FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Driver Assist System (DAS) Technology to Support Bus-on-Shoulder (BOS) Operations

JUNE 2019

FTA Report No. 0135
Federal Transit Administration

PREPARED BY

Minnesota Valley Transit Authority

U.S. Department of Transportation
Federal Transit Administration

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Courtesy of Minnesota Valley Transit Authority

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PREPARED BY

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1200 New Jersey Avenue, SE
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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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13. ABSTRACT

This report summarizes the project activities and results of the Generation 2 (Gen2) Driver Assist System (DAS) used by the Minnesota Valley Transit Authority (MVTA) for bus shoulder operations. It provides warnings for lane departure, side collision, and forward collision. The Gen2 DAS is a GPS-based technology suite that provides lane position feedback to the driver via light emitting diode (LED) warning lights embedded in the dashboard, warning icons on a liquid crystal display (LCD) touch screen, and a vibrating seat. The Gen2 DAS has several modifications that distinguish it from the Gen1 DAS, including the elimination of the head-up display, virtual mirror, and steering feedback. Also, the Gen2 DAS uses lidar for front collision sensing and radar for side collision sensing, whereas the Gen1 DAS used lidar for both. MVTA's primary goal for the Gen2 DAS was the same as for Gen1—to enhance driver confidence during bus shoulder operations, especially during adverse weather, to bypass traffic congestion when speeds in general-purpose lanes drop below 35 miles per hour. Secondary goals included reduced travel times, increased reliability and safety, and improved customer satisfaction

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ABSTRACT

This report summarizes the project activities and results of the Generation 2 (Gen2) Driver Assist System (DAS) used by the Minnesota Valley Transit Authority (MVTA) for bus shoulder operations. It provides warnings for lane departure, side collision, and forward collision. The Gen2 DAS is a GPS-based technology suite that provides lane position feedback to the driver via light emitting diode (LED) warning lights embedded in the dashboard, warning icons on a liquid crystal display (LCD) touch screen, and a vibrating seat. The Gen2 DAS has several modifications that distinguish it from the Gen1 DAS, including the elimination of the head-up display, virtual mirror, and steering feedback. Also, the Gen2 DAS uses lidar for front collision sensing and radar for side collision sensing, whereas the Gen1 DAS used lidar for both. MVTA's primary goal for the Gen2 DAS was the same as for Gen1—to enhance driver confidence during bus shoulder operations, especially during adverse weather, to bypass traffic congestion when speeds in general-purpose lanes drop below 35 miles per hour. Secondary goals included reduced travel times, increased reliability and safety, and improved customer satisfaction.

EXECUTIVE SUMMARY

This report documents the activities and results of the Federal Transit Administration (FTA)-sponsored Driver Assist System (DAS) Technology to Support Bus-on-Shoulder (BOS) Operations project and demonstration. It also provides information on the approach and results of the corresponding independent evaluation.

In March 2017, the Minnesota Valley Transit Authority (MVTA) began its second iteration of using a DAS for BOS operations along Cedar Avenue (Trunk Highway 77) in revenue service. The first iteration was in 2010 and used a prototype package developed by the Intelligent Vehicles Laboratory at the University of Minnesota. The Gen1 DAS was installed on 10 buses that operated on Cedar Avenue. The project was a success and met all of its objectives. The second iteration, Gen2, uses an updated and commercialized version of the DAS and was developed by MTS Systems Corporation. The Gen2 DAS is a GPS-based technology suite that provides lane position feedback to the driver via light emitting diode (LED) warning lights embedded in the dashboard, warning icons on a liquid crystal display (LCD) touch screen, and a vibrating seat. The Gen2 DAS has several modifications that distinguish it from the Gen1 DAS, including the elimination of the head-up display, virtual mirror, and steering feedback. Also, the Gen2 DAS uses lidar (light detection and ranging) for front collision sensing and radar for side collision sensing, whereas the Gen1 DAS used lidar for both.

The Gen2 DAS was installed on 11 Gillig buses (10 Gen1 DAS-equipped buses are being upgraded to Gen2; however, the upgrade of these vehicles was not a part of this project). The MVTA team developed a test plan and procedures to document acceptance of the DAS buses. For training purposes, led by MTS, a "Train-the-Trainer" model was used to train supervisors to implement the system. Additional documentation was created for training and reference.

An independent evaluation of the 11 Gen2 DAS-equipped buses was conducted by the National Bus Rapid Transit Institute (NBRTI) at the University of South Florida (USF) Center for Urban Transportation Research (CUTR), with assistance from Athey Creek Consultants. The revenue service demonstration took place over 12 months, starting in March 2017. MVTA supported the independent evaluation by providing input and review during evaluation planning and execution as well as access to data and staff and bus drivers for surveys and interviews, as identified in the evaluation plan developed by NBRTI and Athey Creek. Details of the evaluation are included in Appendix A.

MVTA coordinated and communicated with industry "partner" organizations to provide awareness and knowledge transfer of the project and its status. Although the project is complete, MVTA plans to continue use of the Gen2 DAS in regular service.

SECTION 1

Project Background

In 2013, the Federal Transit Administration (FTA) published a Notice of Funding Availability (NOFA) in the *Federal Register* that announced $29 million in funds for Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery Research Demonstration projects of national significance. In 2015, FTA awarded the Minnesota Valley Transit Authority (MVTA) $1.79 million under the research area of Resiliency to equip 11 buses with driver assist system (DAS) technology to assist with bus on shoulder (BOS) operations. The Twin Cities Metropolitan area has an extensive network (approximately 250 miles) of BOS operations. Bus operators use roadway shoulders at their discretion when speeds on general purpose lanes drop below 35 miles per hour. The DAS provides lane keeping information, lane departure warnings, and collision avoidance advisories to operators guiding their buses on the shoulders of the Cedar Avenue (Trunk Highway 77) corridor in congested areas.

This project was MVTA's second iteration of using DAS technology. Use of the first iteration (Generation 1 [Gen1]) began in 2010 and was a prototype developed by the Intelligent Vehicles Laboratory at the University of Minnesota. It was installed on 10 buses that operated on Cedar Avenue. The project was a success and met most of its objectives. This second iteration (Generation 2) and its upgrade use an updated and commercialized version of the DAS developed by MTS Systems Corporation, a private company that hired the original DAS engineers. The Gen2 DAS was installed on 11 additional buses that operate on Cedar Avenue. Similar to the previous iteration, the Gen2 DAS augmented BOS operations. Furthermore, MVTA's primary goal for implementing the DAS remained the same—to increase operator confidence in roadway shoulders, particularly during inclement weather, by assisting bus drivers in driving on the shoulder to bypass traffic congestion when speeds in the general purpose lanes drop below 35 mph.

The Gen2 DAS includes several modifications to the original version; chief among them is elimination of the head-up display as a form of visual feedback to the operator, the virtual mirror, and the haptic feedback of the torque-actuated steering wheel. The Gen2 DAS uses a series of light emitting diodes (LEDs) and a liquid crystal display (LCD) touch panel. Two amber colored LEDs are mounted to the bus's A-pillar (one on the left and one on the right) for lane departure warning. One red-colored LED is mounted on the operator's instrument panel for forward collision warning. The LCD touch panel is mounted to the left A-pillar and is used to provide side and forward collision warnings and to activate and deactivate the various DAS components. Another change involves the use of radar. Whereas lidar (light detection and ranging) was used in the original DAS to provide both front and side collision sensing, the Gen2 DAS uses lidar only for front collision sensing; side collision sensing is provided by radar. Despite these changes, the Gen2 DAS retains the tactile vibrating driver's seat. The original DAS was installed in model years 2005 and 2007 Gillig low floor buses. For this project, Gillig's 2015 model year buses (4505–4515) had DAS installed with a few modifications to the system to accommodate the newer model year.

The 10 buses equipped with the Gen1 DAS were upgraded later to the Gen2 DAS. The upgrade of these buses was not part of the project documented in this report. An evaluation of the Gen1 DAS may be found at https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0010.pdf. The evaluation of the Gen2 DAS is discussed later in this report.

SECTION

2

Project Description

Project Summary

This project expanded the existing fleet of Gillig DAS-equipped buses. As ridership demand increases, the need for additional buses equipped with DAS increases as well, providing support to bus operators to consistently drive on a highway shoulder to bypass traffic congestion. Customers have grown accustomed to reliable, all-weather service; the additional DAS-equipped buses will meet the demand for reliable, all-weather operation.

The demonstration project operated on two Minnesota trunk highways—Cedar Avenue (Minnesota Trunk Highway 77 [MN-77]) and Crosstown Commons (Minnesota Trunk Highway 62 [MN-62]). The buses that support the express service between downtown Minneapolis and the southern suburbs generally travel the Cedar Avenue–Crosstown–I-35W trajectory.

An independent evaluation was conducted by the National Bus Rapid Transit Institute (NBRTI) of the University of South Florida (USF) Center for Urban Transportation Research (CUTR), with assistance from Athey Creek Consultants. MVTA supported the independent evaluation by providing input and review during evaluation planning and execution as well as access to data from several sources and staff and bus drivers for surveys and interviews, as identified in the evaluation plan developed by NBRTI and Athey Creek. NBRTI/Athey Creek developed, organized, and conducted surveys and interviews of bus operators. The evaluation examined the Gen2 DAS according to five core areas—route system performance, customer satisfaction, bus operator satisfaction, maintenance, and safety.

System Components and Design

The DAS provides three primary capabilities for transit applications—lane keeping, forward-collision awareness, and side-collision awareness. The system provides assistance only; the driver is always responsible for control of the vehicle. The DAS is made up of two sub-systems—an infrastructure-based subsystem and a vehicle-based subsystem. The infrastructure-based subsystem consists of a GPS base station network, including Differential GPS (DGPS) corrections. The vehicle-based subsystem includes several in-vehicle technological system components, including an A-Kit vehicle computer processor, a vehicle system interface, system sensors, and a graphical user interface installed on 2015 model year Gillig buses (4505–4515). The vehicle-based subsystem components are discussed below.

A-Kit Computer Assembly (RTK GPS)

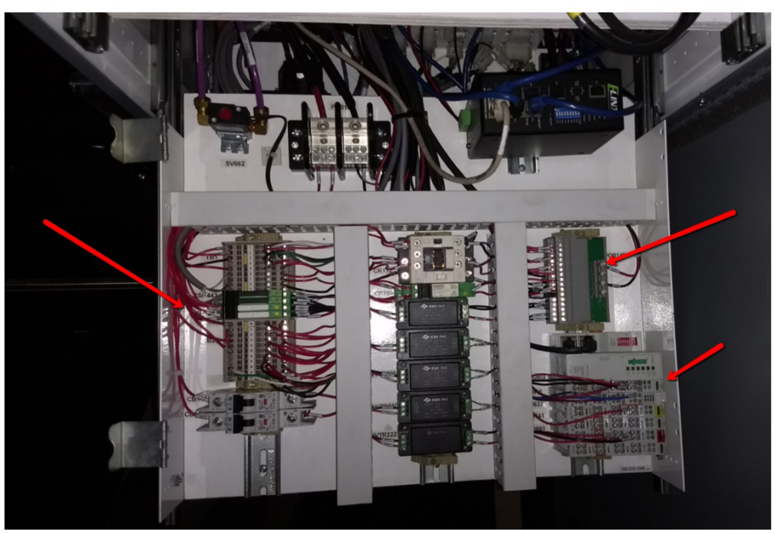
The in-vehicle computer processor consists of an A-Kit, which includes and integrated Real-Time Kinematic Global Positioning System (RTK GPS). The A-Kit provides a robust, compact positioning and computational package. The integrated system consumes much less space in the equipment cabinet compared to the GenI DAS.

Figure 2-1
A-Kit Computer Assembly

Vehicle Interface

The vehicle interface system is a hardware module that connects the in-vehicle computer processor with the brake and left-turn, and right-turn signals. The vehicle interface also connects to the vehicle's ignition signal to sense when the bus is turned on/off.

Figure 2-2
Vehicle Interface System



The Generation 1 DAS vehicle system interface was a custom design from the University of Minnesota. The vehicle system interface for this project is based on commercial off-the-shelf (COTS) hardware, which provides improved system reliability and support.

System Sensors

The DAS system includes several system sensors for collision awareness and lane keeping assistance while operating within designated shoulders.

Side Radar Sensors

Lidar side collision awareness sensors were replaced by side radar sensors. With the Gen1 DAS, lidar was used for both forward and side collision awareness sensing. In practice, the side-looking lidar sensors were susceptible to damage. Recently introduced side-looking radar sensors have a much lower profile and are less susceptible to damage. As such, radar technology replaced lidar technology for side-looking collision awareness sensors.

Figure 2-3

Side-Looking Radar Component

Figure 2-4

Side-Looking Radar Installed

Light Detection and Ranging (LIDAR) Sensor

Sensing for forward-collision awareness is provided by a front bumper-mounted multiplane scanning lidar sensor. The lidar scans out to 200m to detect vehicles and other obstacles in front of the bus.

Figure 2-5

Front Lidar Sensor

Dimensional (2-D) Velocity Sensor

The 2D speed sensor is an optical device that accurately measures a vehicle's ground speed in two directions—longitudinal (forward/backward) and lateral (left/right). This sensor is mounted under the bus forward of the front axle looking down at the road. The 2D speed sensor computes vehicle velocity, which is used for GPS augmentation.

Figure 2-6
2D Sensor Light

Inertial Measurement Unit

The Inertial Measurement Unit (IMU), which is also used for GPS augmentation, measures accelerations and rotation rates of the bus in all three directions.

Figure 2-7
Inertial Measurement Unit

GPS Position Augmentation

Measurements from the 2D speed sensor, along with acceleration and rotation rate measurements from an IMU are used to determine the position of the bus when GPS is not available. When the bus travels under a bridge and loses its GPS position, this position augmentation calculates the bus position until the GPS position is reacquired. For the short time when the GPS signal is lost (<15 seconds), the computed position is accurate enough to provide lane departure warnings to the operator without interruption.

Ambient Light Sensor

The ambient light sensor is used to automatically adjust the intensity of the dash-mounted LED feedback to changing lighting conditions.

Driver-Vehicle Interface

The DAS driver-vehicle interface (DVI) consists of the following components and feedback mechanisms:

- Driver user interface screen
- Lane departure warning indicators
- Lane departure tactile seat
- Forward collision awareness indicators (LED and driver user interface screen)
- Side collision awareness indicators (driver user interface screen)

The locations of these components and feedback mechanisms within the driver area are shown is Figure 2-8 and discussed in the following sections.

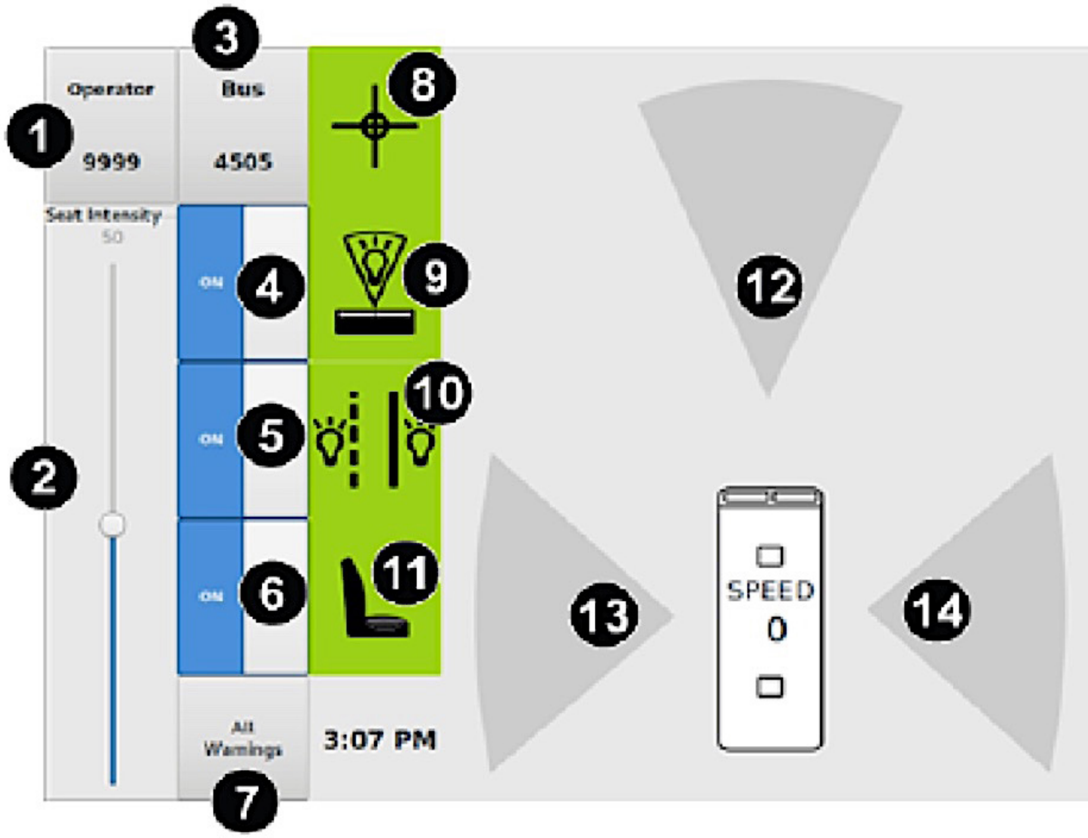
1. **Driver User Interface Screen (touch screen)**
2. **Lane Departure Warning LED (one on each side of dash)**
3. **Lane Departure Warning Tactile Seat**
4. **Forward Collision Awareness LED**
5. **DAS Power Button (green button, not in view)**

Figure 2-8

DAS DVI Component and Feedback Mechanism Locations

Driver User Interface Screen

The driver user interface LCD screen provides system configuration and forward and side collision awareness capabilities, allowing the operator to turn all driver feedback off or to select individual feedback mechanisms to turn off. It also allows the operator to adjust the sensitivity level of seat vibrations. The screen presents a plan view of the bus as it operates on either a shoulder or traffic lane and the presence and location of obstacles in close proximity to the front and both sides of the bus (forward and side collision awareness). Figure 2-9 shows the driver user interface screen in its typical configuration. From the touch screen, the driver can address the functions listed in the table shown in Figure 2-9.



1. **Operator ID – press to log out of system**
2. **Seat Intensity Level – in percent-adjustable side bar (default 50%)**
3. **Bus ID – press to show Detailed Sensor Status screen**
4. **Enable/Disable – pressing turns on/off Forward Collision Awareness LED**
5. **Enable/Disable – pressing turns on/off Lane Departure Warning LEDs**
6. **Enable/Disable – pressing turns on/off Seat Lane Departure Warning**
7. **Enable/Disable – pressing turns on/off all feedback**
8. **Positioning Accuracy Status icon**
9. **Current state of Forward Collision Awareness feedback**
10. **Current state of Lane Departure Warning LED feedback**
11. **Current state of seat feedback**
12. **Forward Collision Awareness feedback area**
13. **Left Side Collision Awareness feedback area**
14. **Right Side Collision Awareness feedback area**

Figure 2-9

Main Driver User Interface Screen Labels

Lane Departure Warning

Lane-departure warnings use a comparison of vehicle position, speed, and heading to the map database to determine when alerts and warnings should be issued. The warnings are provided via a multimodal human-machine interface (HMI) through two modes—l) graphically, using two dash-mounted LEDs that illuminate respectfully in the event of a lane departure, and 2) tactically, through a seat equipped with actuators that vibrate on the side of the seat to which the lane is being departed.

Lane-departure warnings come in stages. When the vehicle-trajectory estimator determines that the likelihood of a lane departure is sufficiently high, a lane departure warning is issued to the driver through the appropriate LED. Should the driver continue towards the lane boundary, a seat-based warning is activated; the side of the seat corresponding to the side of the lane departure vibrates, warning the driver. This multistage approach captures the driver's attention, but if he/she responds in a timely fashion, annoyance is limited.

Figure 2-10

Lane Departure Warning LEDs

Forward Collison Awareness

The forward collision awareness feature is used to warn the operator of an impending forward collision event. It uses an LED indicator mounted on the instrument panel directly in front of the bus driver to indicate a possible collision of the front of the bus with another object if the feedback mode is enabled on the driver user interface and an obstacle is present in front of the bus. Further, the LED uses a combination of frequency and intensity to cue a driver as to the level of threat posed by the obstacle ahead.

Figure 2-11

Forward Collison Awareness LED

Similarly, forward collision alerts are provided via an indicator on the driver user interface screen, as show in Figure 2-12.

Figure 2-12

Forward Collision Awareness Indication on Driver User Interface Screen

Side Collision Awareness

The side collision awareness feature is used to warn the operator of side collision events. Side-looking information is of particular value when negotiating through entrance and exit ramps where conflicts arise with vehicles crossing the shoulder area while transitioning between the normal lane of traffic and the ramp. Alerts are provided via an indicator on the driver user interface screen, as illustrated in Figures 2-13 and 2-14.

Figure 2-13

Side Collision Awareness Indication on Driver User Interface Screen – Potential Left-Side Collision

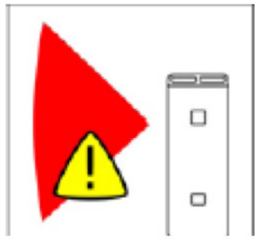
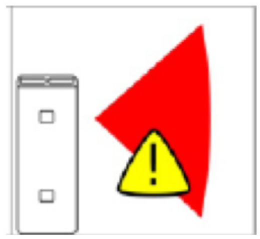


Figure 2-14

Side Collision Awareness Indication on Driver User Interface Screen – Potential Right-Side Collision



Acceptance Testing

Overview

The MVTA project team developed a test plan and test procedures to facilitate the acceptance of the DAS system installed on the 11 MVTA buses.

The test plan consisted of three similar but separate tests:

- Functionality test – Verify all components prior to performing test drives.
- Test Drive 1 – Collect data necessary to determine mounting angle of 2D-velocity sensor used to augment the RTK GPS when GPS signals are blocked by overpasses and overhead signs. Data collected in Test Drive 1 was post-processed, and the results were applied to the DAS on that bus before Test Drive 2 occurred.
- Test Drive 2 – Verify that 2D velocity sensor setup and bias adjustment are correct and system is accurate.

Each test required two personnel—one to drive the bus or act as a target and the other to record the response of the system. Tests were performed and completed on an individual bus before moving on to the next bus. When a deficiency was found during testing of a DAS-equipped bus, it was addressed by the DAS installation team, and the portion of the test that originally identified the deficiency was repeated to ensure that the deficiency was completely addressed.

Description of Tests

Functionality Test

The functionality test was performed on a bus after the DAS was installed but before it was taken outside the bus garage. This test confirmed that all system signals, inputs, and outputs were operating as specified.

Test Drive 1

Test Drive 1 was the first on-road test of the DAS. The test provided confirmation that:

- Interfaces to the driver operated as designed.
- Warnings and advisories worked as designed.
- Data files were written properly to both on-board USB memory and MVTA server.
- DAS computer powered down after writing its data to the MVTA server, and remaining DAS components powered down when the "delay on break" timer on the bus turned the remaining bus components off.

Also associated with Test Drive 1 was the collection of RTK GPS position and heading data, IMU data, and 2D-velocity sensor data required to determine the mounting angle bias associated with the 2D-velocity sensor.

Test Drive 2

Test Drive 2 represented the final validation of the performance of the DAS on its intended route, specifically:

- Any anomalies found during Test Drive 1 had to be addressed before Test Drive 2 to confirm that the problems identified in Test Drive 1 were addressed. If not addressed satisfactorily, they must be tested again until proven to be corrected.
- Test Drive 2 also ensured that the bias adjustment made to the 2D-velocity sensor was correct, allowing the DAS to "ride through" RTK GPS outages. If the results of Test Drive 2 were false lane departure events:
  - Data collection portion of Test Drive 1 was repeated.
  - Data processing associated with determining 2D-velocity sensor bias angle was repeated.
  - Validation of RTK GPS augmentation system set forth in Test Drive 2 was repeated until no false lane departure warnings were issued.

Test Results

Installation occurred over a period of two months, as individual bus installations were completed. No software errors were encountered during the pre-test checks or road testing. Software was loaded, and parameters specific to each bus were entered during installation. Installation of hardware was dependent on the physical layout of each bus, conforming to standard locations and dimensions. Minor adjustments were made as necessary for physical variation when attaching components to the outside of the bus. Interior components were uniformly installed to achieve the same look and feel for all drivers.

Functionality testing prior to test drives uncovered three hardware abnormalities that were corrected prior to on-road testing. One abnormality occurred during road testing, resulting in faulty GPS indication, which was traced to a faulty ribbon cable in the IDAN computer. The cable was swapped out with a spare and the test repeated. GPS indications were correct after the cable replacement, and the 2D velocity sensor calculations were completed.

A summary of the test results for each DAS-equipped bus is shown in Table 2-1.

Table 2-1

Summary of DAS Acceptance Test Results

Bus	Date	Abnormalities	Actions	Retest Required	Pass/ Fail
4505	3/1/17	None	None	None	Pass
4506	3/1/17	None	None	None	Pass
4507	3/2/17	GPS antenna backward	Reinstalled	Fixed in pretest	Pass
4508	3/2/17	GPS antenna backward	Reinstalled	Fixed in pretest	Pass
4509	3/1/17	None	None	None	Pass
4510	2/1/17	None	None	None	Pass
4511	2/1/17	None	None	None	Pass
4512	2/17/17	Steering feedback hums, message says ok during E-stop	Inspect all electrical/ mechanical connections, repeat test	E-stop behaves normally on retest	Pass
4513	2/17/17	None	None	None	Pass
4514	3/3/17	None	None	None	Pass
4515	3/3/17	Heading GPS not reporting position	Ribbon cable unplugged and replaced from IDAN computer	GPS performed normally during second run	Pass

Driver Training

Training for the project consisted of several forms of training methods and devices. The first consisted of the “Train-the-Trainer” model, with MTS working closely with MVTA and Schmitty and Sons Transit (SST)[1] training supervisors to implement the system. After the training supervisors where trained using this model, supervisors worked to train individual drivers.

Field Operational Demonstration

The operational demonstration included all 11 DAS vehicles in revenue service for a one-year period, from March 2017 to March 2018. The operational demonstration included a one-month period (February 2018) when the DAS was set to passive mode to compare bus operator use of the shoulder with and without the DAS.

Specific routes on Cedar Avenue that had the DAS-equipped vehicles were MVTA routes 470, 472, 475, 476, 477, 478, and 479. These routes operate on some portion of Cedar Avenue during AM and PM peak periods northbound and southbound (see Table 2-2). Although these routes operate beyond Cedar Avenue, the DAS was used only on Cedar Avenue because it was the only portion of the routes that had been mapped. The demonstration corridor was between the Apple Valley Transit Station in the south and the Crosstown Highway (MN-62) in the north, a distance of approximately 12 miles.

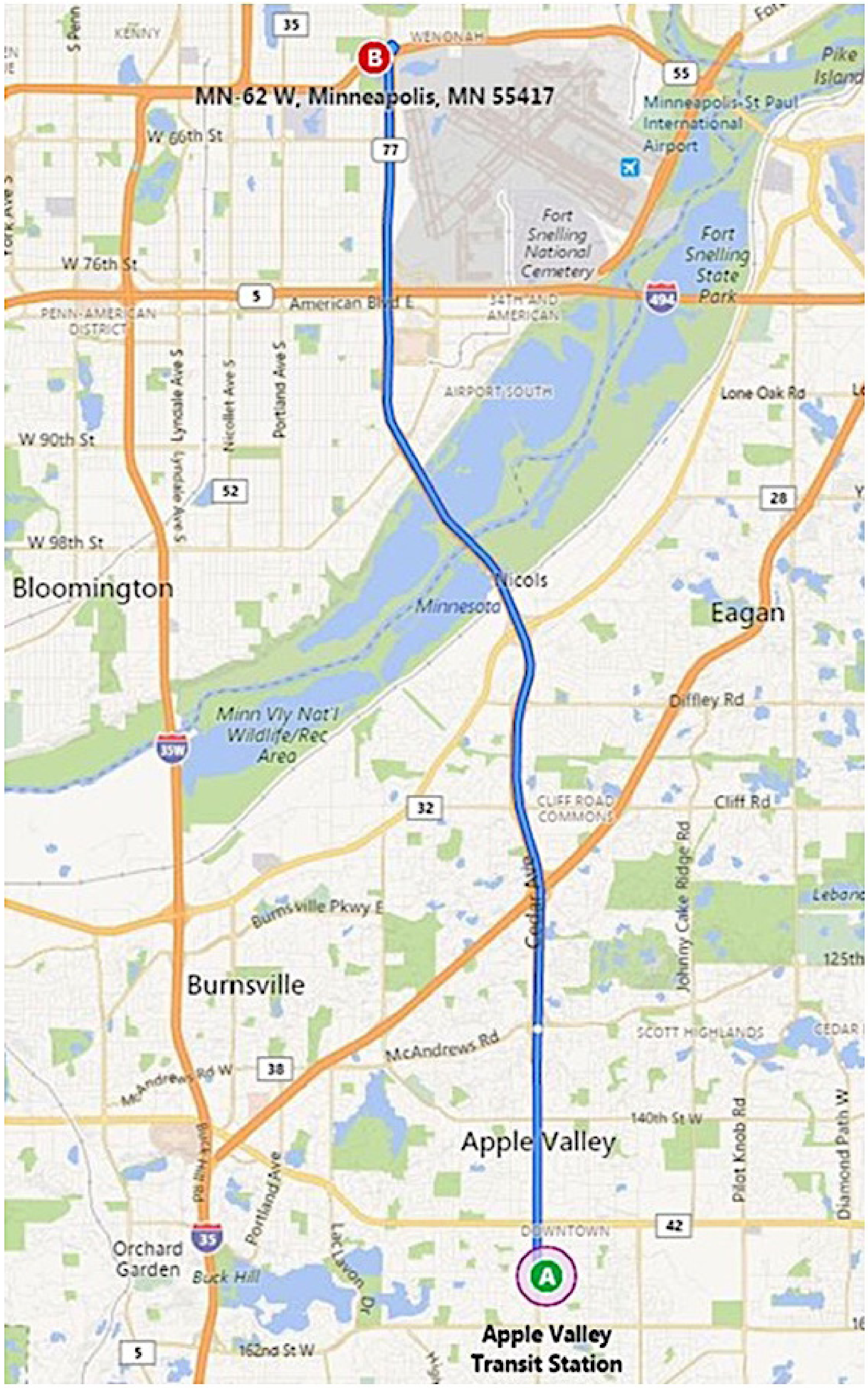
Table 2-2
Peak Periods

Peak Period	Start/End Times	Direction
AM Peak	6:00–9:00 AM	Northbound
PM Peak	3:00–7:00 PM	Southbound

[1]Schmitty and Sons Transit is currently an MVTA contract provider of bus operators, mechanics, and road supervisors.

Figure 2-15

Demonstration Corridor



Independent Evaluation

MVTA supported the operational demonstration by providing input and review during the planning and execution phases of this project. MVTA coordinated with NBRTI/Athey Creek, the independent evaluators, to assist in developing an evaluation plan and provided NBRTI with baseline and post-treatment quantitative and qualitative data, as specified in the plan. MVTA supported NBRTI/Athey Creek by providing access to MVTA staff and bus operators for surveys and interviews, as identified in the plan, and also assisted with organizing and conducting surveys, interviews, and/or focus groups of bus riders. Athey Creek led the onsite surveys and focus groups and coordinated some of the data collection.

Examples of data collected by Athey Creek and provided to NBRTI included the following:

- DAS processed data (e.g., vehicle location and speed)
- Collision data
- Maintenance data
- Traffic data
- Weather data
- Automated Vehicle Location (AVL) data
- Bus operator satisfaction data
- Customer satisfaction data

SECTION

3

Summary of Evaluation Results

NBRTI and Athey Creek conducted the independent evaluation and produced an evaluation plan that identified the evaluation approach (e.g., with/without comparison, before/after comparison), evaluation goals and hypotheses, performance measures, data elements, data sources/instruments, data quantities, collection timeframes, analysis methods, and an evaluation schedule. The evaluation included the following analysis areas:

- Route System Performance
- Customer Satisfaction
- Bus Operator Satisfaction
- Maintenance
- Safety

NBRTI/Athey Creek analyzed data collected from the operational demonstration and documented the findings. A summary of the methodologies used to evaluate the analysis areas and high-level results are discussed in the next section. The full, detailed results are included in Appendix A.

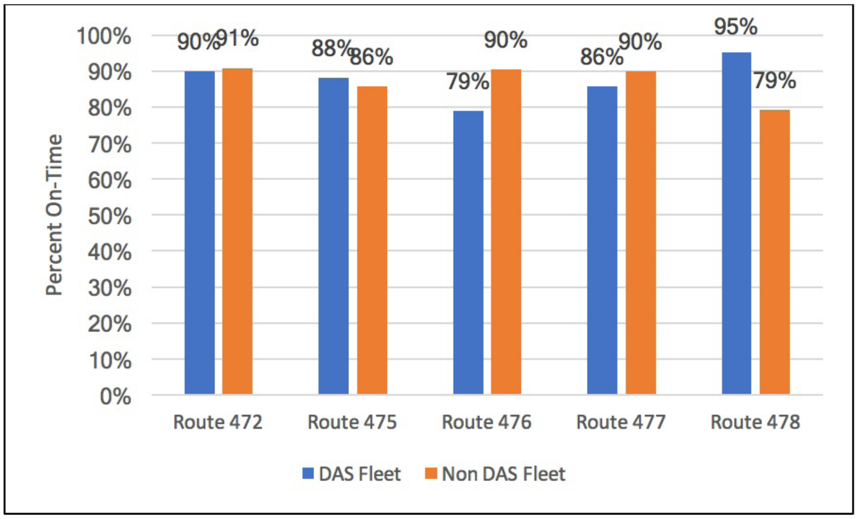
Route System Performance

Part of the evaluation examined DAS's impact on route performance and included measures such as bus travel times, on-time performance, and percentage of shoulder used. It included analysis at both the macro- and micro-levels (i.e., route-level and bus-level). At the macro-level, the analysis compared route-level performance from the baseline year to the implementation year (one-year demonstration). At the micro-level, the analysis compared the performance of the DAS-equipped buses to the non-DAS buses of the same route during the implementation year.

On-time performance was based on arrival time at the end of the route. Because MVTA does not have an established on-time performance standard, a five-minute on-time performance standard was adopted for the evaluation. On-time performance was measured based on bus arrival time at the end of the line because all DAS-designated routes are commuter express routes. A bus was considered on-time as long as it arrived within five minutes of the scheduled arrival time. The results for AM and PM on-time performance are shown in Figures 3-1 and 3-2. Results for bus travel times and percentage of shoulder used can be found in Appendix A.

Figure 3-1

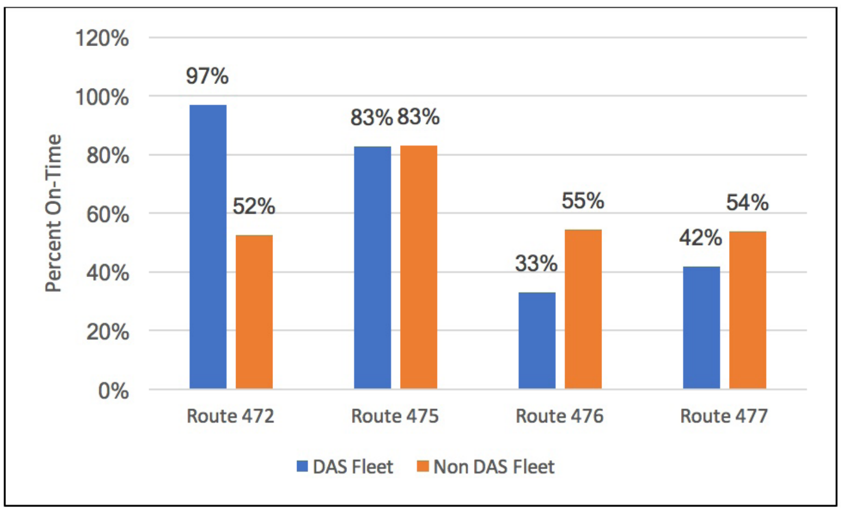
Average On-Time Performance, AM NB Peak Period



Fleet	Average AM OTP
DAS	88%
Non DAS	87%

Figure 3-2

Average On-Time Performance, PM SB Peak Period



Fleet	Average AM OTP
DAS	64%
Non DAS	61%

Customer Satisfaction

A common customer complaint that MVTA receives is that bus operators do not use the shoulder lane to bypass congestion as frequently as they could. The evaluation compared the number of complaints related to shoulder lane usage on the DAS-designated routes from the baseline year to the implementation year. The hypothesis was that the DAS will help to lower the number of complaints.

During the baseline year, there were 12 customer complaints related to shoulder lane usage; 8 occurred in June 2015, and most were due to detours caused by rain. During the implementation year, only 4 customer complaints related to shoulder usage were received, and none originated from passengers on DAS-equipped buses.

Table 3-1

Customer Complaints Related to Shoulder Usage, Baseline Year

Route	Baseline Year												
	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Total
472	0	0	0	1	0	0	0	0	0	0	0	0	1
475	0	0	0	0	1	0	0	0	0	0	0	0	1
476	0	0	0	0	0	0	0	0	0	0	0	0	0
477	0	0	0	7	2	0	0	1	0	0	0	0	10
478	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Complaints	*0*	*0*	*0*	*8*	*3*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*12*

Table 3-2

Customer Complaints Related to Shoulder Usage, Implementation Year

Route	Implementation Year												
	Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2017	Aug 2017	Sep 2017	Oct 2017	Nov 2017	Dec 2017	Jan 2018	Feb 2018	Total
472	0	0	0	0	0	0	0	0	0	0	0	0	0
475	0	0	0	0	0	0	0	0	0	0	0	0	0
476	0	0	0	0	0	0	0	0	0	0	1	0	1
477	0	0	0	1	1	0	0	0	0	0	0	0	2
478	0	0	0	1	0	0	0	0	0	0	0	0	1
Total Complaints	*0*	*0*	*0*	*2*	*1*	*0*	*0*	*0*	*0*	*0*	*1*	*0*	*4*

Bus Operator Satisfaction

Athey Creek Consultants administered two surveys to DAS-trained operators—a baseline survey before the DAS was implemented, and a follow-up survey during the demonstration period when the DAS was implemented.

The baseline ("before") survey was conducted in April 2016, immediately prior to DAS training, and served as a benchmark for driver level of confidence driving in the shoulder. The follow-up ("after") survey was completed in February 2018, the last month of the demonstration, and revisited the question of confidence in the shoulder and solicited operator feedback on the Gen2 DAS components.

In both the before and after surveys, bus operators were asked to rate on a scale of 0 to 3 how confident they feel driving in the shoulder, how stressful they find driving in the shoulder, and how safe they feel it is to drive in the shoulder. Table 3-3 shows the rating scale that was used, and Table 3-4 displays the results. The mean score for the stated level of confidence improved from 2.41 to 2.53 (from "Confident" to "Very confident"). For additional results from the bus operator satisfaction survey, refer to Appendix A.

Table 3-3

Rating Scale

Rating Level	Range
Not at all confident/stressful/safe	0.00–0.25
Somewhat confident/stressful/safe	0.26–1.50
Confident/stressful/safe	1.51–2.50
Very confident/stressful/safe	2.51–3.00

Table 3-4

On a scale of 0 to 3, how confident do you feel operating in the shoulder?

	Mean	Rating
"Before" survey	2.41	Confident
"After" survey	2.53	Very confident

0 = Not at all confident; 1 = Somewhat confident;
2 = Confident; 3 = Very confident

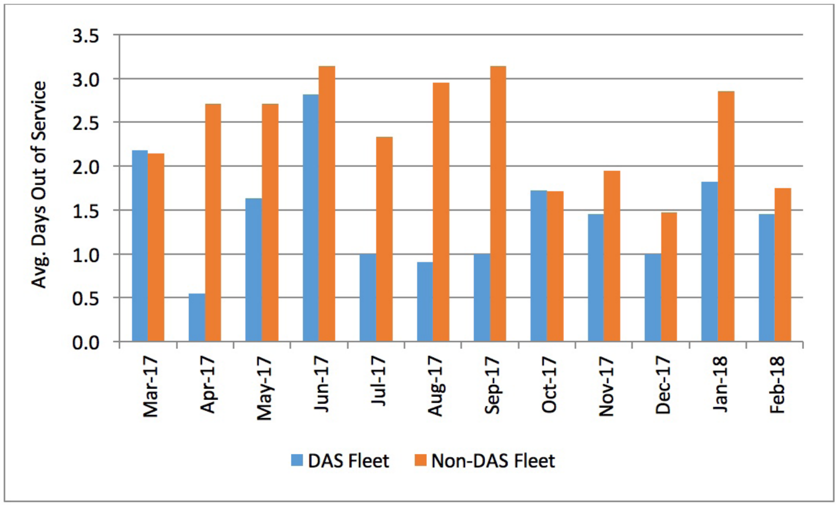
Maintenance

In the first iteration of the DAS (Gen1), the Intelligent Vehicles Lab at the University of Minnesota was primarily responsible for the maintenance of the DAS. Because the Gen2 DAS uses off-the-shelf hardware, MVTA was responsible for the maintenance this time around for the DAS. MVTA tracked the number of days, if any, that the Gen2 DAS-equipped buses were not available for service due to needed repairs.

The evaluation compared the amount of down time due to repairs for these buses compared to MVTA buses not equipped with DAS (non-DAS buses). The DAS fleet had better maintenance performance than the non-DAS fleet—a bus from the DAS fleet was out of service 1.5 days per month, on average, compared to 2.4 days per month for a non-DAS bus. The results shown in Figure 3-3.

Figure 3-3

Maintenance Performance of DAS Fleet vs. Non-DAS Fleet



Fleet	Average Days per Month Out of Service
DAS	1.5
Non-DAS	2.4

The evaluation also analyzed the mean time between failures (MTBF) for the DAS-equipped buses. The best month was November 2017, with no reported failures. The next best month was June 2017, when the MTBF was 29,436 miles. The one-year average MTBF was 6,470 miles. The results are shown in Figure 3-4.

Based on the results of the data analysis, the DAS buses had better maintenance performance than the non-DAS buses. This is because the DAS buses are newer than the non-DAS buses.

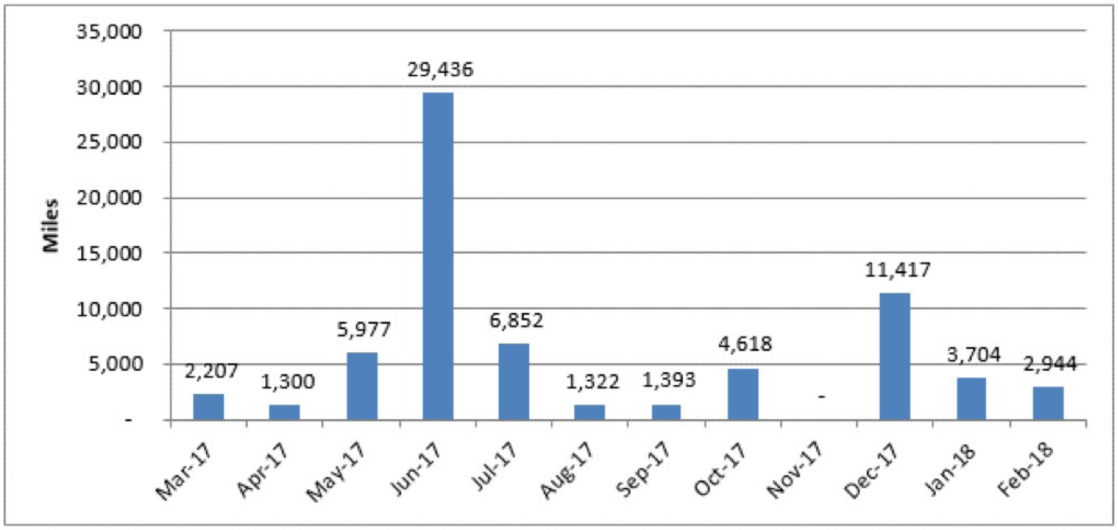


Figure 3-4

Mean Time between Failures (MTBF) for DAS System

Safety

The evaluation compared all accidents in the shoulder (if any) from the baseline year to the implementation year for the routes on Cedar Avenue that were selected to receive the DAS. The evaluation also compared the number of shoulder accidents for the DAS-equipped buses to the non-DAS buses of the same route during the implementation year. For added context, the evaluation also looked at the number of shoulder accidents system-wide in MVTA from baseline to implementation year. There were zero accidents in the shoulder during the baseline year and the implementation year. This applies not just to the DAS buses but to the entire MVTA fleet.

SECTION 4

Conclusion

Implementation of DAS by the MVTA was successful. In total, 11 Gillig buses were equipped with technology improvements to reduce capital. Technology improvements with the deployment of radar technology over lidar allowed for cost reductions as a whole.

Technology and human-machine interface improvements from the Gen1 DAS to the GEN2 DAS included the following:

- Lidar technology was replaced with less expensive radar technology for side collision sensing and avoidance.
- Head-up display was replaced with an LCD display mounted on the bus A-pillar. The LCD presents a plan view of the bus as it operates on either a shoulder or traffic lane and the presence and location of obstacles in close proximity to the front and both sides of the bus. In addition, forward collision warning is provided by an LED array located on the instrument panel directly in front of the bus driver and uses a combination of frequency and intensity to cue a driver as to the level of threat posed by the obstacle ahead.
- Virtual mirror was removed.
- Steering feedback component was eliminated.

The DAS continues to use of a vibrating driver's seat; when a lane departure event is detected, the driver's seat vibrates on the side of the lane departure. The natural human response is to move away from the stimulus, which results in the driver moving the bus to its proper position within the lane or shoulder.

Lessons learned during this project related to this type of technology include that it requires additional levels of end-user engagement during the system design process. Greater input from transit managers to vehicle operators could have increased bus operator satisfaction. For example, common complaints by operators were that DAS-equipped vehicles did not necessarily make driving easier or safer for the operator; it was more of an impediment because the feedback system was overwhelming.

Other feedback included the following:

- Application/scope was too limited—shoulder use was limited along the designated stretch of roadway. The system may be more effective if it were expanded.
- Snow build-up in the shoulders (unplowed shoulders) impeded shoulder running operations even with the DAS.
- From a safety perspective, the lane departure and collision avoidance features would have been more useful if the functionality was available within the general-purpose lanes.

The independent evaluation of the Gen2 DAS yielded mixed results. The independent evaluation yielded positive results in regards to customer satisfaction and maintenance, a mix of positive and negative results in regards to safety, and mix of neutral to negative results in regards to route system performance and bus operator satisfaction.

The evaluation findings, while disappointing in some areas, should not be judged as a failure. The automotive industry has invested billions of dollars in automation research to learn what works and what does not work related to vehicle automation. The transit industry lags behind the automotive industry in vehicle automation research. This independent evaluation was able to measure bus operator use and acceptance of transit automation technology; therefore, any information that can be learned about what does and does not work is valuable. Although the project is complete, MVTA plans to continue use of the Gen2 DAS in regular service.

Appendix A contains the methodology and results of the independent evaluation of the Gen2 DAS used by MVTA for bus shoulder operations. The independent evaluation was conducted from March 2017 to March 2018 and covered five core areas: route system performance, customer satisfaction, bus operator satisfaction, maintenance, and safety.

APPENDIX

A

DAS Technology to Support Bus-on-Shoulder Operations Evaluation Report

Driver Assist System Technology to Support Bus-on-Shoulder Operations

Evaluation Report

October 2018

Prepared by

National Bus Rapid Transit Institute (NBRTI) at the
Center for Urban Transportation Research (CUTR)
University of South Florida (USF)

Athey Creek Consultants

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Abstract

This report summarizes an evaluation of the Generation 2 (Gen2) Driver Assist System (DAS) used by the Minnesota Valley Transit Authority (MVTA) for bus shoulder operations and provides warnings for lane departure, side collision, and forward collision. The Gen2 DAS is a GPS-based technology suite that provides lane position feedback to the driver via LED warning lights embedded in the dashboard, warning icons on a LCD touch screen, and a vibrating seat. The Gen2 DAS has several modifications that distinguish it from the Generation 1 (Gen1) DAS, including the elimination of the head-up display and actuated steering. Also, whereas lidar was used in the Gen1 DAS to provide both front and side collision sensing, the Gen2 DAS uses lidar for the front collision sensing and radar for the side collision sensing. MVTA's primary goal for the Gen2 DAS remained the same as for the Gen—to enhance operator confidence during bus shoulder operations, especially during adverse weather. MVTA bus operators are allowed to drive in the highway shoulder to bypass traffic congestion when speeds in the general purpose lanes drop below 35 miles per hour. Secondary goals included reduced travel times, increased reliability, safety, and customer satisfaction.

Executive Summary

In March 2017, the Minnesota Valley Transit Authority (MVTA) began using its second iteration of a Driver Assist System (DAS) for bus on shoulder operations along Cedar Avenue (Trunk Highway 77 [MN-77]), a north-south highway that runs from Apple Valley to Minneapolis. Use of the first iteration began in 2010 and was a prototype developed by the Intelligent Vehicles Laboratory at the University of Minnesota. It was installed on 10 buses that operated on Cedar Avenue. The project was a success and met most of its objectives. The second iteration and upgrade used an updated and commercialized version of the DAS developed by MTS Systems Corporation. The Generation 2 (Gen2) DAS was installed on 11 buses that operate on Cedar Avenue. MVTA's primary goal for the Gen2 DAS remains the same as for Gen1—to increase operator confidence in the shoulders, particularly during inclement weather. MVTA bus operators are allowed to drive in the highway shoulder to bypass traffic congestion when speeds in the general purpose lanes drop below 35 miles per hour. Secondary goals included reduced travel times, increased reliability, safety, and customer satisfaction.

The National Bus Rapid Transit Institute (NBRTI) at the Center for Urban Transportation Research (CUTR) the University of South Florida evaluated the Gen1 DAS. The findings from that evaluation were published in a December 2011 report, FTA Report No. 0010, *Cedar Avenue Driver Assist System Evaluation Report*. NBRTI was selected by MVTA to conduct the Gen2 DAS evaluation as well. There are similarities and differences between the Gen1 and Gen2 evaluations. Similar to the Gen1 evaluation, the Gen2 evaluation looked at route system performance, customer satisfaction, bus operator satisfaction, maintenance, and safety. Unlike the Gen1 evaluation, the Gen2 evaluation did not revisit technology performance (i.e., how well the DAS helps the bus to stay centered in the lane); it is stipulated that the DAS technology works as designed. Another difference is the time length of the evaluation; whereas the Gen1 evaluation was limited to two months of data collection, the Gen2 evaluation looked at bus shoulder operations over the course of an entire year. A final difference is that the Gen2 evaluation included an analysis of traffic speed data. The purpose was not to attribute causation (i.e., that the DAS contributed to changes in traffic speeds) but to provide context. Because the bus operators can drive in the shoulder only when speeds in the general purpose lanes fall below 35 miles per hour, it was important to determine how often this happens.

The evaluation yielded positive results in regards to customer satisfaction and maintenance, a mix of positive and negative results related to safety, and a mix of neutral to negative results related to route system performance and bus operator satisfaction. The number of customer complaints regarding shoulder usage dropped from 12 in the baseline year to 4 in the implementation year, and none of the complaints originated from passengers on DAS-equipped buses. The DAS buses had a better maintenance record than the non-DAS buses, which is likely due to the fact that the DAS buses are newer. There were zero accidents in the shoulder system-wide in both the baseline and implementation years; however, there was a potentially dangerous safety incident early in the evaluation when the steering locked up on a DAS bus.[1] For route system performance, the DAS buses had slightly better on-time performance at the end of the routes. However, the non-DAS buses had better travel times inside the DAS test corridor. The DAS did not lead to increased shoulder usage; the percentage distance

[1] This incident is described in more detail in Section 8, Safety. Because of the incident, the steering actuator was subsequently removed from all of the DAS buses.

traveled in the shoulder by the DAS-trained bus operators remained steady at around 5% and was correlated to the percentage of time that speeds in the general purpose lanes dropped below 35 miles per hour. For bus operator satisfaction, the DAS does not appear to have positively impacted operator confidence. Although the mean score for confidence improved from 2.41 (“Confident”) in the “before” survey to 2.53 (“Very confident”) in the “after” survey, 82.4% of bus operators said that their level of confidence while driving in the shoulder was the same with or without a DAS-equipped bus. Only 41.2% of bus operators agreed or strongly agreed that the DAS was helpful.

Section 1 – Driver Assist System (DAS) Project

Background

In 2013, the Federal Transit Administration (FTA) published a Notice of Funding Availability (NOFA) in the *Federal Register* that announced $29 million in funds for Innovative Safety, Resiliency, and All-Hazards Emergency Response and Recovery research demonstration projects of national significance. In 2015, FTA awarded the Minnesota Valley Transit Authority (MVTA) $1.79 million under the research area of Resiliency to equip 11 buses with driver assist system (DAS) technology to assist with bus on shoulder (BOS) operations. The Twin Cities Metropolitan area has an extensive network (approximately 250 miles) of BOS operations. Bus operators use the shoulders at their discretion when speeds in the general purpose lanes drop below 35 miles per hour. The DAS provides lane keeping information, lane departure warnings, and collision avoidance advisories to operators guiding their buses in the shoulders of the Cedar Avenue (Trunk Highway 77 [MN-77] corridor) in congested areas.

This project is MVTA's second iteration of using DAS technology. Use of the first iteration began in 2010 and was a prototype developed by the Intelligent Vehicles Laboratory at the University of Minnesota. It was installed on 10 buses that operated on Cedar Avenue. The project was a success and met most of its objectives. This second iteration and upgrade uses an updated and commercialized version of the DAS developed by MTS Systems Corporation. The Generation 2 (Gen2) DAS is installed on 11 additional buses that operate on Cedar Avenue. Similar to the Generation 1 (Gen1) DAS, the Gen2 DAS is used to augment BOS operations. MVTA's primary goal for implementing the DAS remains the same—to increase operator confidence in using roadway shoulders, particularly during inclement weather.

DAS Components

The Gen2 DAS has three applications—lane keeping, forward collision awareness, and side collision awareness. It provides only driver assistance; the bus operator is in control of the vehicle at all times. According to SAE International, this is considered Level 0 Automation because the driver is still performing all tasks[2] (see Figure 1-1).

The Gen2 DAS has several modifications to the Gen1 version. Chief among them are elimination of both the head-up display as a form of visual feedback and the torque-actuated steering wheel as a form of haptic feedback. Torque-actuated steering was included in the original design of the Gen2 DAS. However, in March 2017, a DAS bus (No. 4512) incident occurred in which the steering locked up on the bus operator and caused a potentially unsafe situation with passengers on board (no one was injured). MVTA made the decision to disable the actuated steering feedback for the remainder of the evaluation. This incident is described in more detail in Section 8 (Safety).

[2] SAE Standard J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

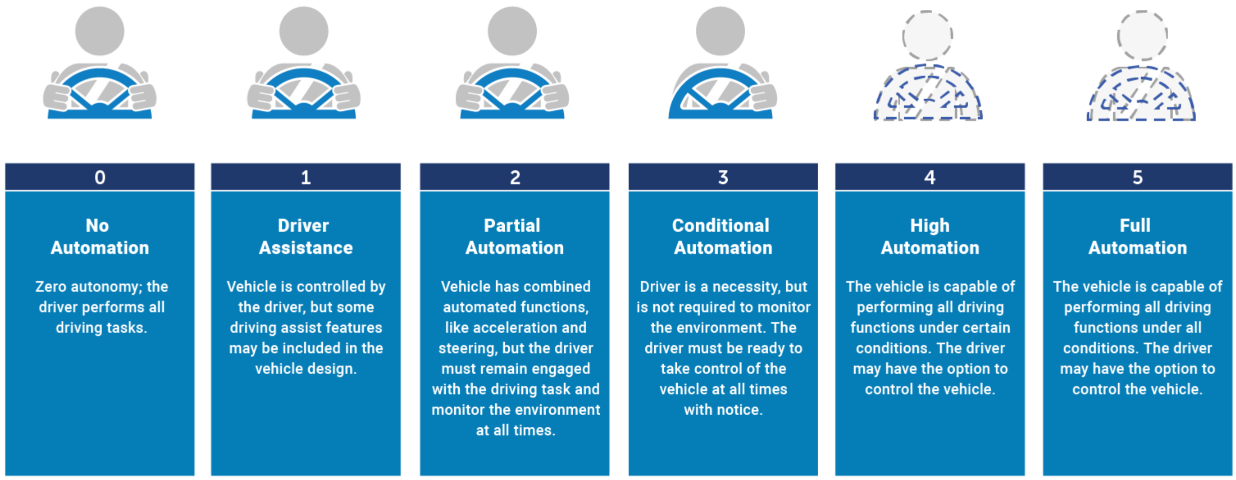


Figure 1-1 Society of Automotive Engineers (SAE) Levels of Automation

The Gen2 DAS has two modes of feedback to the bus operator—visual and tactile. Visual feedback is provided through a combination of light emitting diodes (LEDs) located on the bus operator's dashboard and a liquid crystal display (LCD) touch screen on the bus's A-pillar. Tactile feedback is provided by vibrators located inside the operator's seat cushion. Another difference between the Gen2 and Gen1 DAS involves the use of radar. Whereas lidar was used in the Gen1 DAS to provide both front and side collision sensing, the Gen2 DAS uses lidar for front collision sensing and radar for side collision sensing. A photo of the interior of the bus operator's area with the DAS components is shown in Figure 1-2.

1 LCD Touch Screen

2 Lane Departure LED (one on each side of dash)

3 Active Seat

4 Forward Collision Awareness LED

5 DAS Power Button (green button, not in view)

Figure 1-2 Interior Components of Driver Area

Forward Collision Warning

Forward collision warning is provided by means of an LED light located in the center of the dashboard (Figure 1-3) and a red warning icon on the LCD display (Figure 1-4). The warning is provided in two stages. Stage 1 occurs when a vehicle or obstacle is detected in front of the bus and the time to collision is greater than three seconds. The LED light glows steady amber, and the red warning icon appears on the LCD display. Stage 2 occurs when a vehicle or obstacle is detected in front of the bus and the time to collision is less than three seconds. The LED light flashes red, and the blinking rate is proportional to the distance from the obstacle. The LCD display continues to display the red warning icon.

Figure 1-3 Forward Collision LED

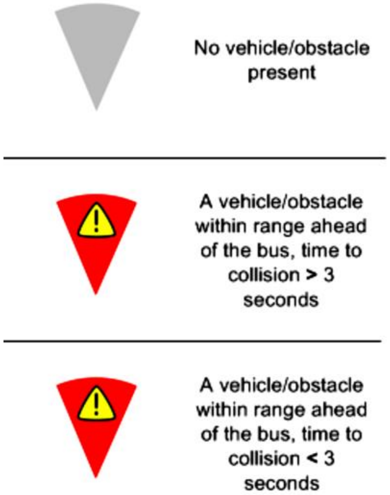


Figure 1-4 Forward Collision Icon on LCD Screen

Lane Departure Warning (Lane Keeping)

Lane departure warning is provided both graphically and tactically. Graphically it is provided by means of LED warning lights located on the left and right sides of the dashboard (Figure 1-5) and an icon of a bus with a red dashed line on the LCD display (Figure 1-6). Tactically, it is provided by vibrators located inside the bus operator's seat cushion. Lane departure warning is provided in two stages. Stage 1 occurs when the vehicle-trajectory estimator determines that an un-signaled lane departure is likely. In Stage 1, the left or right side LED glows yellow, and the LCD icon appears. Stage 2 occurs if the bus continues on the trajectory toward the lane's edge without the turn signal being activated. In Stage 2, the LED light switches to red, the LCD icon continues to appear on the display, and the seat vibrates on the side to which the bus is drifting.

Figure 1-5 Lane Departure Warning LEDs

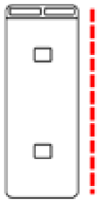


Figure 1-6 Lane Departure Icon on LCD Screen

Side Collision Warning

Side collision warning is provided to the bus operator via icons on the LCD touch screen. Examples of the warnings are shown in Figure 1-7. If the turn signal is activated and an obstacle is detected to the side of the bus, the bus operator will see the side of bus icon on the LCD screen change from gray to red with a yellow triangle and exclamation point in the middle.

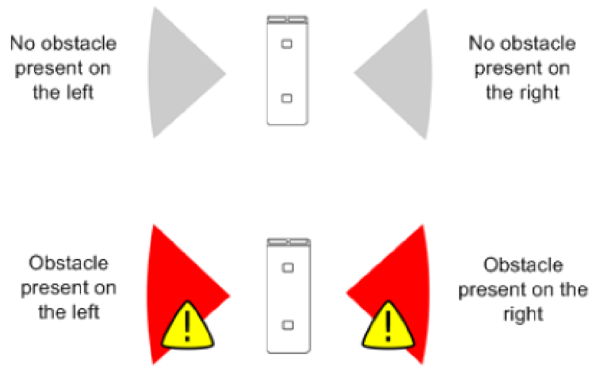


Figure 1-7 Side Collision Icon on LCD Screen

Section 2 – Methodology

Evaluation Time Frame

The evaluation of the Gen2 DAS was a two-year evaluation that included one year of baseline (pre-DAS) data and one year of implementation (post-DAS) data. The original implementation (demonstration) start date was June 2016; however, the project was delayed until March 2017 because of contracting issues.

Table 2-1 shows the final evaluation periods for the baseline and implementation years. Of note is that there is a two-year gap between them. Normally, it is best to have the baseline period immediately precede the implementation period; however, a large amount of the baseline data had already been collected based on the original timeline. By using the evaluation periods shown in Table 2-1, it was possible to retain most of the baseline data that had already been collected. During the month of January 2018, the DAS was set to passive mode, meaning that the various DAS feedback mechanisms were not available to the bus operators. However, the DAS's on-board computer system continued to track the bus's lane position (i.e., in and out of the shoulder). The purpose of this part of the evaluation was to determine if there was any change in the amount of shoulder used by the bus operators with and without the DAS.

Table 2-1 Evaluation Period

Evaluation Period	Designated Months
Baseline Year (before DAS)	March 2015 to February 2016
Implementation Year (after DAS)	March 2017 to February 2018
DAS turned off for evaluation purposes	January 2018

Peak Periods and Directions

The peak travel periods and directions were defined as follows:

Table 2-2 Peak Periods

Peak Period	Start/End Times	Direction
AM Peak	6:00–9:00 AM	NB
PM Peak	3:00–7:00 PM	SB

Test Corridor

The Gen2 DAS was implemented on Cedar Avenue (MN-77). The evaluation test corridor goes from Apple Valley Transit Station in the south to the Crosstown Highway (MN-62) in the north, a distance of approximately 12 miles. A map of the test corridor is shown in Figure 2-1.

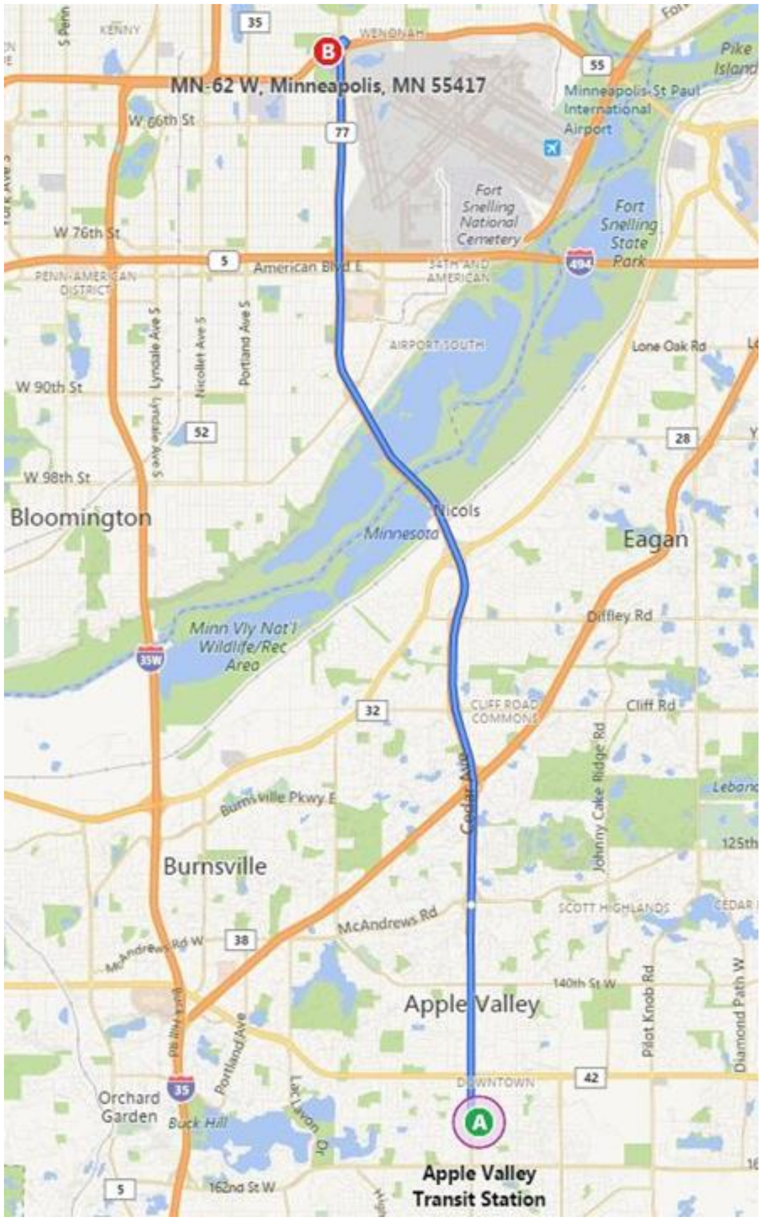


Figure 2-1 DAS Test Corridor

DAS Designated Routes

Eleven Gillig buses (No. 4505–4515) were equipped with the Gen2 DAS. These buses were assigned to five routes that operate on Cedar Avenue—472, 475, 476, 477, and 478. All of these routes are commuter express routes that provide service into Downtown Minneapolis, which is approximately seven miles further north from where the DAS test corridor ends at the junction of Cedar Avenue (MN-77) and MN-62 (Crosstown Highway).

Core Evaluation Areas

The evaluation examined the DAS according to five core areas—route system performance, customer satisfaction, bus operator satisfaction, maintenance, and safety. The methodologies used to evaluate these core areas are described below.

Route System Performance

Route system performance was evaluated in terms of bus on-time performance, bus travel time, and distance traveled in the shoulder. Data from the buses' automated vehicle location (AVL) system was used to calculate on-time performance and travel time. Because the DAS-designated routes are commuter express bus routes, the on-time performance was based on the arrival time at the end of the line. A bus was considered on-time if it arrived at the end of line within five minutes of its scheduled arrival time. Bus travel time was limited to travel time inside the DAS test corridor on Cedar Avenue. Geo-fence points were established for each route based on where it entered the test corridor. The on-time performance and bus travel time of the DAS buses were compared to the non-DAS buses of the same route. Data on the distance traveled in the shoulder was collected from the DAS on-board computer system. For each DAS-equipped bus, the on-board computer system tracked the distance traveled in the shoulder, the distance traveled outside the shoulder, and the total distance. To normalize the data, the percentage distance traveled in the shoulder was calculated by dividing the distance traveled in the shoulder by the total distance.

This information was collected for the entire one-year implementation period to determine if there were any changes in bus operator behavior as the year progressed and the operators became more accustomed to using the DAS. During January 2018, the DAS was set to passive mode. This meant that although the DAS on-board computer continued to track the distance traveled in and out of the shoulder, the DAS feedback mechanisms were not available to the bus operator. This test was done to determine if there was any change in operator behavior with and without the DAS.

Customer Satisfaction

Customer satisfaction was measured by reviewing MVTA's monthly customer complaint logs and tallying the number of complaints related to shoulder usage. Records from both the baseline period and the implementation period were examined.

Bus Operator Satisfaction

Bus operator satisfaction was measured by conducting "before" and "after" surveys of the DAS-trained bus operators via face-to-face interviews. The "before" surveys were conducted in April 2016, immediately prior to DAS training, and the "after" surveys were conducted in February 2018, the last month of the evaluation. In total, 37 bus operators participated in the "before" survey and 17 in the "after" survey. The reason for the drop in numbers is because of bus operator turnover. Bus operator satisfaction was also measured by tracking the percentage of time drivers activated the various DAS feedback mechanisms. The bus operators had the option of turning on and off some of the various DAS feedbacks mechanisms according to their personal preference. This part of the evaluation looked at whether certain feedback components were preferred over others.

Maintenance

In regards to maintenance, the Gen2 DAS-equipped buses are fairly new (purchased in Summer 2015). For this reason, it was expected that they would have a better maintenance record than the older buses in the MVTA fleet. The maintenance component of the evaluation consisted of two parts. The first part compared the average number of days each month that the DAS-equipped and non-DAS-equipped buses were down for maintenance. This was done by examining the monthly maintenance logs and calculating the number of days each bus was out of service. The second part looked at the mean time between failures (MTBF) for the DAS itself. MVTA's Information Technology (IT) department maintains a spreadsheet of reported DAS issues that is separate from the maintenance logs. The monthly MTBF was calculated by dividing the number of miles logged by the DAS fleet by the number of DAS issues reported. A higher number is better because it signifies that the buses are traveling farther without any reported issues.

Safety

Safety was measured in terms of accidents reported in the shoulder lane. This was done by examining MVTA's monthly accident log. Baseline year data were compared to implementation year data at the route level. During the implementation year, accident data were compared between the DAS and non-DAS buses of the same route.

Return on Investment

The evaluation was to include a return on investment (ROI) component. However, this was not done for reasons explained below. The purpose of the ROI calculation was to estimate how long it would take MVTA to recoup its $1.79 million investment in the Gen2 DAS.[3] The planned approach was to calculate the total annual dollar savings for DAS bus riders in terms of improved travel time and travel time reliability. Values of $13.60 per hour for travel time savings and $0.23 per minute for travel time reliability savings were to be used. These values were based on the most recent guidance issued by USDOT in a 2016 memorandum entitled "Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis." The travel time component of the calculation would have compared the average travel time of the DAS buses to non-DAS buses of the same route. The travel time reliability calculation would have compared the 95th percentile travel time of the DAS buses to non-DAS buses of the same route. The 95th percentile often is used as an indicator of travel time reliability because it represents the worst travel time that a traveler would experience during the "heaviest" traffic of the day. However, as the evaluation report shows, the DAS buses did not exhibit better travel times than the non-DAS buses. Consequently, there was no ROI based on the travel time and travel time reliability metrics.

Traffic Data

The evaluation included an analysis of travel speeds in the DAS test corridor using data from traffic detectors maintained by the Minnesota Department of Transportation (MnDOT). These data are archived and made available to the public via an online DataExtract tool

[3] Not all of the $1.79 million was for DAS procurement; the grant also covered project management, training, data collection for the evaluation, and the evaluation, totaling approximately $217,000.

(http://data.dot.state.mn.us/datatools/) and can be obtained either by individual detector or by station, which is a composite of detectors. For this evaluation, the following stations were used—S921, S928, S797, S813, S802, S808, S524, S541, S528, and S537. Their locations are shown in Figure 2-2.

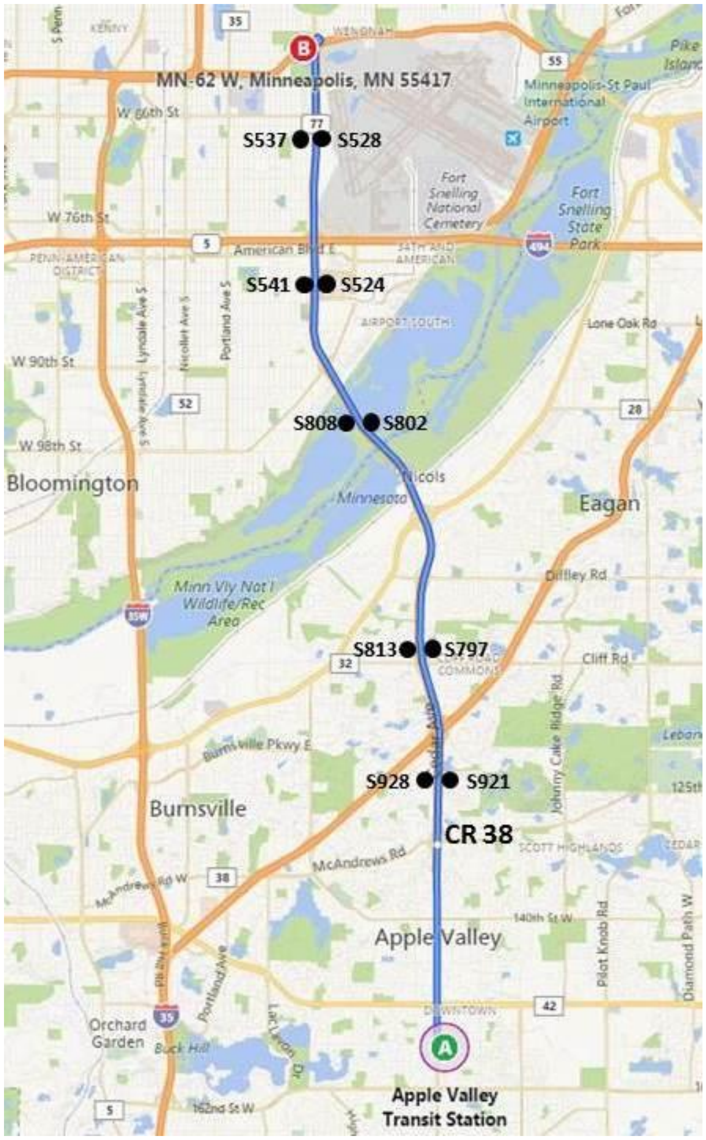


Figure 2-2 MnDOT Traffic Detector Locations

As the buses are allowed to operate in the shoulders only when speeds in the general purpose lanes drop below 35 mph, it was important for the evaluation to know how often this actually happens. The speed data were captured at five-minute increments from 6:00–9:00 AM in the northbound direction and from 3:00–7:00 PM in the southbound direction for weekdays only (Monday–Friday), as service is not provided for these routes on the weekends.

Weather Data

Because the Gen2 DAS project was funded by FTA under the research area of Resiliency, the evaluation took into consideration the performance of the DAS under poor weather conditions. Weather data from the online web portal of the National Oceanic and Atmospheric Administration (NOAA) (http://www.ncdc.noaa.gov/cdo-web/) was used. Specifically, monthly "Record of Climatological Observations" reports were downloaded for the weather station at the Minneapolis–St. Paul International Airport. Using these reports, it was possible to tally the total inches of rain and snow each month and to identify specific days of heavy rain and snow. The weather data were used to help analyze bus operator behavior during inclement weather. During January 2018, the DAS was set to passive mode, meaning that the various DAS feedback mechanisms were not available to the bus operators. Using the weather data, it was possible to zero in on snow days before, during, and after January 2018 to determine if there was any change in bus operator behavior with and without the DAS.

Section 3 – Route System Performance

Three hypotheses were set for route system performance:

Hypothesis	Finding
DAS buses will have better on-time performance than non-DAS buses of the same route.	Mixed
DAS buses will have better travel times than non-DAS buses of the same route.	Not supported
Bus operators will use the shoulder more with the DAS.	Not supported

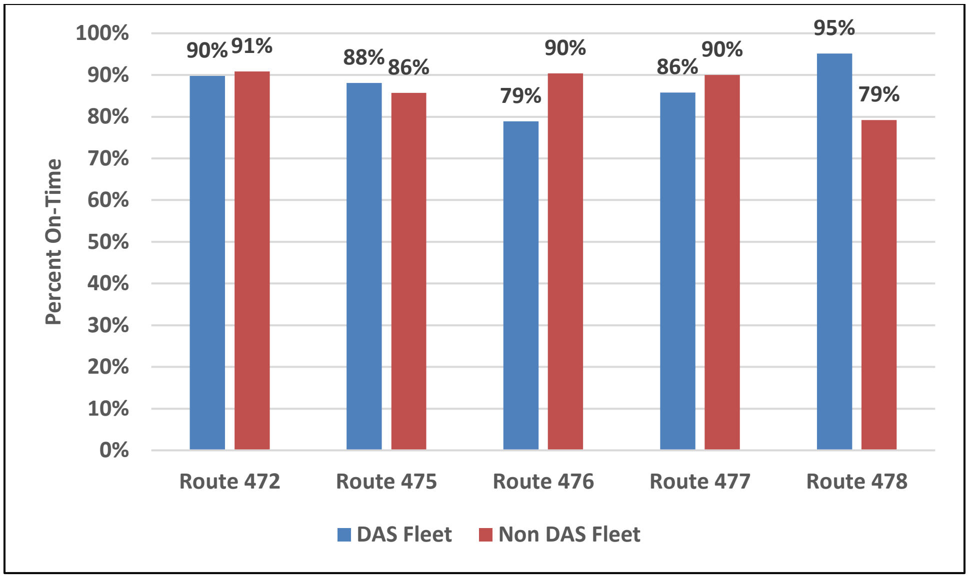
MVTA does not have an established on-time performance standard. For the evaluation, a five-minute on-time performance standard was used. A bus was considered on-time as long as it arrived within five minutes of the scheduled arrival time at the end of the line. On-time performance was based on arrival time at the end of the line because all DAS-designated routes are commuter express routes.

On-time performance results were mixed, depending on how the data is viewed. Figure 3-1 shows average on-time performance for the AM peak period, and Figure 3-2 shows it for the PM peak period. The DAS fleet overall had slightly better on-time performance than the non-DAS fleet. Average AM peak period on-time performance was 88% for the DAS fleet and 87% for the non-DAS fleet. Average PM peak-period on-time performance was 64% for the DAS fleet and 61% for the non-DAS fleet. By route, the non-DAS fleet had better on-time performance than the DAS fleet on three of the five routes in the AM peak period. In the PM peak period, the non-DAS fleet had better on-time performance than the DAS fleet on two of the four routes.[4] On one route, the on-time performance between the DAS and non-DAS buses was the same.

Detailed month-by-month results are provided in Appendix A.

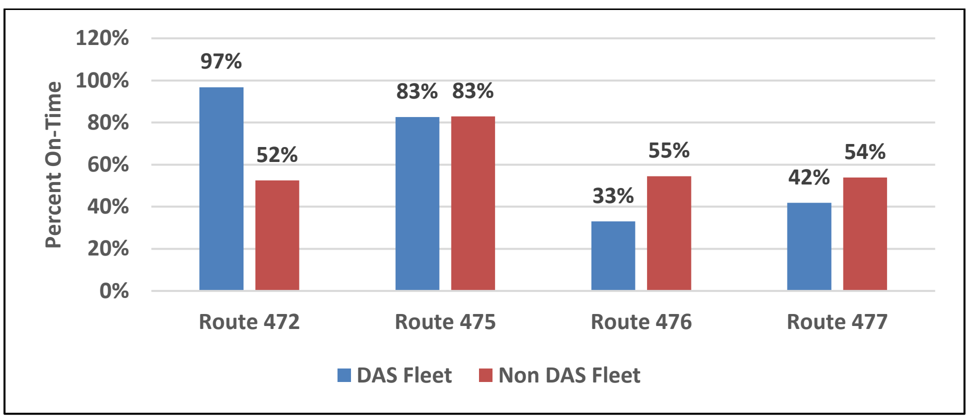
Downtown Minneapolis is approximately seven miles from the northern terminus of the DAS test corridor, which means that factors other than the DAS could have contributed to a difference in on-time performance. For this reason, the evaluation included an analysis of bus travel times specifically within the DAS test corridor on Cedar Avenue. Route-specific geo-fence points were created in the AVL system based on where the buses entered and exited the test corridor. Because each of the five routes enters Cedar Avenue at different locations, each has a different test corridor travel time. Therefore, it was not possible to aggregate the travel time data into one composite figure for the DAS fleet and another composite figure for the non-DAS fleet similar to on-time performance.

[4] In the PM peak period, only four routes had DAS-equipped buses, and Route 478 did not have DAS-equipped buses in the PM peak period.



Fleet	Average AM OTP
DAS	88%
Non-DAS	87%

Figure 3-1 Average On-Time Performance, AM NB Peak Period



Fleet	Average AM OTP
DAS	64%
Non-DAS	61%

Figure 3-2 Average On-Time Performance, PM SB Peak Period

Bus travel time results are shown in Figure 3-3 for the AM peak period and Figure 3-4 for the PM peak period. In the AM peak period, the non-DAS fleet had better (shorter) travel times on only three of the five routes. In the PM peak period, travel times were shorter on only two of the four routes. Based on these results, the DAS did not contribute to better travel times in the DAS test corridor.

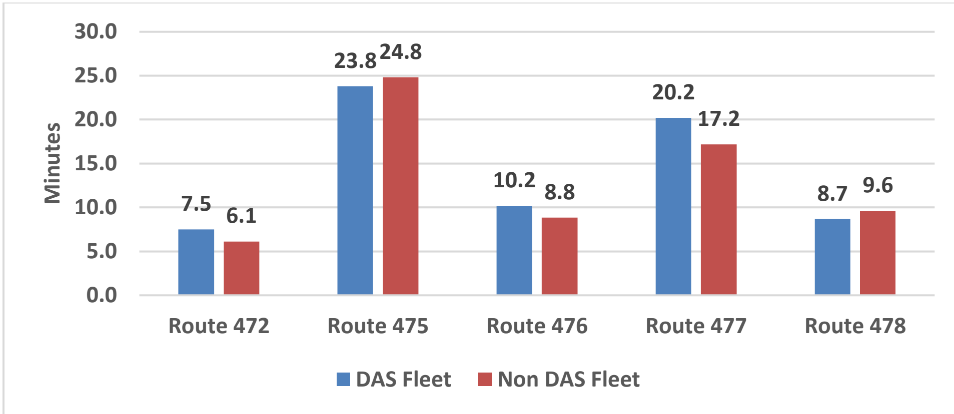


Figure 3-3 Average Bus Travel Time, AM NB

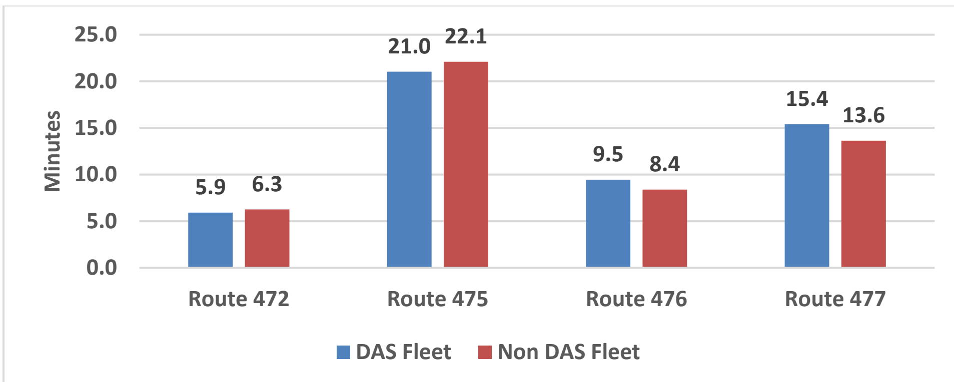


Figure 3-4 Average Bus Travel Time, PM NB

Because the DAS tracks bus lane position, it was possible to track the total distance the bus operators traveled in and out of the shoulder lane. It was hypothesized that the bus operators would use the shoulder more frequently over the course of the evaluation as they gained more confidence with the DAS; however, that did not occur, as shown in Figure 3-5. The percentages shown represent the percent distance traveled in the shoulder. This was calculated by dividing the distance in meters traveled in the shoulder by the total distance traveled. In the first month of the evaluation period, shoulder usage was 3% in AM NB direction; in the last month, it was 4%. Shoulder usage in the PM SB direction was 5% in the first month of the evaluation; in the last month, it was 3%. The one-year average was 5% for both AM NB and PM SB. Based on these findings, the DAS did not lead to an increase in shoulder usage.

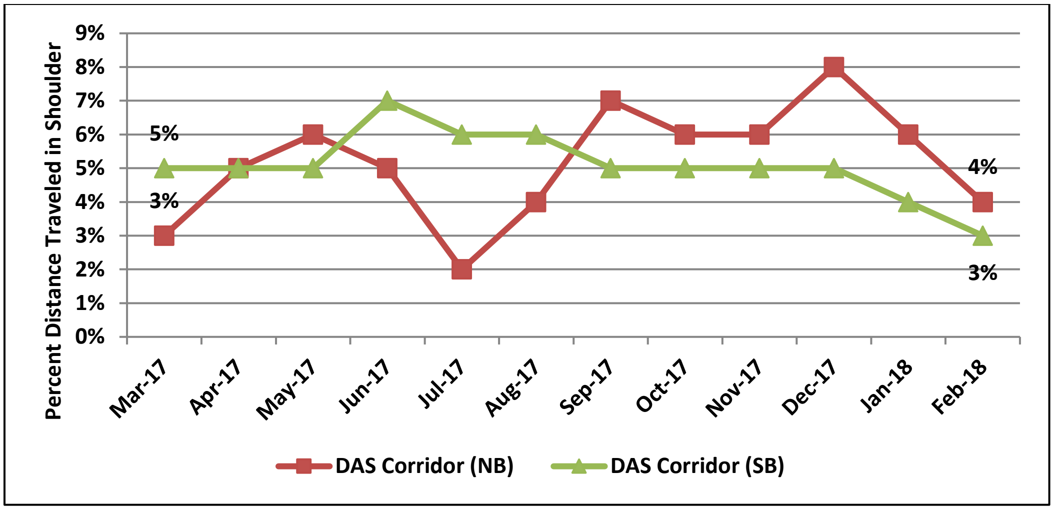


Figure 3-5 Average Percent Distance Traveled in Shoulder by DAS Buses

Analysis of Traffic Speeds in Corridor

It needs to be kept in mind that the buses are only allowed to operate in the shoulder when speeds in the general purpose lanes drop below 35 mile per hour (mph). A traffic speed data analysis was conducted using data from 10 MnDOT detectors located in the test corridor (5 in the northbound direction and 5 southbound direction). The data was collected every weekday (Mon-Fri) in 5-minute increments from 6:00 a.m. to 9:00 a.m. in the northbound direction and from 3:00 p.m. to 7:00 p.m. in the southbound direction. On average, general purpose lane speeds dropped below 35 mph 6.3% of the time in the AM Northbound and 2.2% of the time in the PM Southbound direction (see Tables 3-1 and 3-2). This correlates with the one-year average for shoulder usage, which was 5% in both the AM Northbound and PM Southbound directions.

Table 3-1 Percentage Time GP Speeds Below 35 mph, AM NB

Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2017	Aug 2017
3.3%	6.0%	9.8%	7.6%	2.9%	3.5%

Sep 2017	Oct 2017	Nov 2017	Dec 2017	Jan 2018	Feb 2018	Avg.
7.2%	7.4%	5.2%	10.5%	9.1%	3.6%	6.3%

Table 3-2 Percentage Time GP Speeds Below 35 mph, PM SB

Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2017	Aug 2017
0.6%	1.5%	0.7%	4.5%	3.2%	3.0%

Sep 2017	Oct 2017	Nov 2017	Dec 2017	Jan 2018	Feb 2018	Avg.
0.2%	1.7%	1.2%	3.4%	5.7%	0.5%	2.2%

This correlation is illustrated in greater detail in Figures 3-6 and 3-7, which compare the percentage distance traveled in the shoulder by the DAS buses to the percentage of time the general purpose lane speeds dropped below 35 mph. A correlation between the two variables in the AM NB direction is clear, as is less of a correlation in the PM SB direction where shoulder usage was relatively flat. A possible explanation for the flat percentage of shoulder usage in the PM SB direction is that the traffic speeds were considerably better than they were in the AM NB. On a small portion of the southern end of the test corridor, operators are required to use the shoulder regardless of general purpose lane speeds. This would help to explain why there would be a certain base percentage of shoulder usage.

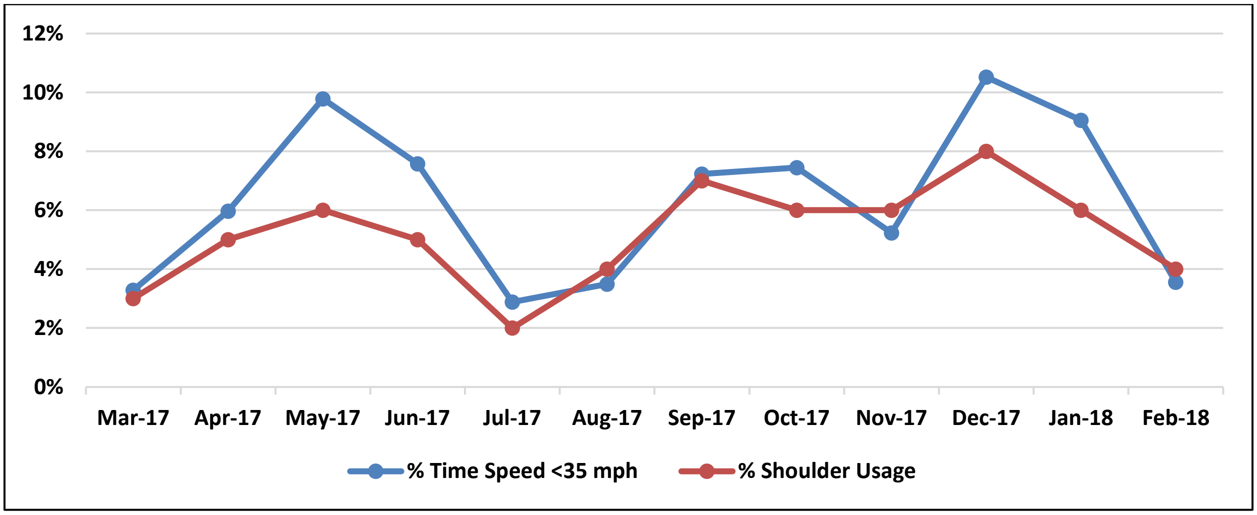


Figure 3-6 Percent Distance Traveled in Shoulder vs. Percent Time Speeds below 35 mph, AM NB

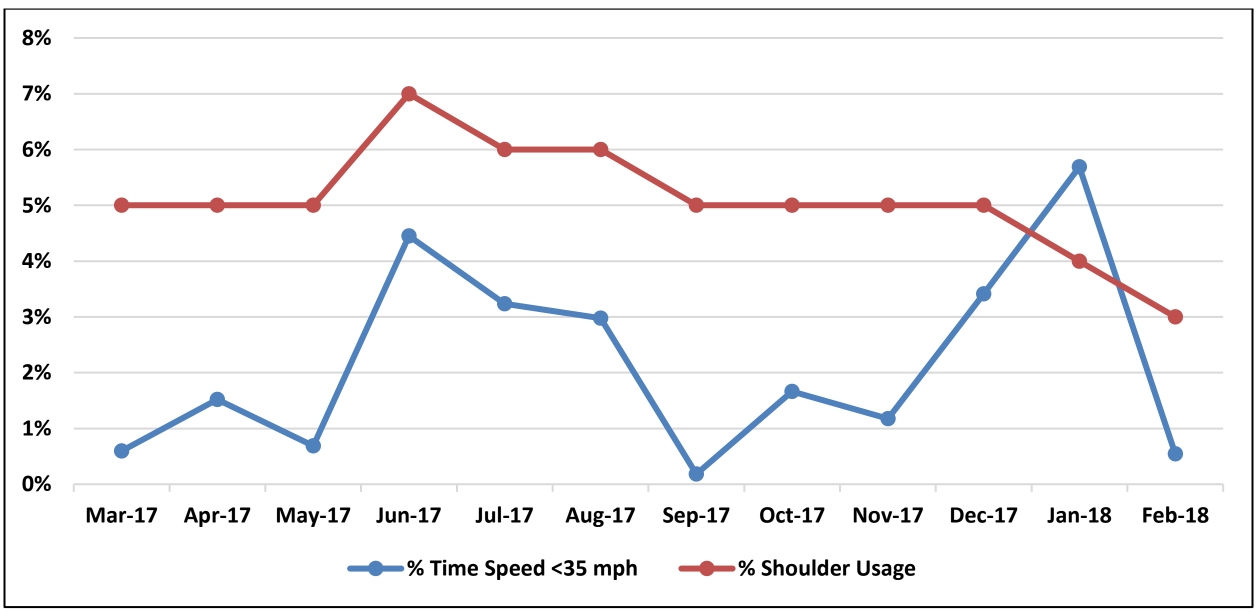


Figure 3-7 Percent Distance Traveled in Shoulder vs. Percent Time Speeds below 35 mph, PM SB

DAS Passive Mode Test

During January 2018, the DAS was set to passive mode. This meant that the various DAS feedback mechanisms to the bus operator were deactivated. However, the DAS computer system continued to track the bus lane position. The purpose of this test was to determine if there was any difference in bus operator behavior (shoulder usage) with and without the DAS. The hypothesis was that there would be a higher level of shoulder usage in December when the DAS was active, a dip in January when the DAS was inactive, and then a return to a higher level in February when the DAS was reactivated. This did not occur; as shown in Figure 3-8, shoulder usage fell consistently from December 2017 to February 2018.

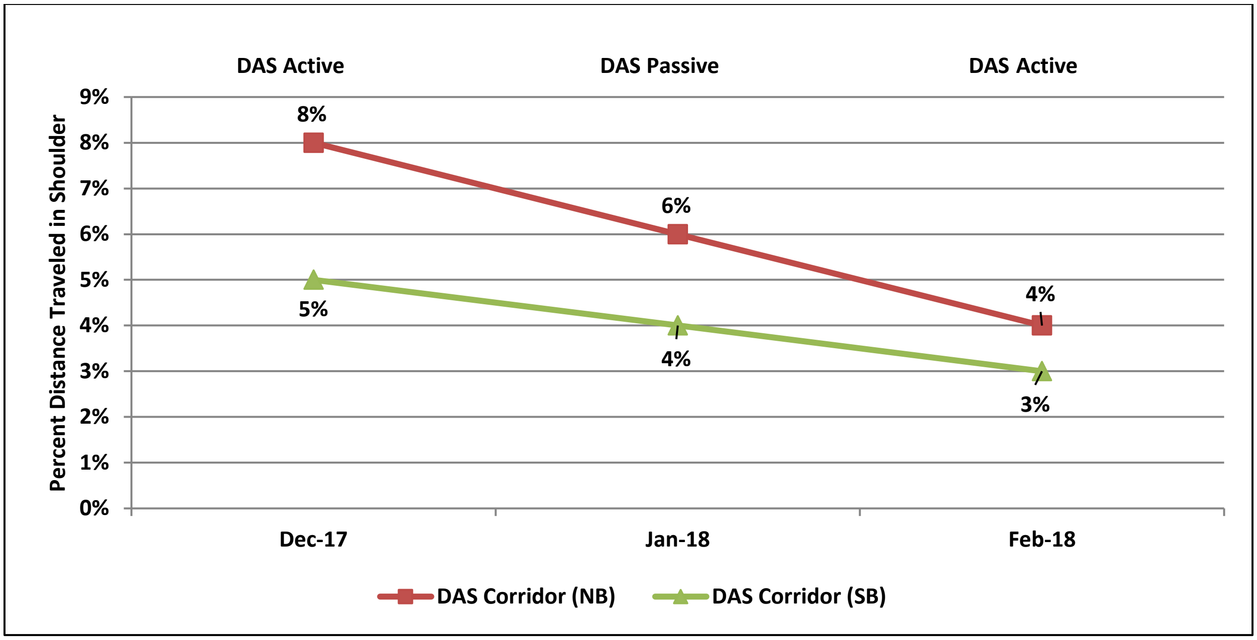


Figure 3-8 Percent Distance Traveled in Shoulder with and without DAS

Because the DAS is designed to increase bus operator confidence in traveling in the shoulders, particularly during inclement weather, the evaluation included an analysis of shoulder usage on snow days. Figure 3-9 compares the percent distance traveled in the shoulder to the inches of recorded snow on six days (two days in December 2017 when the DAS was active, two days in January 2018 when the DAS was in passive mode, and two days in February 2018 when the DAS was active). Two observations stand out. First, there was more snow in February than there was in December, and there was less shoulder usage in February. Second, shoulder usage on the two snow days in January (when the DAS was in passive mode) was higher than three of the four snow days in December and February when the DAS was active. On January 11, there was 2.4 inches of snow and shoulder usage was 10%. On January 22, there was 12.4 inches of snow and shoulder usage was 7%. That is higher than the percentage distance traveled in the shoulder on December 4, February 22, and February 23 when the DAS was in active mode.

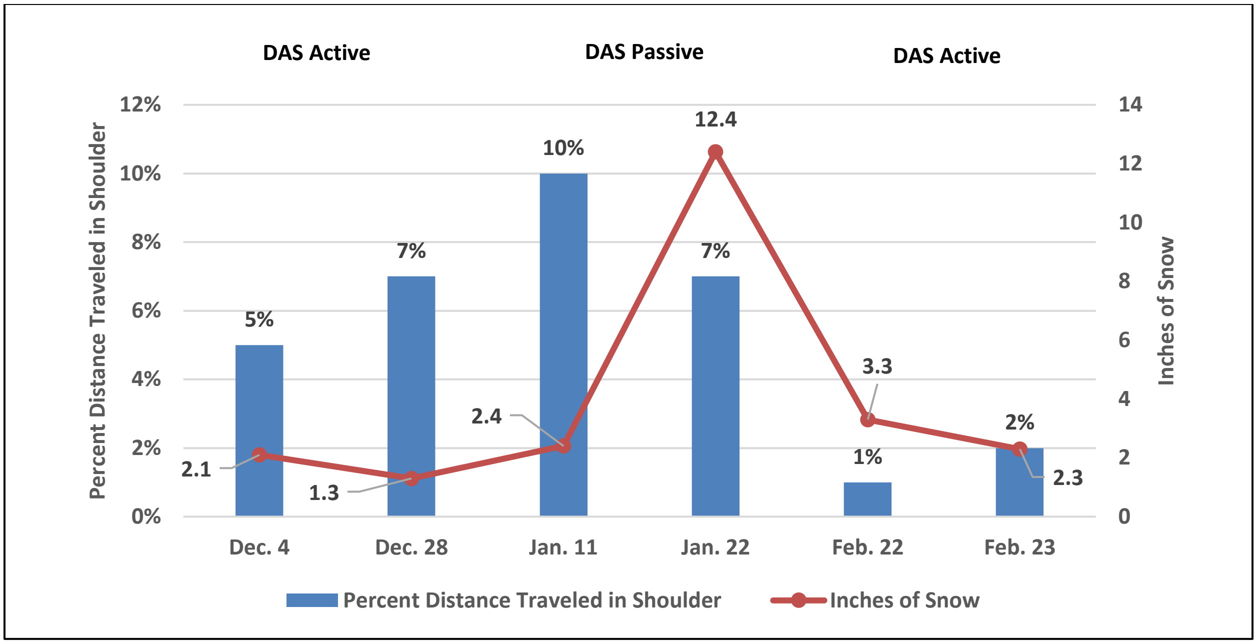


Figure 3-9 Percent Distance Traveled in Shoulder vs. Inches of Snowfall, PM SB

Traffic speed, not snow, was the primary factor in how often the shoulder was used. Figure 3-10 shows for the PM peak period the percentage distance traveled in the shoulder, the percentage time that speeds in the general purpose lanes dropped below 35 mph, and the amount of snowfall reported for the six snow days.[5] A more direct correlation between shoulder usage and traffic speed is clear. One exception is January 22, when 12.4 inches of snow was reported. Traffic congestion was severe because of the large amount of snowfall, and speeds fell below 35 mph 73% of the time; however, the DAS buses only used the shoulder 7% of the time. During the second round of bus operator interviews in February 2018, the operators indicated that snow build-up in the shoulder is a problem and that when this happens they are prevented from using the shoulders. It is likely that there was a large amount of snow build-up in the shoulder on January 22, which prevented the operators from using the shoulder.

[5] Snowfall analysis was limited to the PM period to be conservative with the analysis. It was not possible to determine from NOAA weather reports whether the snow occurred in the AM or PM.

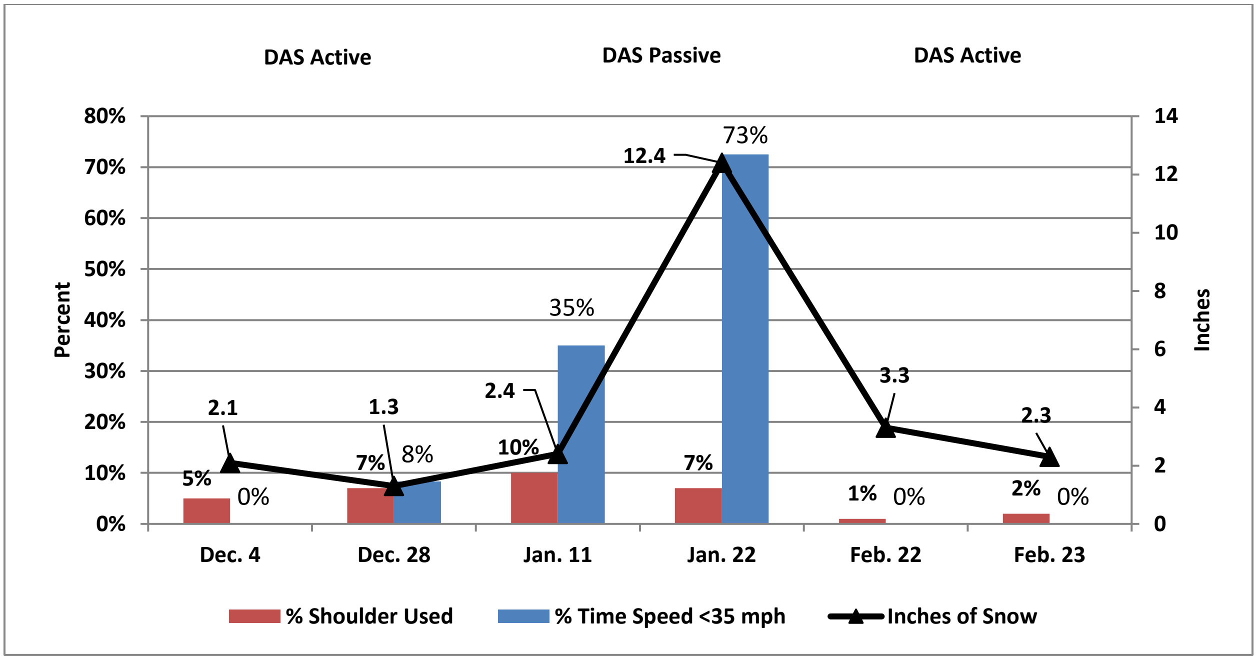


Figure 3-10 Percent Distance Traveled in Shoulder vs. Percent Time Speeds below 35 mph, PM SB

Section 4 – Customer Satisfaction

One hypothesis was set for customer satisfaction:

Hypothesis	Finding
The DAS will facilitate a reduction in shoulder related customer complaints.	Supported

According to MVTA, a common customer complaint is that the bus operators do not use the shoulder lane to bypass congestion as frequently as they could. The evaluation compared the number of complaints related to shoulder lane usage on the DAS-designated routes from the baseline year to the implementation year. During the baseline year, there were 12 customer complaints related to shoulder lane usage; 8 occurred in June 2015, and most were due to a detour caused by rain. During the implementation year, only four customer complaints were received related to shoulder usage, and none originated from passengers on DAS-equipped buses. Based on these findings, the hypothesis was supported.

Table 4-1 Customer Complaints Related to Shoulder Usage, Baseline Year

Route	Baseline Year												
	Mar 2015	Apr 2015	May 2015	Jun 2015	Jul 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Total
472	0	0	0	1	0	0	0	0	0	0	0	0	1
475	0	0	0	0	1	0	0	0	0	0	0	0	1
476	0	0	0	0	0	0	0	0	0	0	0	0	0
477	0	0	0	7	2	0	0	1	0	0	0	0	10
478	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Complaints	0	0	0	8	3	0	0	1	0	0	0	0	12

Table 4-2 Customer Complaints Related to Shoulder Usage, Implementation Year

Route	Implementation Year												
	Mar 2017	Apr 2017	May 2017	Jun 2017	Jul 2017	Aug 2017	Sep 2017	Oct 2017	Nov 2017	Dec 2017	Jan 2018	Feb 2018	Total
472	0	0	0	0	0	0	0	0	0	0	0	0	0
475	0	0	0	0	0	0	0	0	0	0	0	0	0
476	0	0	0	0	0	0	0	0	0	0	1	0	1
477	0	0	0	1	1	0	0	0	0	0	0	0	2
478	0	0	0	1	0	0	0	0	0	0	0	0	1
Total Complaints	0	0	0	2	1	0	0	0	0	0	1	0	4

Section 5 – Bus Operator Satisfaction

Two hypotheses were set for bus operator satisfaction:

Hypothesis	Finding
The DAS will improve driver confidence, reduce stress, and improve job performance.	Not supported
The DAS feedback components will be regularly used by bus operators.	Not supported

The first hypothesis was tested by conducting "before" and "after" surveys of the DAS-trained bus operators via face-to-face interviews. The "before" surveys were conducted at MVTA's Burnsville Garage in April 2016 immediately prior to DAS training, and the "after" surveys were conducted in February 2018, the last month of the evaluation. There were 37 bus operators in the "before" survey and 17 bus operators in the "after" survey. Of the 17 bus operators in the "after" survey, 11 had also participated in the before survey. The other 6 had not participated. The reason for the drop in numbers was because of employee turnover. Based on the data findings from the surveys, the DAS did not improve driver confidence, reduce stress, or improve job performance.

In both the "before" and "after" surveys, the bus operators were asked to rate on a scale of 0 to 3 how confident they feel driving in the shoulder, how stressful they find driving in the shoulder, and how safe they feel it is to drive in the shoulder. Table 5-1 shows the rating scale used.

Table 5-1 Rating Scale

Rating Level	Range
Not at all confident/stressful/safe	0.00–0.25
Somewhat confident/stressful/safe	0.26–1.50
Confident/stressful/safe	1.51–2.50
Very confident/stressful/safe	2.51–3.00

The mean score for the stated level of confidence improved from 2.41 to 2.53 (from "Confident" to "Very confident"). The mean score for stated level of stress worsened from 1.08 to 1.41, and the mean score for perceived safety worsened from 1.86 to 1.65. However, it should also be pointed out that the "before" and "after" scores for stress and safety still fell within the same rating level. In other words, the "before" and "after" scores for stress both fell within the range for "Somewhat stressful", and the "before" and "after" scores for safety both fell within the range for "Safe."

Table 5-2 On a scale of 0 to 3, how confident do you feel operating in the shoulder?

	Mean	Rating
"Before" Survey	2.41	Confident
After Survey	2.53	Very confident

0 = Not at all confident; 1 = Somewhat confident; 2 = Confident; 3 = Very confident

Table 5-3 On a scale of 0 to 3, how stressful do you find it to operate in the shoulder?

	Mean	Rating
"Before" survey	1.08	Somewhat stressful
"After" survey	1.41	Somewhat stressful

0 = Not at all stressful; 1 = Somewhat stressful; 2 = Stressful; 3 = Very stressful

Table 5-4 On a scale of 0 to 3, how safe do you feel it is to operate in the shoulder?

	Mean	Rating
"Before" survey	1.86	safe
"After" survey	1.65	safe

0 = Not at all safe; 1 = Somewhat safe; 2 = Safe; 3 = Very safe

Although the score for confidence increased, the cause may or may not be attributable to the DAS. To get a sense of how much the Gen2 DAS influenced their level of confidence, bus operators were asked whether they feel more confident, less confident, or the same when driving in the shoulder with a DAS-equipped bus compared to a non-DAS equipped bus. As shown in Table 5-5, the majority of the Gen2 operators said their level of confidence was the same (82.4%). This question about confidence was asked in the Gen1 DAS evaluation in 2011. Comparing the responses of Gen1 and Gen2 DAS operators, a larger percentage of the Gen1 operators said they felt more confident driving in the shoulder with a DAS-equipped bus (32.0% compared to 11.8%). However, it should be noted that these were two different groups of bus operators.

Table 5-5 Are you more or less confident when driving in the shoulder with a DAS-equipped bus compared to a bus not equipped with the DAS, or is your confidence level the same?

	Gen2 DAS		Gen1 DAS	
	Frequency	%	*Frequency*	%
More confident	2	11.8	8	32.0
Less confident	1	5.9	0	0.0
The same	14	82.4	15	60.0
Don't know	n/a	n/a	2	8.0
Total	17	100.0	25	100.0

Bus operators were asked to give their opinion about the helpfulness of the DAS and the various forms of feedback. The results are shown in Table 5-6. Only 41.2% agreed or strongly agreed that the DAS was helpful overall. The operators had strong negative opinions about the lane departure warning LED lights located in the dashboard as well as the vibrating seat; 64.7% disagreed or strongly disagreed that these two feedbacks were helpful. The negative response to the vibrating seat was surprising, as this feature had been praised in the Gen1 DAS evaluation by the bus operators. However, as noted, this was a different group than the Gen1 operators surveyed in 2011. The Gen2 bus operators seemed to prefer the LCD touch screen and its accompanying display icons; 70.6% agreed or strongly agreed that the LCD was helpful, and 58.8% agreed or strongly agreed that the forward collision and side collision warning icons on the LCD were helpful.

Table 5-6 Bus Operator Opinions on DAS Feedback

Statement	Agree or Strongly Agree (%)	Disagree or Strongly Disagree (%)
I find the lane departure warning LED lights helpful.	35.3	64.7
I find the lane departure warning icon on the user interface helpful.	52.9	47.1
I find the forward collision warning LED light helpful.	52.9	47.1
I find the forward collision warning icon on the user interface helpful.	58.8	41.2
I find the side collision warning icon on the user interface helpful.	58.8	41.2
I find the vibrating seat helpful.	35.3	64.7
I find the LCD touchscreen helpful.	70.6	29.4
Overall, I find the DAS helpful.	41.2	58.8

The bus operators were asked in an open-ended question to elaborate on what they liked the most and the least about the DAS. Five mentioned the side and front collision warnings as the feature they liked the most, and three mentioned the speed display on the LCD screen, which is a feature unrelated to vehicle automation. When asked what they liked least about the DAS, five operators mentioned the vibrating seat. This response was unexpected, as the vibrating seat had been praised by the Gen1 DAS bus operators. Four bus operators said the LCD touch screen was too bright at night, three complained about the size and placement of the LCD touch screen, and three stated that the DAS was unneeded. Example comments were:

- "If I need equipment to tell me how to drive, I shouldn't be driving a bus."
- "If you're a professional driver, you shouldn't need the DAS. We have enough to worry about when driving. It's a distraction that's not needed."

Impact of Snow Build-Up in the Shoulders on Bus Operator Satisfaction

The "after" survey questionnaire included two questions about snow, one about whether snow build-up in the shoulder is a problem and another about whether the presence of snow influences their decision to drive in the shoulder. The "after" surveys were conducted on February 27, 2018, and there had been heavy snowfall several days earlier. The weather report from NOAA indicated that on February 22, 23, and 24, there was 3.3, 2.3, and 6.0 inches of snow, respectively. As shown in Table 5-7, 82.4% of the bus operators said that snow build-up in the shoulder is a problem, and as shown in Table 5-8, 76.5% said snow build-up in the shoulder influences their decision to use the shoulder.

Table 5-7 Is snow build-up in the shoulder a problem, in your opinion?

	Frequency	%
Yes	14	82.4
No	3	17.6

Table 5-8 Does snow build-up in the shoulder influence your decision to use the shoulder?

	Frequency	%
Yes	13	76.5
No	4	23.5

The second hypothesis was that the DAS feedbacks would be used regularly by the bus operators. The operators have the option of turning on or off some (but not all) of the DAS feedbacks according to their personal preferences, including the forward LED warning light, the lane departure LED warning lights, and the vibrating seat. The DAS computer system can track which devices they turn on and off. Figure 5-1 shows the results. On average, the bus operators enabled the forward collision warning LED light 55% of the time and the lane departure warning LED light 56% of the time. The vibrating seat was enabled only 28% of the time, confirming comments in the interviews about the operators not liking the vibrating seat. Based on the data findings, the DAS feedbacks were not regularly used.

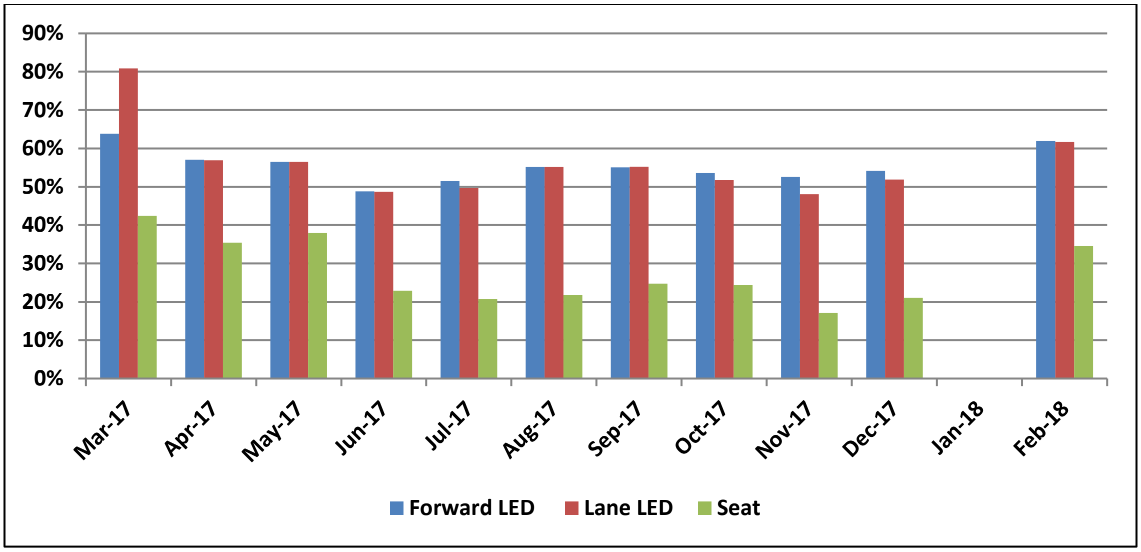


Figure 5-1 Percent Time DAS Feedback Activated

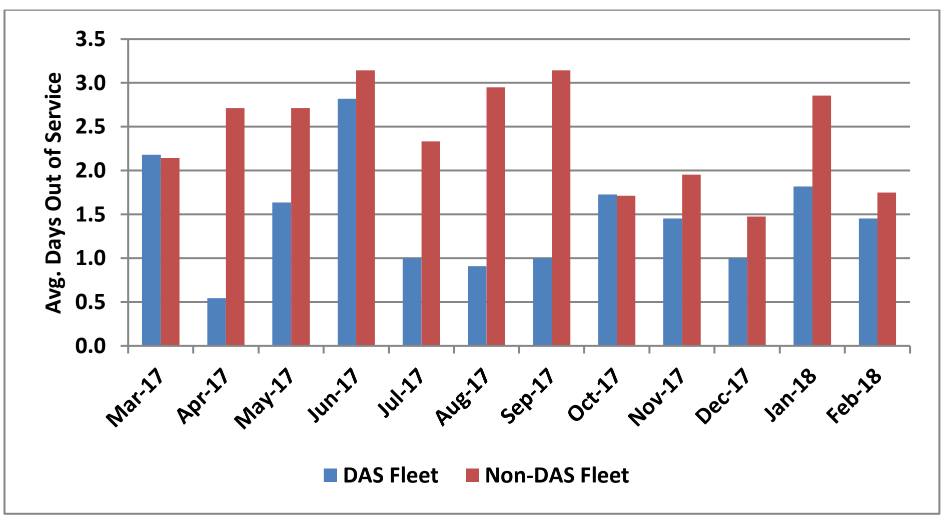
Section 6 – Maintenance

One hypothesis was set for the maintenance component:

Hypothesis	Finding
The service availability of the DAS-equipped buses will be the same or better as the non-DAS buses of the same route during the implementation year.	Supported

As noted, the Gen2 DAS-equipped buses are fairly new (purchased in Summer 2015). As such, it was expected that they would have a better maintenance record than the older buses in the MVTA fleet. The maintenance component of the evaluation consisted of two parts. The first part compared the average number of days each month that the DAS-equipped and non-DAS-equipped buses were down for maintenance. This was done by examining the monthly maintenance logs and calculating the number of days each bus was out of service for maintenance repairs. It is important to note that the maintenance logs captured only non-DAS-related repairs (engine repairs, tire repairs/replacement, etc.). The second part looked specifically at DAS-related malfunctions. MVTA's IT department maintains a spreadsheet of reported DAS issues that is separate from the maintenance logs. The MTBF for the DAS system was calculated by dividing the monthly total of miles logged by the DAS fleet by the total number of DAS issues reported that month. A higher number is better because it signifies that the buses are traveling farther without DAS malfunctions.

As expected and as shown in Figure 6-1, the DAS fleet had better maintenance performance than the non-DAS fleet. A bus from the DAS fleet was out of service 1.5 days per month, on average, compared to 2.4 days per month for a non-DAS bus.



Fleet	Average Days per Month Out of Service
DAS	1.5
Non-DAS	2.4

Figure 6-1 Maintenance Performance, DAS Fleet vs. Non-DAS Fleet

In regards to DAS MTBF, the best month was November 2017, when there were no reported DAS failures. The next best month was June 2017, when the MTBF was 29,436 miles. The one-year average MTBF was 6,470 miles. The results are shown in Figure 6-2.

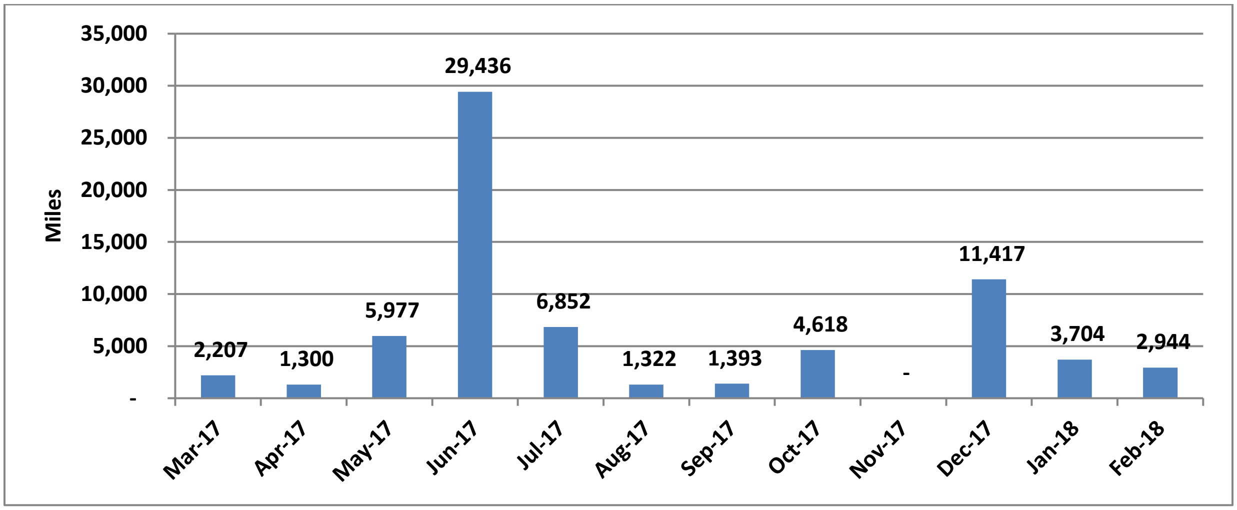


Figure 6-2 Mean Time between Failures (MTBF) for DAS System

Based on the results of the data analysis, the DAS buses had better maintenance performance than the non-DAS buses. This is because the DAS buses are newer than the non-DAS buses.

Section 7 – Safety

One hypothesis was set for the safety component:

Hypothesis	Finding
The DAS will facilitate safe operations in the shoulder.	Supported

Safety was evaluated in two ways. First, monthly accident logs were reviewed, and the number of accidents in the shoulder during the baseline year was compared to the implementation year. Second, bus operators were asked in the "before" and "after" surveys to rate how safe they felt driving in the shoulder on a scale of 0 to 3, where 0 = Not at all safe, 1 = Somewhat safe, 2 = Safe, and 3 = Very safe.

There were zero accidents in the shoulder during both the baseline year and the implementation year. This applied not just to the DAS buses but to the entire MVTA fleet. Although there were no accidents with the DAS buses, there was one safety-related incident early in the evaluation, which is described in further detail below. On the bus operator surveys, the mean score for perception of safety worsened somewhat, from 1.86 to 1.65. However, both numbers still fell within the accepted range on the rating scale for "safe." MVTA's bus operations in the shoulder were and continue to be safe. Based on the data findings, the bus operators felt safe overall driving in the shoulder.

Safety Incident

On March 20, 2017, Bus No. 4512 had a safety incident in which the steering locked up on the bus operator and caused a potentially unsafe situation for passengers on board. No one was injured. The operator noticed that the steering felt tight when going into a turn as the bus left South Bloomington Transit Station. However, the operator was able to complete the turn and proceeded as normal. The problem occurred again at the off ramp from I-35W southbound to Highway 13. This time the steering completely failed. Alarmed by the situation, the bus operator applied the parking brake, brought the bus to a stop, and contacted MVTA Dispatch. The operator was able to get the bus to Burnsville Transit Station where it was swapped out with a replacement bus. MVTA maintenance staff returned the bus to the Burnsville Bus Garage, and upon entering the facility, an audible sound from the bus was heard. During inspection of the bus, no damage was found with the steering or steering linkages. However, the steering drive motor pulley/clutch for the DAS steering activator was missing. Maintenance staff later found this piece laying on the ground damaged. MVTA made the decision to disable the DAS steering feedback from all DAS buses out of concern for passenger safety. It also directed its DAS integrator, MTS, to inspect the steering feedback mechanism on all DAS buses. After the inspections were completed, MTS reported that the suspected cause of the problem was a loose bolt that allowed the torque limiter to move on the shaft. MVTA decided to leave the steering actuator disabled from all of the DAS buses.

Section 8 – Conclusions

MVTA implemented the Gen2 DAS to build on the success of the Gen1 DAS and further enhance bus operator confidence while driving in roadway shoulders. This evaluation looked at five core areas—route system performance, customer satisfaction, bus operator satisfaction, maintenance, safety.

The evaluation of customer satisfaction and maintenance yielded positive results. Whereas there were 12 customer complaints related to shoulder usage in the baseline year, there were only 4 complaints during the implementation year, and none originated from passengers on DAS-equipped buses. The DAS-equipped buses had better maintenance performance than the non-DAS buses. Although this is likely due to the DAS buses being newer (purchased in Summer 2015), it shows that there were no unexpected compatibility issues between the DAS technology and the buses.

The evaluation of safety yielded mixed results. There were zero accidents in the shoulder system-wide during both the baseline and implementation years. However, there was a safety incident with a DAS bus early in the implementation period in which the steering locked up. The incident occurred while the bus was in revenue service with passengers on board. Although no one was injured, the incident led MVTA to disconnect the actuated steering mechanism on the DAS from all DAS buses for the remainder of the evaluation.

The evaluation of route system performance and bus operator confidence yielded a mix of neutral to negative results. For route system performance, the DAS buses had slightly better on-time performance than the non-DAS buses at their final stops; however, they did not exhibit better travel times in the DAS test corridor itself. The percentage distance traveled in the shoulder did not increase over the course of the one-year implementation period; rather, it remained fairly steady at 5% in both directions.

For bus operator confidence, although the mean score for confidence in the shoulder improved from 2.41 (“Confident”) in the “before” survey to 2.53 (“Very confident”) in the “after” survey, it does not appear that the DAS was the cause of the improvement. In a follow-up survey question, 82.4% of the bus operators said that their level of confidence driving in the shoulder was the same with or without a DAS-equipped bus, and only 41.2% agreed or strongly agreed that the DAS was helpful.

The evaluation included a one-month period in January 2018 when the DAS was set to passive mode, which meant that the DAS feedbacks were not available to bus operators. The purpose of the test was to determine if there was any difference in bus operator behavior (shoulder usage) with and without the DAS. The analysis revealed two observations. First, total shoulder usage dropped steadily from December 2017 to February 2018, i.e., the percentage distance traveled in the shoulder continued to drop even after the DAS was reactivated in February. Second, there was more shoulder usage on two snow days in January when the DAS was set to passive mode than there was on three snow days in December and February when there was a comparable amount of snow and the DAS was set to active mode.

It should be pointed out that these findings do not mean that the DAS caused poor route system performance. Rather, there is no evidence to suggest that the DAS improved route system performance. Traffic speed in the general purpose lanes rather than the DAS appears to be the determining factor in whether the bus operators used the shoulder. Bus operators can use the shoulder only when traffic speeds in the general purpose lanes drop below 35 mph. In the DAS test corridor, traffic speeds in the general purpose lanes dropped below 35 mph only 6.3% of the time in the AM NB direction and 2.2% in the PM SB direction. This helps to explain why shoulder usage remained at around 5% throughout the evaluation. If MVTA decides to continue use of the DAS, it may wish to consider a different corridor that has worse congestion.

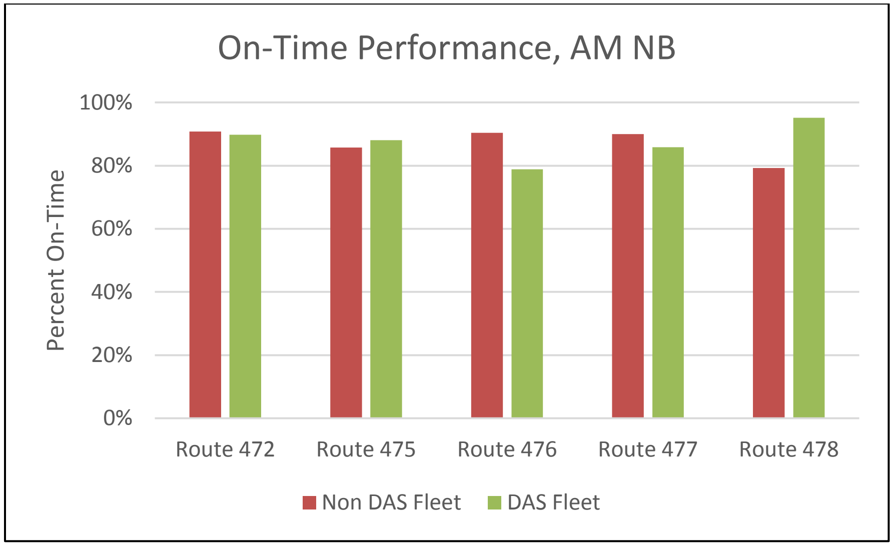
These findings, while disappointing, should not be construed as a failure. The automotive industry has invested billions of dollars into the research and development of vehicle automation technology. In doing so, it has learned what works and what does not work from a driver perspective. In contrast, the transit industry is lagging behind the automotive industry in this field. Therefore, any information that can be learned about what does and does not work in transit automation is valuable. It is possible that the Gen2 DAS did not generate a more positive response from the bus operators because it is Level 0 Automation and, perhaps, they did not perceive any benefit to using the Gen2 DAS because they still had the same driving responsibilities as without it. It is possible that higher levels of automation will yield a more positive response from bus operators.

Some data exist that support this theory. For example, the National Bus Rapid Transit Institute (NBRTI) at the Center for Urban Transportation Research at the University of South Florida conducted an evaluation of the magnetic guidance system used by Lane Transit District in Eugene, Oregon for precision docking of its EmX Bus Rapid Transit System, which is Level 1 Automation. As the EmX bus approaches the station, the bus operator controls the acceleration and deceleration while the magnetic guidance system controls the steering. EmX operators overwhelmingly reported a positive impression of the precision docking system and wanted to expand its use from the initial three BRT stations to the entire BRT system.6 This indicates that more research is needed in this area.

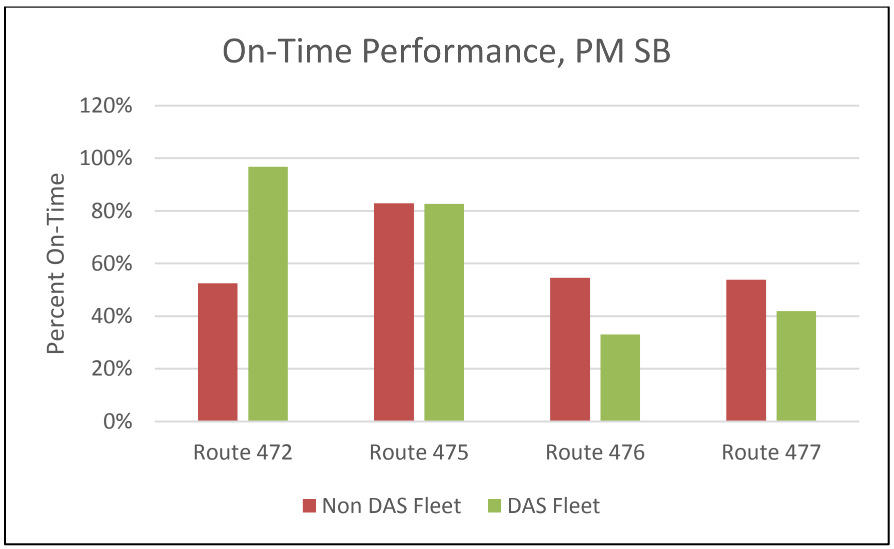
[6] FTA Report 0093, *Vehicle Assist and Automation (VAA) Demonstration Evaluation Report*, January 2016.

Appendix A – On-Time Performance

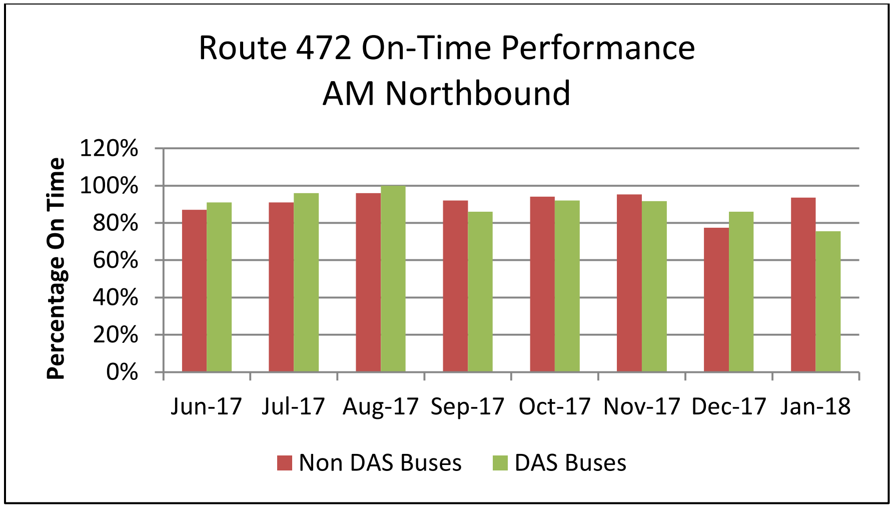
Appendix A contains the month-by-month on-time performance results for the DAS-designated routes. This part of the evaluation relied on data provided by MVTA's AVL integrator, which was able to provide data for June 2017 to January 2018. On-time performance was calculated based on the arrival time at the end of the line. A bus was considered on-time as long as it arrived within five minutes of its scheduled arrival time.

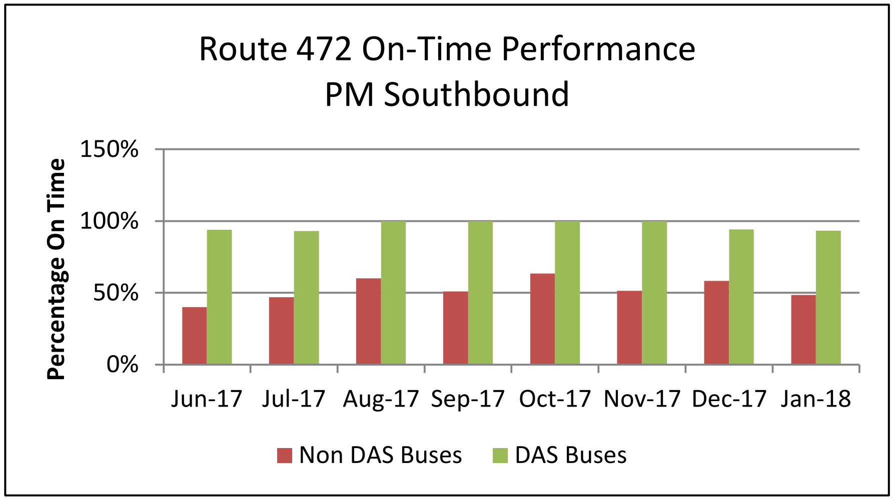


Average On-Time Performance, AM NB June 2017–January 2018			
Route	**Non-DAS Fleet**	**DAS Fleet**	**Better OTP**
472	91%	90%	NONDAS
475	86%	88%	DAS
476	90%	79%	NONDAS
477	90%	86%	NONDAS
478	79%	95%	DAS



Average On-Time Performance, PM SB June 2017–January 2018			
Route	**Non-DAS Fleet**	**DAS Fleet**	**Better OTP**
472	52%	97%	DAS
475	83%	83%	TIE
476	55%	33%	Non-DAS
477	54%	42%	Non-DAS



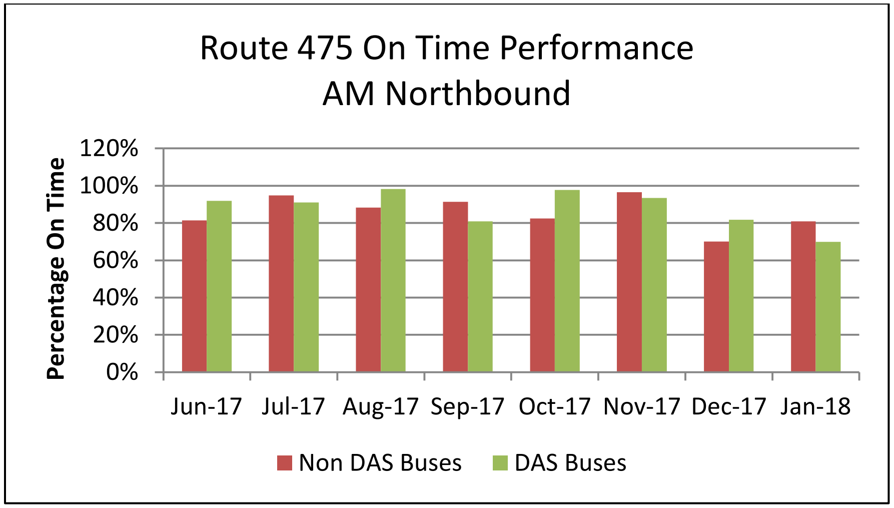


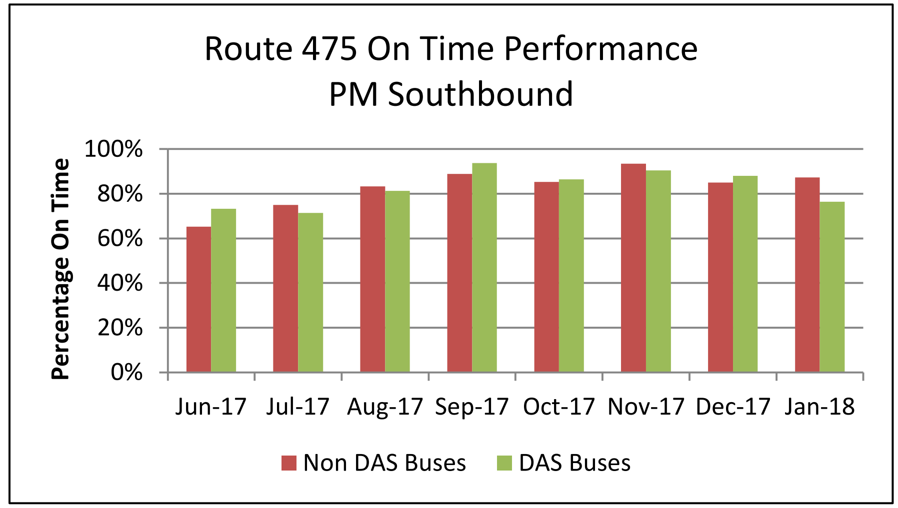
Route 472 On-Time Performance, AM NB

	Jun-17	*Jul-17*	*Aug-17*	*Sep-17*	*Oct-17*	*Nov-17*	*Dec-17*	*Jan-18*	*AVG*
Non-DAS Buses	87%	91%	96%	92%	94%	95%	78%	94%	**91%**
DAS Buses	91%	96%	100%	86%	92%	92%	86%	76%	**90%**
Better OTP	DAS	DAS	DAS	Non-DAS	Non-DAS	Non-DAS	DAS	Non-DAS	**Non-DAS**

Route 472 On-Time Performance, PM SB

	Jun-17	*Jul-17*	*Aug-17*	*Sep-17*	*Oct-17*	*Nov-17*	*Dec-17*	*Jan-18*	*AVG*
Non-DAS Buses	40%	47%	60%	51%	63%	51%	58%	49%	**52%**
DAS Buses	94%	93%	100%	100%	100%	100%	94%	93%	**97%**
Winner	DAS	DAS	DAS	DAS	DAS	DAS	DAS	DAS	**DAS**



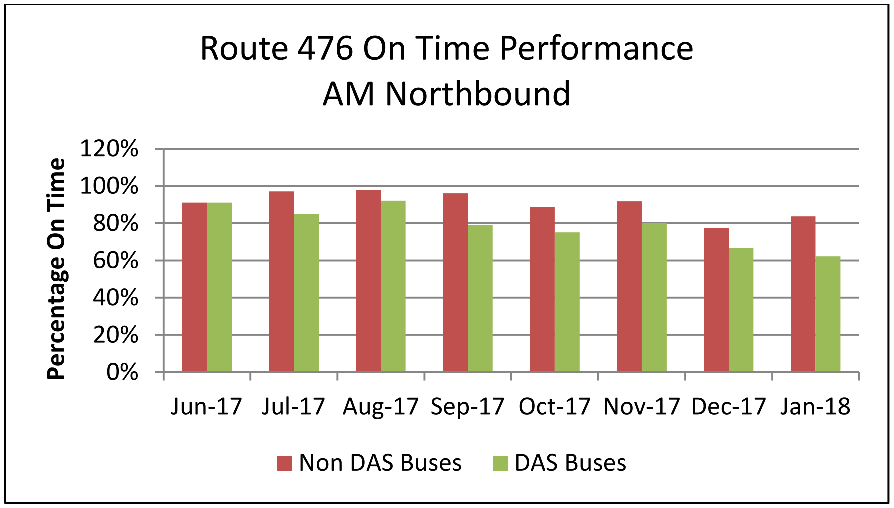


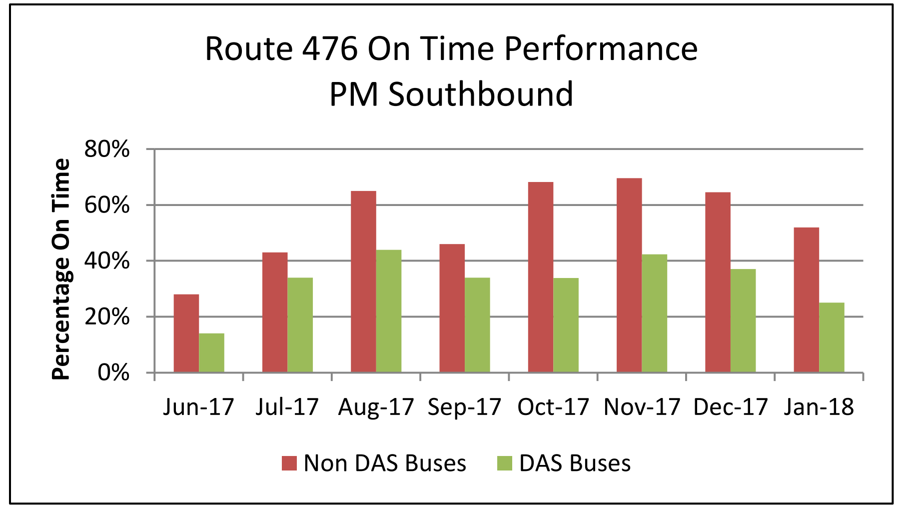
Route 475 On-Time Performance, AM NB

	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	81%	95%	88%	91%	82%	97%	70%	81%	**86%**
DAS Buses	92%	91%	98%	81%	98%	93%	82%	70%	**88%**
Better OTP	DAS	Non-DAS	DAS	Non-DAS	DAS	Non-DAS	DAS	Non-DAS	**DAS**

Route 475 On Time Performance, PM SB

	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	65%	75%	83%	89%	85%	93%	85%	87%	**83%**
DAS Buses	73%	71%	81%	94%	86%	90%	88%	76%	**83%**
Better OTP	DAS	Non-DAS	Non-DAS	DAS	DAS	Non-DAS	DAS	Non-DAS	**Non-DAS**



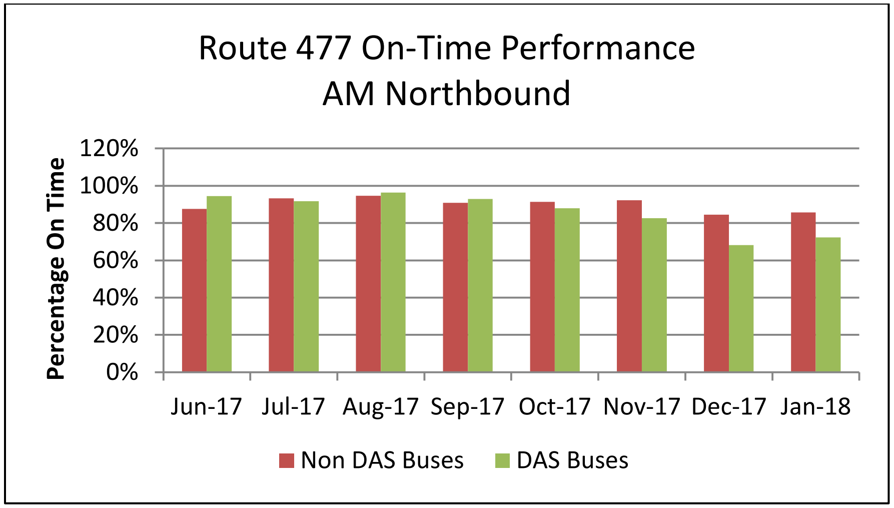


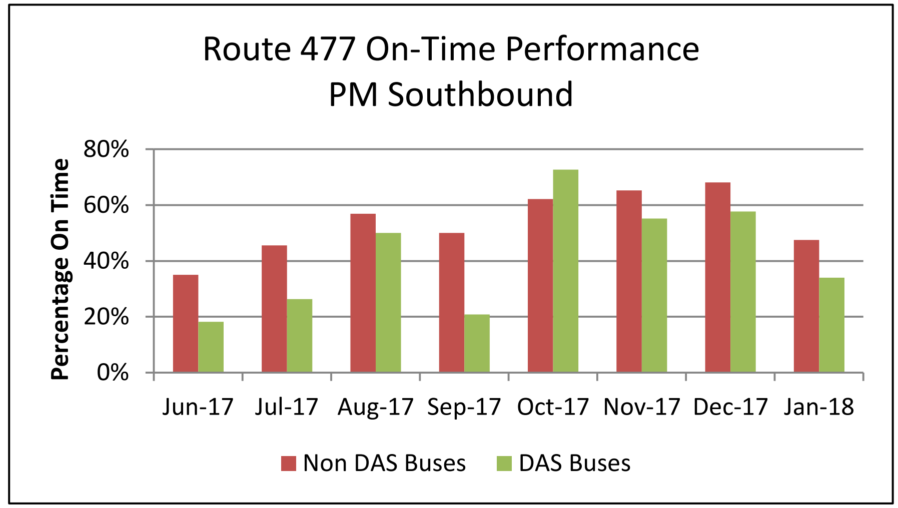
Route 476-On Time Performance, AM NB

	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	91%	97%	98%	96%	89%	92%	77%	84%	**90%**
DAS Buses	91%	85%	92%	79%	75%	80%	67%	62%	**79%**
Better OTP	DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**

Route 476 On-Time Performance, PM SB

	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	28%	43%	65%	46%	68%	70%	65%	52%	**55%**
DAS Buses	14%	34%	44%	34%	34%	42%	37%	25%	**33%**
Better OTP	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**



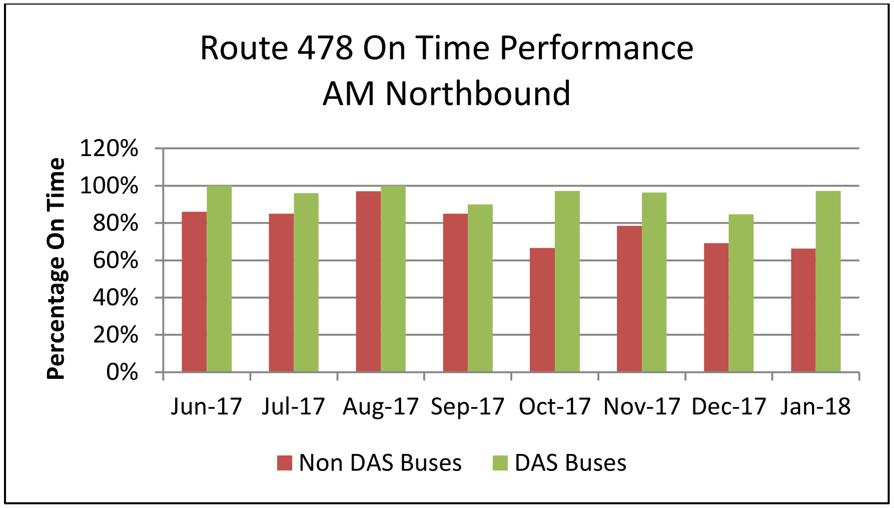


Route 477 On-Time Performance, AM NB

	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	88%	93%	95%	91%	91%	92%	84%	86%	**90%**
DAS Buses	94%	92%	96%	93%	88%	83%	68%	72%	**86%**
Better OTP	DAS	Non-DAS	DAS	DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**

Route 477 On Time Performance, PM SB

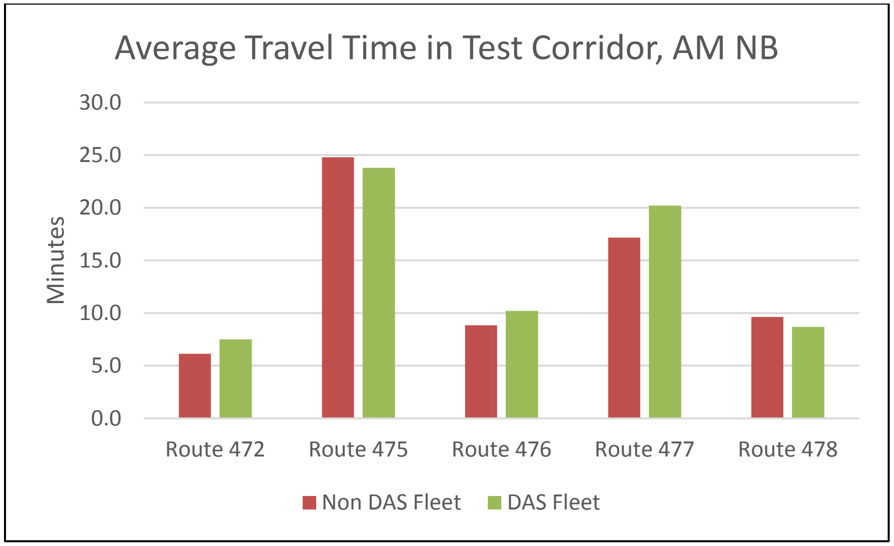
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	35%	46%	57%	50%	62%	65%	68%	48%	**54%**
DAS Buses	18%	26%	50%	21%	73%	55%	58%	34%	**42%**
Better OTP	Non-DAS	Non-DAS	Non-DAS	Non-DAS	DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**



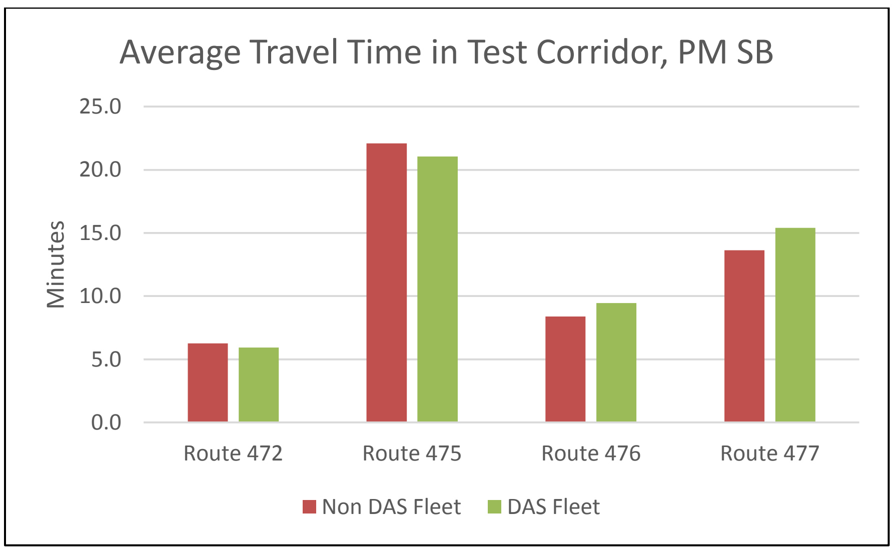
Route 478 On-Time Performance, AM NB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	86%	85%	97%	85%	67%	78%	69%	66%	**79%**
DAS Buses	100%	96%	100%	90%	97%	96%	85%	97%	**95%**
Better OTP	DAS	DAS	DAS	DAS	DAS	DAS	DAS	DAS	**DAS**

Appendix B – Bus Travel Times

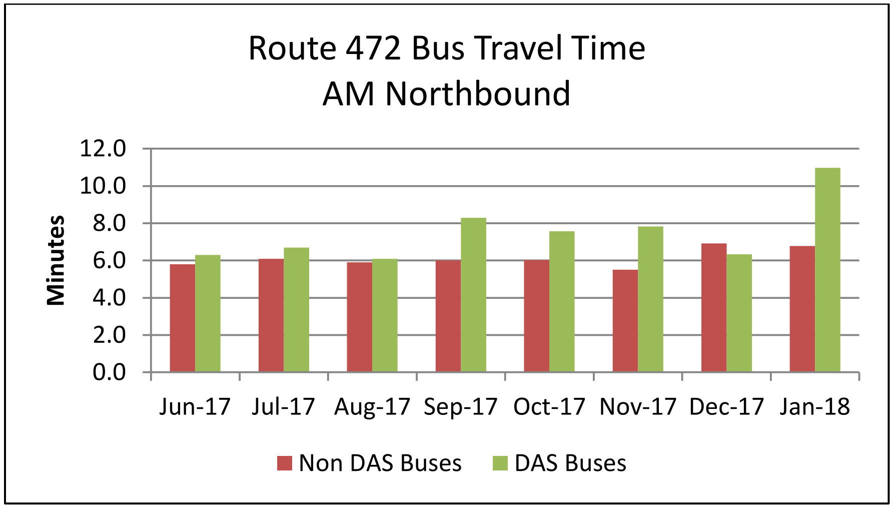
Appendix B contains the month-by-month bus travel time results for the DAS-designated routes. This part of the evaluation relied on data provided by MVTA's AVL integrator, which was able to provide data for June 2017 to January 2018. The travel times shown are for the DAS test corridor. Because the routes enter and exit the DAS corridor at different locations, travel times vary from route to route.

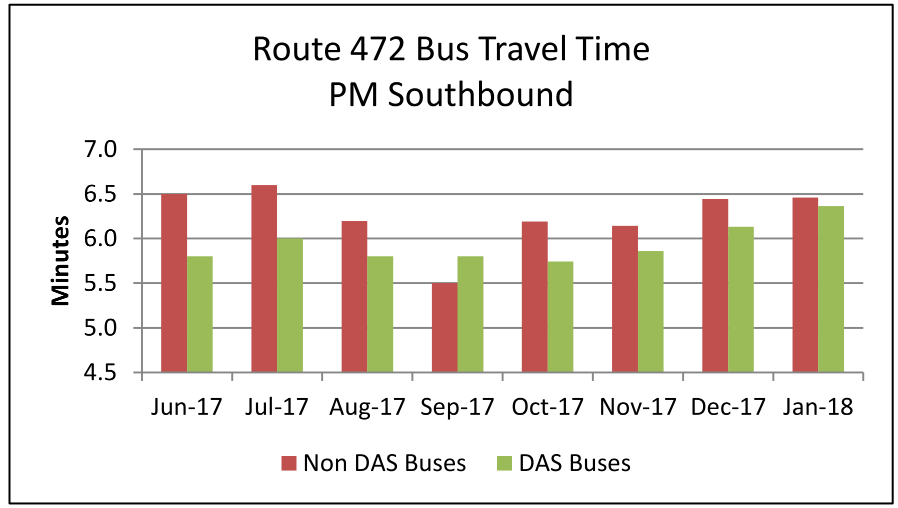


Average Travel Time in Test Corridor, AM NB June 2017–January 2018			
Route	**Non-DAS Fleet**	**DAS Fleet**	**Better Time**
472	6.1	7.5	Non-DAS
475	24.8	23.8	DAS
476	8.8	10.2	Non-DAS
477	17.2	20.2	Non-DAS
478	9.6	8.7	DAS



Average Travel Time in Test Corridor, PM SB June 2017–January 2018			
Route	**Non-DAS Fleet**	**DAS Fleet**	**Better Time**
472	6.3	5.9	DAS
475	22.1	21.0	DAS
476	8.4	9.5	Non-DAS
477	13.6	15.4	Non-DAS



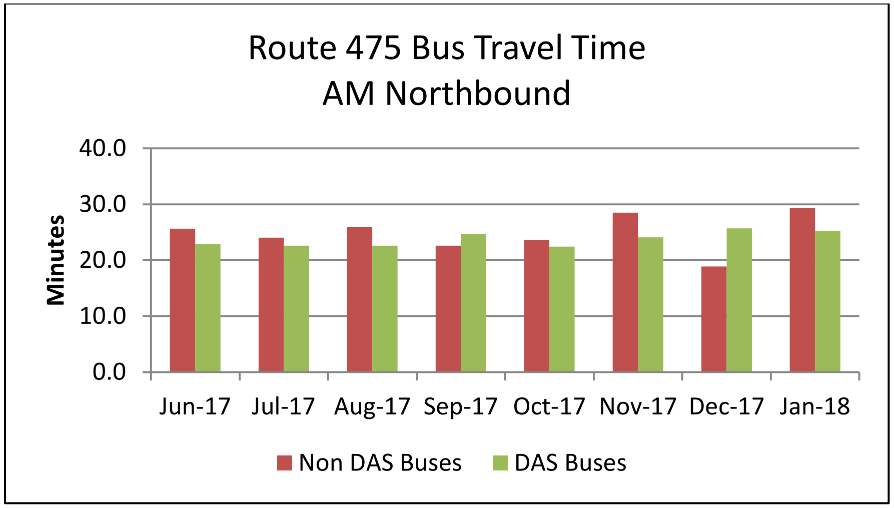


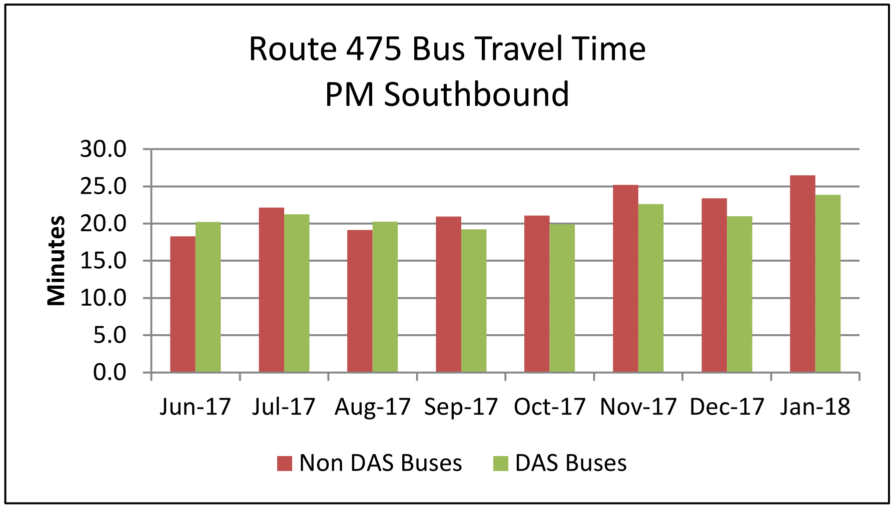
Route 472 Bus Travel Time (min), AM NB

	Jun-17	*Jul-17*	*Aug-17*	*Sep-17*	*Oct-17*	*Nov-17*	*Dec-17*	*Jan-18*	*AVG*
Non-DAS Buses	5.8	6.1	5.9	6.0	6.0	5.5	6.9	6.8	**6.1**
DAS Buses	6.3	6.7	6.1	8.3	7.6	7.8	6.3	11.0	**7.5**
Better Time	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	DAS	Non-DAS	**Non-DAS**

Route 472 Bus Travel Time (min), PM SB

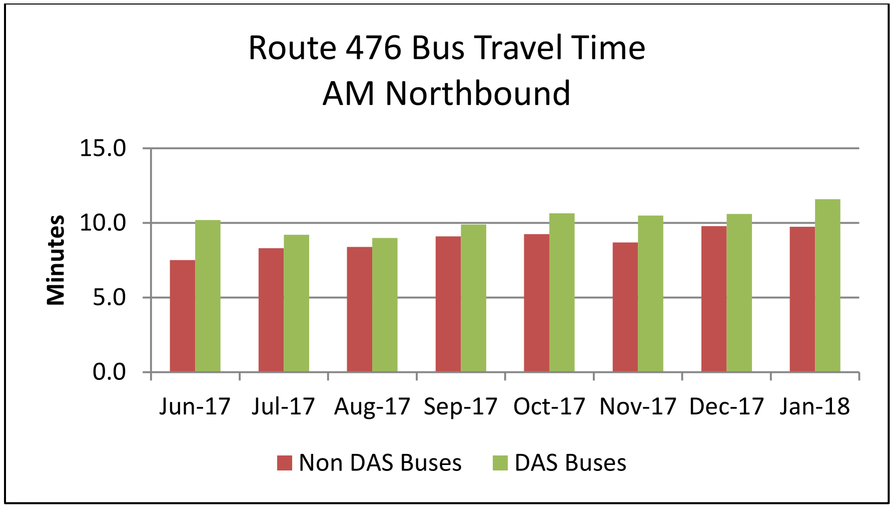
	Jun-17	*Jul-17*	*Aug-17*	*Sep-17*	*Oct-17*	*Nov-17*	*Dec-17*	*Jan-18*	*AVG*
Non-DAS Buses	6.5	6.6	6.2	5.5	6.2	6.1	6.4	6.5	**6.3**
DAS Buses	5.8	6.0	5.8	5.8	5.7	5.9	6.1	6.4	**5.9**
Better Time	DAS	DAS	DAS	Non-DAS	DAS	DAS	DAS	DAS	**DAS**

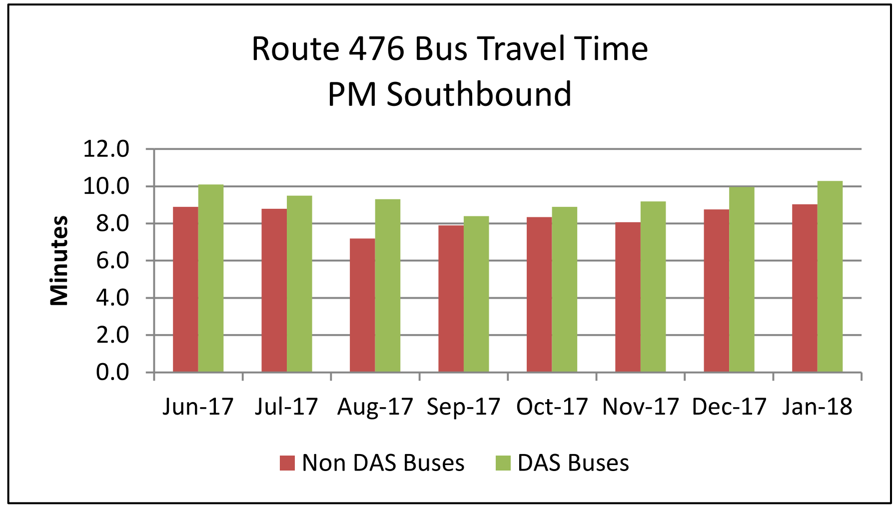




Route 475 Bus Travel Time (min), AM NB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	25.6	24.0	25.9	22.6	23.6	28.5	18.9	29.3	**24.8**
DAS Buses	22.9	22.6	22.6	24.7	22.4	24.1	25.7	25.2	**23.8**
Better Time	DAS	DAS	DAS	Non-DAS	DAS	DAS	Non-DAS	DAS	**DAS**

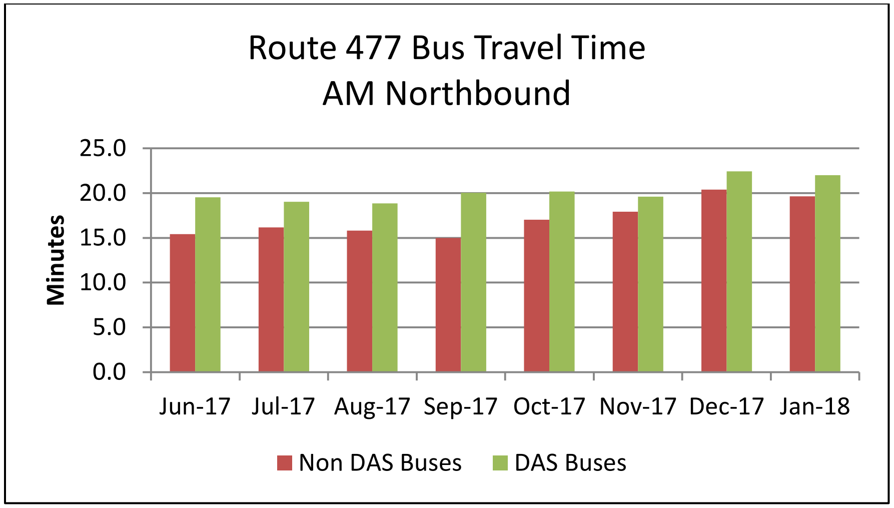
Route 475 Bus Travel Time (min), PM SB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	18.3	22.2	19.2	21.0	21.1	25.2	23.4	26.5	**22.1**
DAS Buses	20.2	21.2	20.3	19.2	19.9	22.6	21.0	23.9	**21.0**
Better Time	Non-DAS	DAS	Non-DAS	DAS	DAS	DAS	DAS	DAS	**DAS**

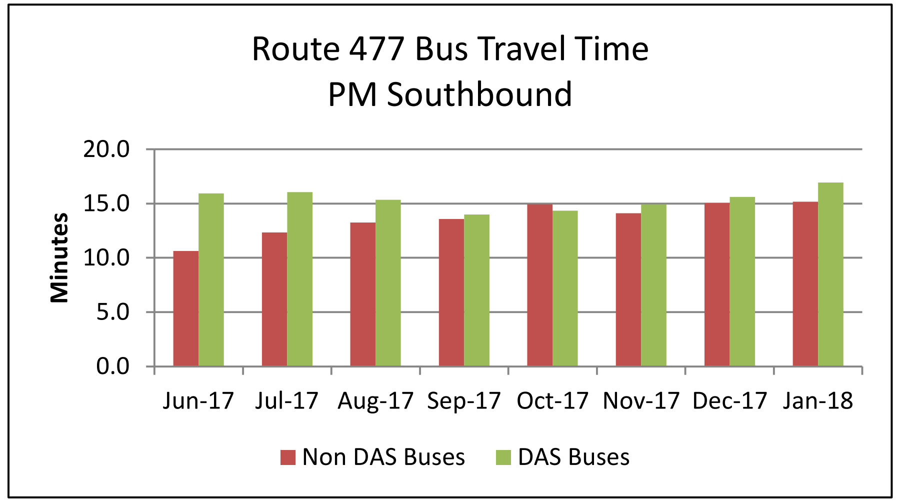




Route 476 Bus Travel Time (min), AM NB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	7.5	8.3	8.4	9.1	9.2	8.7	9.8	9.8	**8.8**
DAS Buses	10.2	9.2	9.0	9.9	10.6	10.5	10.6	11.6	**10.2**
Better Time	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**

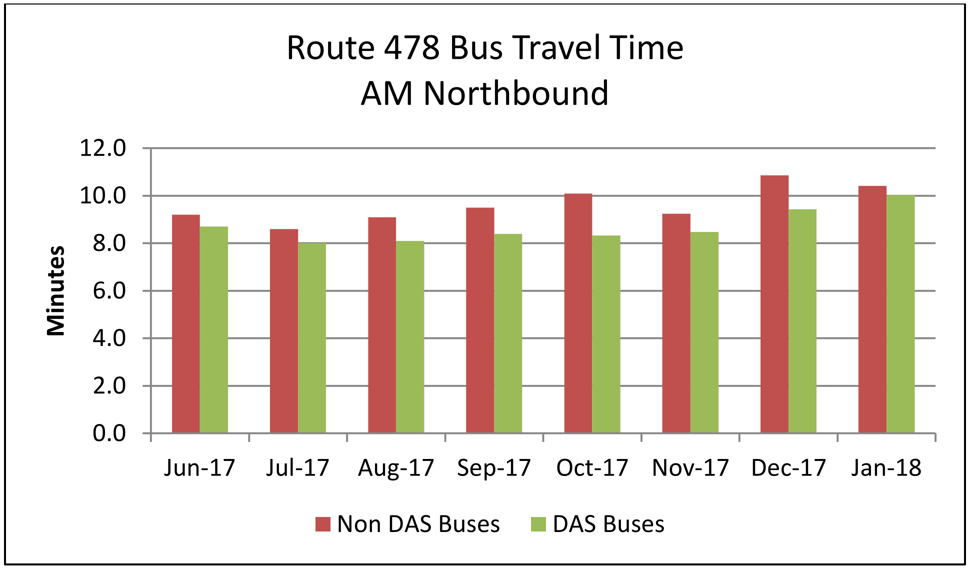
Route 476 Bus Travel Time (min), PM SB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	8.9	8.8	7.2	7.9	8.3	8.1	8.8	9.0	**8.4**
DAS Buses	10.1	9.5	9.3	8.4	8.9	9.2	10.0	10.3	**9.5**
Better Time	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**





Route 477 Bus Travel Time (min), AM NB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	15.4	16.2	15.8	15.0	17.0	17.9	20.4	19.6	**17.2**
DAS Buses	19.6	19.0	18.9	20.0	20.2	19.6	22.4	22.0	**20.2**
Better Time	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**

Route 477 Bus Travel Time (min), PM SB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	10.6	12.3	13.2	13.6	14.9	14.1	15.0	15.2	**13.6**
DAS Buses	16.0	16.1	15.4	14.0	14.4	14.9	15.6	16.9	**15.4**
Better Time	Non-DAS	Non-DAS	Non-DAS	Non-DAS	DAS	Non-DAS	Non-DAS	Non-DAS	**Non-DAS**



Route 478 Bus Travel Time (min), AM NB									
	Jun-17	***Jul-17***	***Aug-17***	***Sep-17***	***Oct-17***	***Nov-17***	***Dec-17***	***Jan-18***	***AVG***
Non-DAS Buses	9.2	8.6	9.1	9.5	10.1	9.2	10.9	10.4	**9.6**
DAS Buses	8.7	8.0	8.1	8.4	8.3	8.5	9.4	10.0	**8.7**
Better Time	DAS	DAS	DAS	DAS	DAS	DAS	DAS	DAS	**DAS**

Appendix C – Bus Operator Surveys

Appendix C contains the survey questionnaires used in the "before" and "after" surveys of the DAS-trained bus operators.

Before Survey

1. On a scale of 0 to 3, how **confident** do you feel operating a bus in the shoulder?

Very Confident	Confident	Somewhat Confident	Not at all Confident
3	2	1	0

2. What factor(s) do you think contribute the most to how you rated your **confidence**?

3. On a scale of 0 to 3, how **stressful** do you find it to operate a bus in the shoulder?

Very Stressful	Stressful	Somewhat Stressful	Not at all Stressful
3	2	1	0

4. What factor(s) do you think contribute the most to how you rated your **stress**?

5. On a scale of 0 to 3, how **safe** do you think it is to operate a bus in the shoulder?

Very Safe	Safe	Somewhat Safe	Not at all Safe
3	2	1	0

6. What factor(s) do you think contribute the most to how you rated **safety**?

7. In what year were you born? __________

8. How many years of experience do you have as an MVTA bus operator? __________

After Survey

This respondent participated in the "before" survey? Yes / No

1. On a scale of 0 to 3, how confident do you feel today operating a bus in the shoulder?

Very Confident	Confident	Somewhat Confident	Not at all Confident
3	2	1	0

2. You rated your confidence driving in the shoulder as (state what it was). What factor(s) do you think contribute the most to how you rated your confidence?

3. On a scale of 0 to 3, how stressful do you find it to operate a bus in the shoulder?

Very Stressful	Stressful	Somewhat Stressful	Not at all Stressful
3	2	1	0

4. You rated your level of stress driving in the shoulder as (state what it was). What factor(s) do you think contribute the most to how you rated your stress?

5. On a scale of 0 to 3, how safe do you think it is to operate a bus in the shoulder?

Very Safe	Safe	Somewhat Safe	Not at all Safe
3	2	1	0

6. You rated the safety of driving in the shoulder as (state what it was). What factor(s) do you think contribute the most to how you rated safety?

7. Are you more or less confident when driving in the shoulder with a DAS-equipped bus compared to a bus not equipped with DAS, or is your confidence level the same?

___ More confident ___ Less confident ___ The same ___ Don't know

8. Please tell us the degree to which you agree or disagree with the following statements.

	Strongly Agree	Agree	Disagree	Strongly Disagree
I find the lane departure warning LED lights (in the dashboard, left and right sides) helpful.				
I find the lane departure warning icon on the user interface (red dashed line on side of bus icon) helpful.				
I find the forward collision warning LED light (in middle of dashboard) helpful.				
I find the forward collision warning icon on the user interface (red triangle with yellow exclamation point) helpful.				
I find the side collision warning icon on the user interface (red triangle with yellow exclamation point) helpful.				
I find the vibrating seat helpful.				
I find the LCD touchscreen helpful.				
Overall, I find the DAS helpful.				

9. What did you like the most about the DAS?

10. What did you like the least about the DAS?

11. In January, you did not have access to the DAS feedback. How did this influence your decision about whether or not to use the shoulder?

12. Is snow build-up in the shoulder a problem, in your opinion?

☒ Yes ☐ No

13. Does snow build-up in the shoulder influence your decision to use the shoulder?

☐ Yes ☐ No

14. In what year were you born? __________

15. How many years of experience do you have as an MVTA bus operator? __________

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