediately to the message (within one second), suggesting that the message would still be effective within a closer proximity to the school bus.

Direct comparisons of roadside sign versus in-vehicle message responses are not advised due to the limitations of this dataset. To accomplish this comparison, researchers advise designing an experiment that utilizes curves with equivalent or similar approach speeds and horizontal curve characteristics.

Naturalistic experimentation with innovative treatments is subject to novelty and observer (Hawthorne) effects. The novelty effect, in particular, may result in overrepresentation of the longer-term comparative benefit of one treatment over another. In recognition of the potential impact to the findings, the research team made every reasonable effort to design and perform experimentation with methods intended to minimize the impact of these effects.

Conclusions and Recommendations

This research project aimed to evaluate drivers' responses to an in-vehicle SBSA message and to similar roadside signing. Drivers traveled a test route that contained four bus stops. Two bus stops had roadside SBSA signing, whereas the other two bus stops were indicated by an in-vehicle SBSA message. Drivers drove past each bus stop location twice: once to gather driver responses to a stopped school bus and once to gather baseline driving data. Driver responses were measured in terms of differences in vehicle speeds, longitudinal acceleration, and jerk.

In-vehicle messages provided drivers with a more reliable means of communicating the hazard of a stopped school bus ahead. The nearly immediate driver responses to in-vehicle messages indicated an increased awareness of their surroundings and served as a surrogate towards identifying a driver's level of caution when approaching a bus along a curvy roadway. The corresponding roadside sign conditions provided little evidence of changing driver behavior prior to visually observing a stopped school bus in the roadway.

Participants favored the reliability of the in-vehicle message more than the roadside sign; however, more than half of the participants indicated that they would rather see both types of information (in-vehicle message and roadside sign) instead of one over the other.

Future Research Recommendations

The research presented in this report covers only one of the five scenarios described in the ConOps Report (http://www.apps.vtti.vt.edu/appendices/schoolbus/Palframan_SBSA - ConOps.pdf). Additional research is needed to evaluate how in-vehicle messages could improve safety around school buses in the remaining four scenarios:

1. Informational and regulatory messages that could be sent from an occupied bus stop to other vehicles in the vicinity
2. Informational messages that a school bus could send to other vehicles in the vicinity of their route
3. Safety-critical messages that other vehicles could relay to a stopped school bus
4. Informational and safety-critical messages that could be sent from a stopped or stopping school bus at a railroad crossing to vehicles approaching from behind.

To enhance the power of this particular experiment (in-vehicle message to warn of a stopped or stopping school bus), the researchers recommend designing a study that enables direct comparison of in-vehicle school bus messages versus roadside signs using equivalent curve features (e.g. approach speed, curve radii, available sight distance).

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Appendix

Expanded Data Results

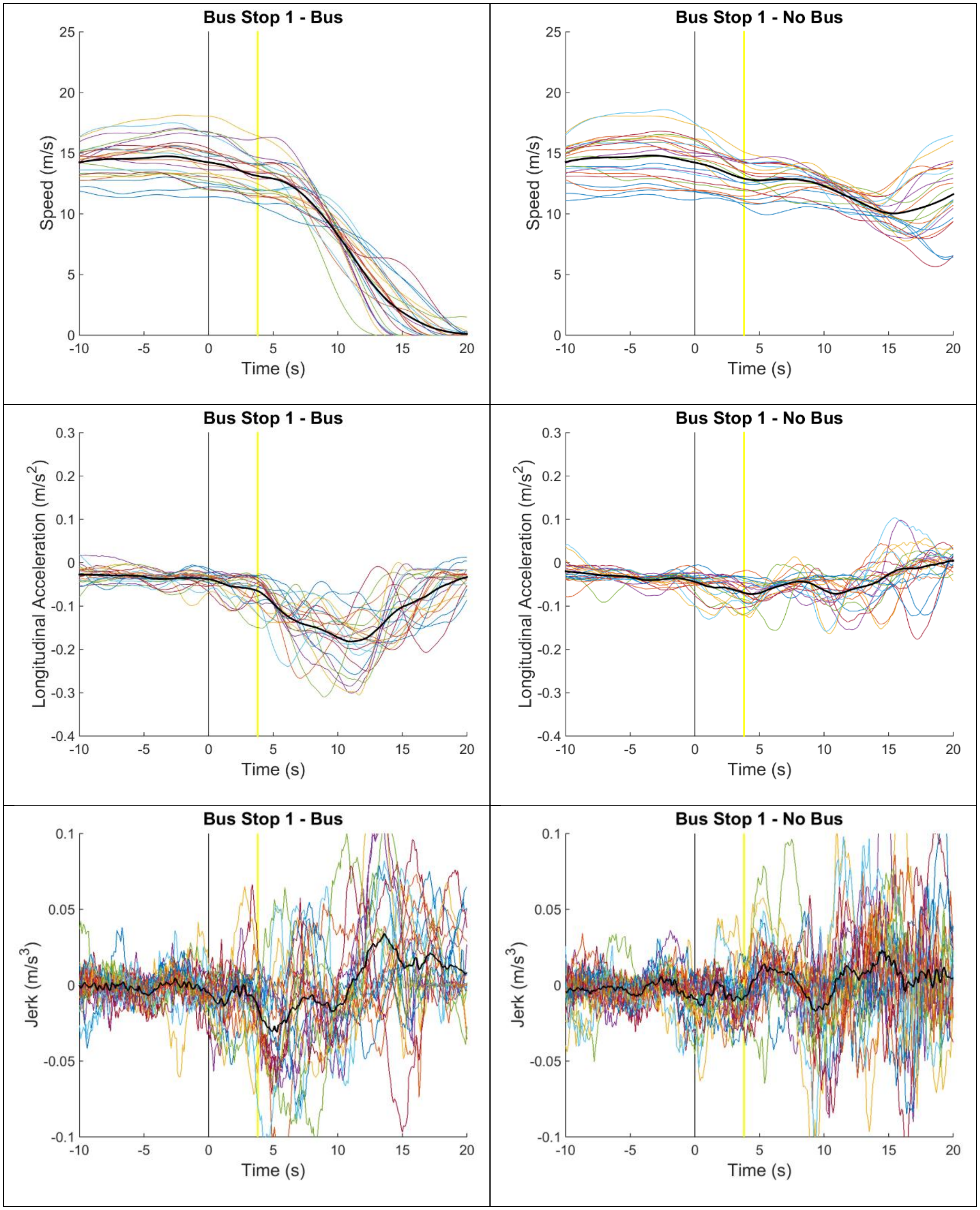

Figure A.1. Bus Stop 1 – roadside SBAS.

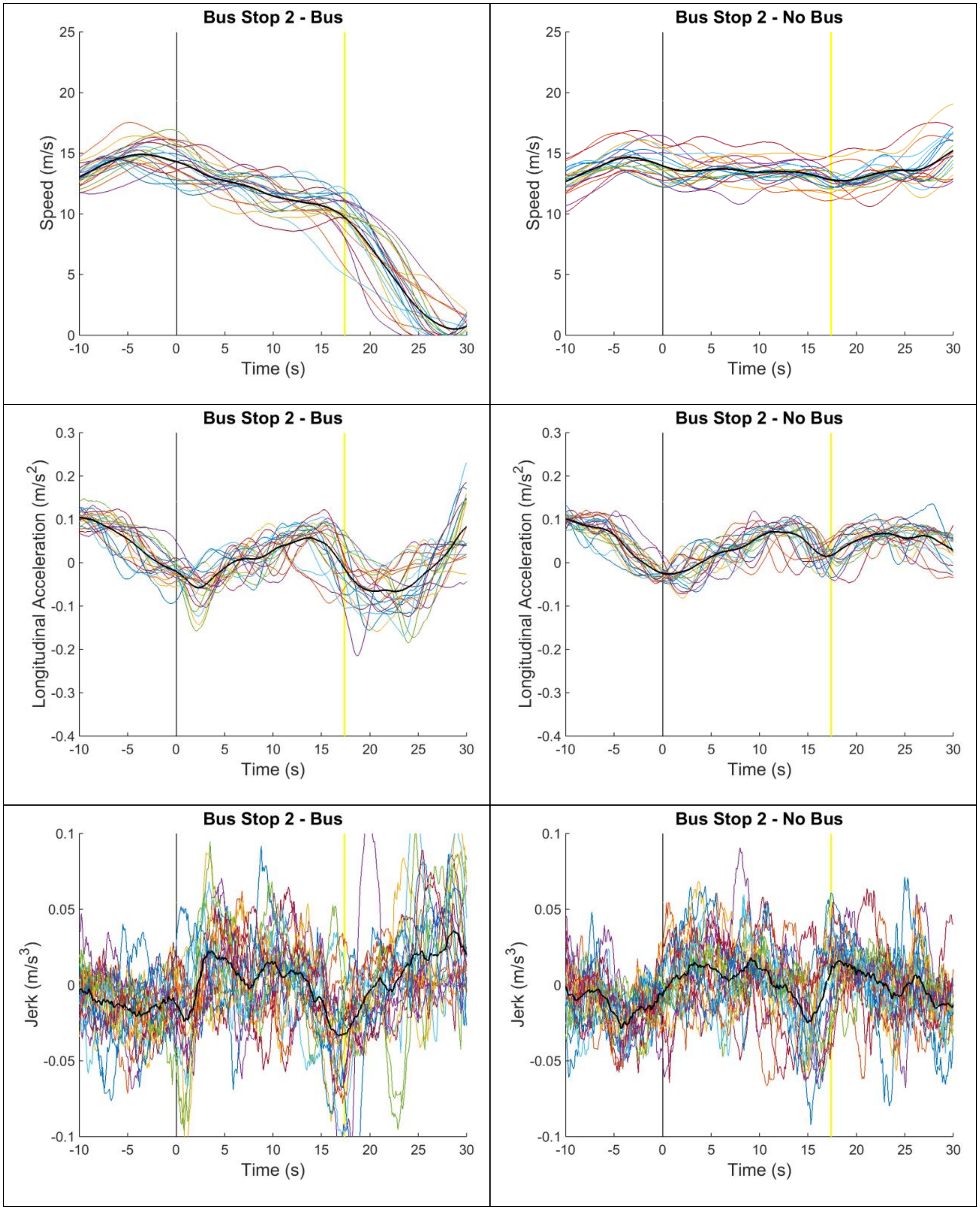

Figure A.2. Bus Stop 2 – in-vehicle SBAS.

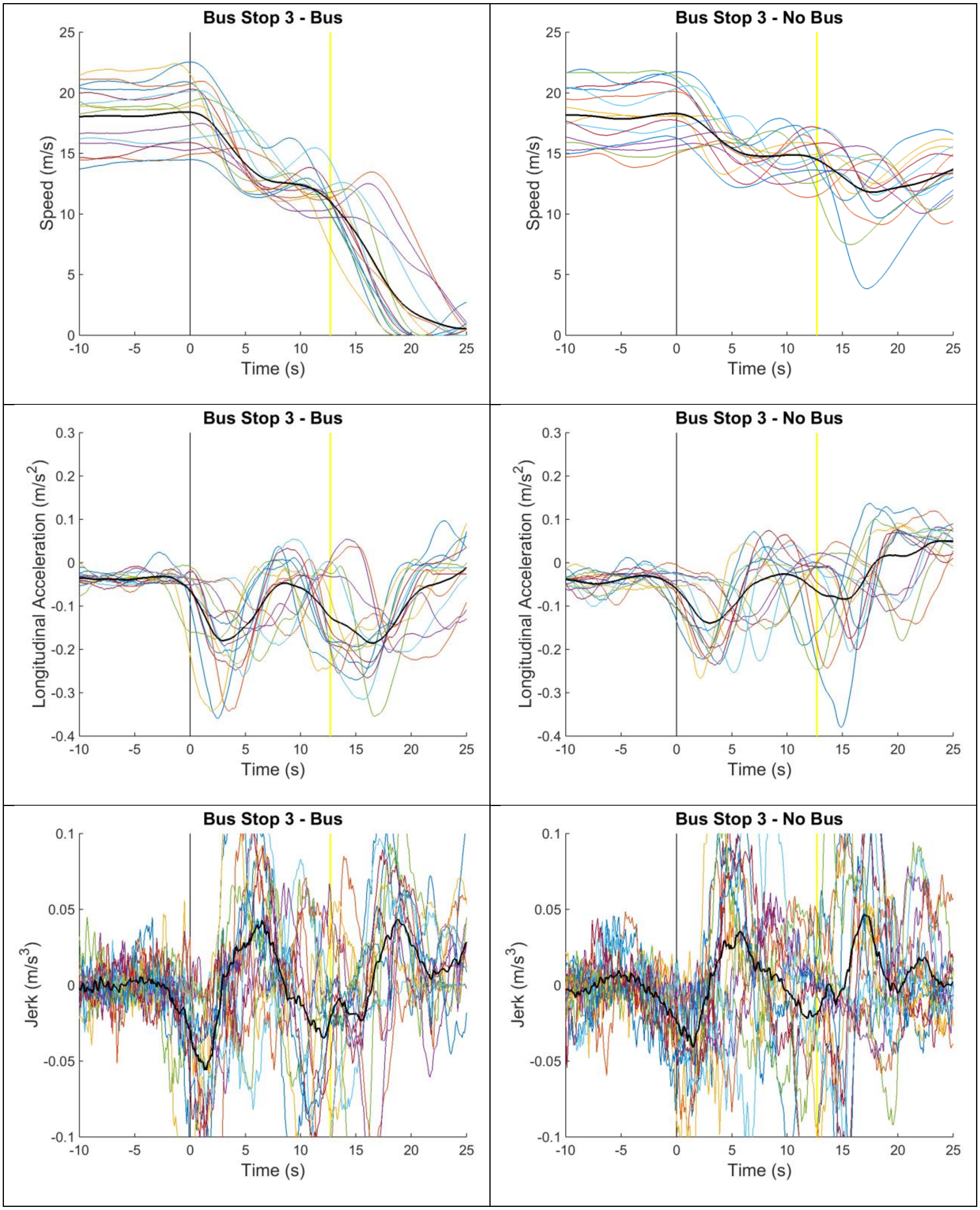

Figure A.3. Bus Stop 3 – in-vehicle SBAS.

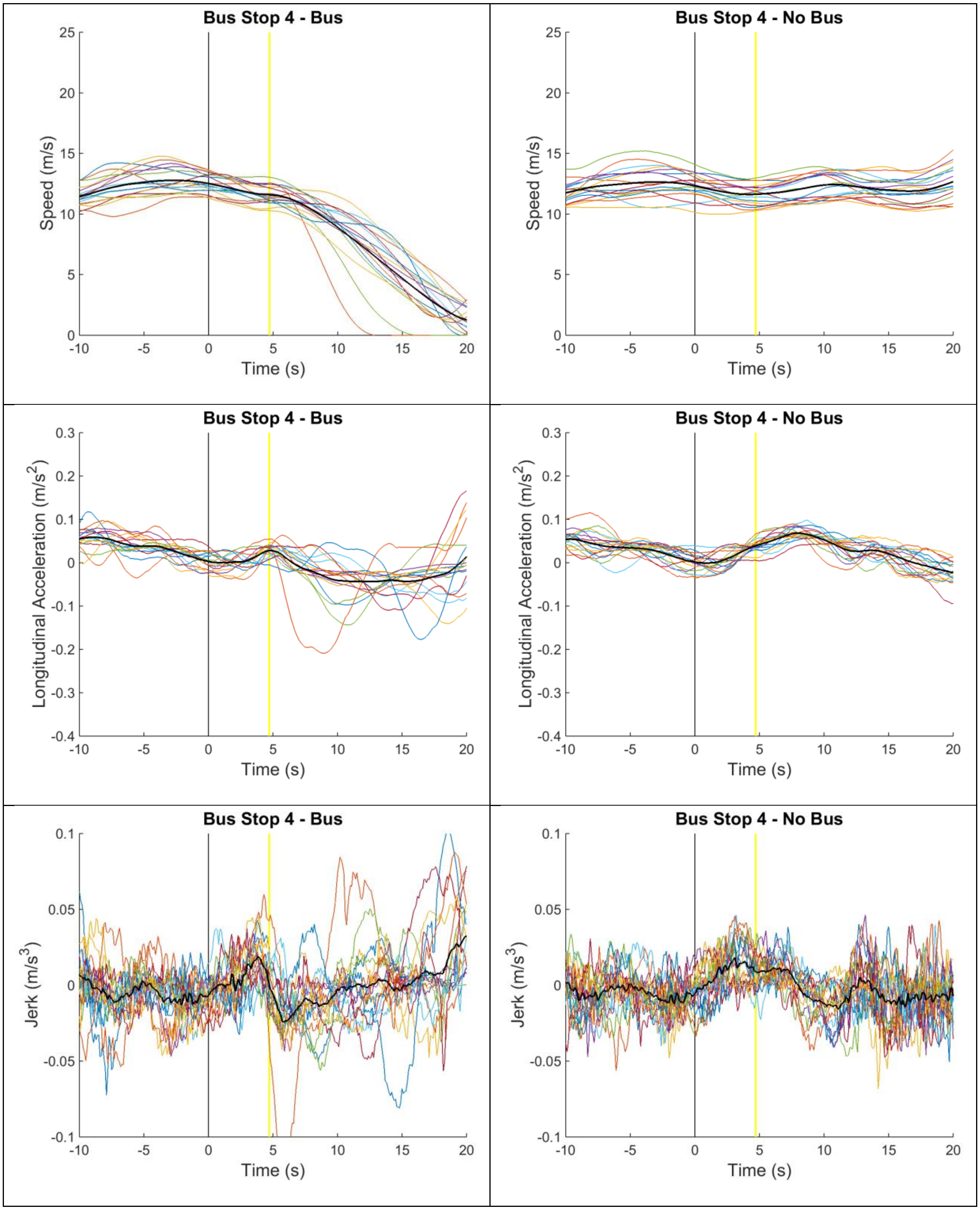

Figure A.4. Bus Stop 4 – roadside SBAS.