

Cedar Avenue Driver Assist System Evaluation Report

DECEMBER 2011

FTA Report No. 0010
Federal Transit Administration

PREPARED BY

Brian Pessaro and Caleb Van Nostrand
National Bus Rapid Transit Institute (NBRTI)
Center for Urban Transportation Research



COVER PHOTO

Minnesota Valley Transit Authority

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Federal Transit Administration
Office of Research, Demonstration and Innovation
U.S. Department of Transportation
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	liters	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

REPORT DOCUMENTATION PAGE		Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY	2. REPORT DATE December 2011	3. REPORT TYPE AND DATES COVERED March - June 2011	
4. TITLE AND SUBTITLE Cedar Avenue Driver Assist System Evaluation Report		5. FUNDING NUMBERS FL-26-7110	
6. AUTHOR(S) Brian Pessaro, Senior Research Associate Caleb Van Nostrand, Graduate Research Assistant			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSE(ES) National Bus Rapid Transit Institute Center for Urban Transportation Research University of South Florida 4202 E. Fowler Avenue, CUT100 Tampa, FL 33620		8. PERFORMING ORGANIZATION REPORT NUMBER FTA Report No. 0010	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration East Building 1200 New Jersey Avenue, SE Washington, DC 20590		10. SPONSORING/MONITORING AGENCY REPORT NUMBER FTA Report No. 0010	
11. SUPPLEMENTARY NOTES			
12A. DISTRIBUTION/AVAILABILITY STATEMENT Available From: National Bus Rapid Transit Institute, Center for Urban Transportation Research, University of South Florida, 4202 E. Fowler Avenue, CUT100, Tampa, FL 33620. Also available through NBRTI web site: http://www.nbrti.org		12B. DISTRIBUTION CODE TRI-20	
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14. SUBJECT TERMS Driver assist system; vehicle assist and automation; shoulder operations; bus rapid transit		15. NUMBER OF PAGES 42	
16. PRICE CODE			
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

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ACKNOWLEDGMENTS

The author would like to thank Michael Abegg of the Minnesota Valley Transit Authority and MVTA's DAS bus drivers who contributed to the surveys and focus groups, and Craig Shankwitz, Ph.D., Pi-Ming Cheng, Ph.D., and Bryan Newstrom of the Intelligent Vehicles Laboratory at the University of Minnesota, all of whom contributed to the development of this report.

ABSTRACT

This paper summarizes an evaluation of the Driver Assist System (DAS) used by the Minnesota Valley Transit Authority (MTVA) for bus shoulder operations. The DAS is a GPS-based technology suite that provides lane-position feedback to the driver via a head-up display, virtual mirror, vibrating seat, and actuated steering. MVTA's primary goal was to enhance driver confidence, especially during adverse weather. Secondary goals included reduced travel times and increased reliability, safety, and customer satisfaction. The evaluation used a "with and without" approach. Performance data were collected from the same drivers, with the DAS set to passive and then active mode. When the DAS was in active mode, the drivers stayed in the shoulders 10 percent longer and drove 3 miles per hour faster. Lateral (side-to-side) movement was reduced by 5.5 inches. These results should be considered preliminary, as only 6 of the 25 trained drivers used the shoulders during both test periods. When surveyed, 32 percent of the bus drivers said their level of confidence driving in the shoulder was greater when using the DAS, while 60 percent said it was the same. A majority believed the DAS made driving in the shoulder safer and less stressful. Nevertheless, many drivers raised concerns about the head-up display being a distraction. By contrast, the vibrating seat was praised as the best feature of the entire system. For customer satisfaction, more than 80 percent of surveyed passengers rated the ride quality in the shoulder as very good or good.

EXECUTIVE SUMMARY

Since October 2010, the Minnesota Valley Transit Authority (MVTA) has employed the use of a Driver Assist System (DAS) for bus-on-shoulder operations along Cedar Avenue (Trunk Highway 77). The DAS is a GPS-based guidance system that provides lane-position feedback to the bus driver via a head-up display (HUD), virtual mirror, vibrating seat, and actuated steering. MVTA's primary goal for the DAS was to enhance driver confidence in the shoulders. Secondary goals included reducing travel times and increasing reliability, safety, and customer satisfaction.

The National Bus Rapid Transit Institute (NBRTI) at the Center for Urban Transportation Research at the University of South Florida evaluated the DAS according to six broad areas: bus driver satisfaction, customer satisfaction, efficiency/productivity, technical performance, maintenance, and safety. Data were collected from a variety of sources, including on-board customer surveys, driver surveys and driver focus groups, accident reports, maintenance reports, and lane-position data from the DAS on-board computer system.

When the DAS was in active mode, the drivers stayed in the shoulders 10 percent longer and drove 3 miles per hour faster. Lateral (side-to-side) movement was reduced by 5.5 inches. These results should be considered preliminary, as only 6 of the 25 trained drivers used the shoulders during both test periods. In the driver survey, 32 percent of the drivers said their level of confidence while driving in the shoulder was greater with the DAS, and 60 percent said it was the same. A majority of the drivers stated that the DAS made driving in the shoulder safer and less stressful (62.5% and 64%, respectively). In terms of actual safety, there were zero accidents in the shoulder. Nevertheless, many drivers raised concerns about the HUD being a distraction. By contrast, the vibrating seat was praised as the best feature of the entire system. For customer satisfaction, more than 80 percent of surveyed passengers rated the ride quality in the shoulder as very good or good. More than 95 percent were very satisfied or satisfied with the travel time reliability and on-time performance of their route. In terms of maintenance, the DAS fleet was operative 91.9 percent of the time during the evaluation period.

Driver Assist System (DAS) Project

Background

The Minnesota Valley Transit Authority (MVTA) received \$4.2 million from the Federal Transit Administration (FTA) as part of the Urban Partnership Agreement (UPA) to implement a Driver Assist System (DAS). The total project cost was \$5.3 million and included equipping 10 buses with the DAS and creating 1 DAS simulator. The DAS uses a combination of differential GPS, digital maps, and lidar to provide lateral guidance and collision avoidance. The DAS is used for bus-only shoulder operations on Cedar Avenue (Hwy 77) and the Crosstown Highway (Hwy 62). DAS service began in October 2010 on three routes: local Route 442 and Express Routes 476 and 477. (See Appendix A for route maps.) Because there are only 10 DAS-equipped buses, including the spare, not every bus on these four routes is a DAS-equipped bus.

According to MVTA, the primary goal of the DAS project was to enhance driver confidence while using the shoulder during bad weather. Bus drivers are allowed to use the shoulders at their discretion when speeds in the general purpose lanes drop below 35 miles per hour. MVTA passengers know when the drivers could use the shoulder but do not, and they complain about it. As a result, MVTA was interested in finding a tool that would motivate their bus drivers to use the shoulders more frequently.

MVTA's idea to use the DAS for bus on shoulder operations originated when MVTA's planning manager, Michael Abegg, saw a display of a "techno bus" at a state conference. The "techno bus" was a Metro Transit bus outfitted with prototype DAS equipment designed by the Intelligent Vehicles Laboratory (IV Lab) at the University of Minnesota. Later, he and MVTA Executive Director Beverley Miller paid a visit to the IV Lab and took a test ride of the "techno bus" on the University of Minnesota's transitway. When the Minnesota Department of Transportation began formulating a proposal for the USDOT's Urban Partnership Agreement Program, MVTA and the IV Lab suggested that a DAS project would be a good candidate for UPA funds. Subsequently, Minnesota was selected by USDOT as a UPA site, and the DAS was included as a UPA-funded project.

DAS Components

The DAS provides three modes of feedback to the bus driver: visual, tactile, and haptic. Visual feedback is provided by a head-up display (HUD) and a virtual mirror. The HUD is used to digitally display the shoulder boundaries and alert the driver to any obstacles in the way of the bus. The virtual mirror shows vehicles that are in the lane adjacent to the left; it is meant to help the drivers merge from the shoulders back into the general purpose lanes. Figure 1-1 shows the virtual mirror and HUD. Figure 1-2 shows what the view looks like through the HUD. Tactile feedback is provided by vibrators located in both sides of the seat bottom cushion; they create the sensation of a virtual rumble strip when the bus drifts too far left or right from the center of the shoulder. The final form of feedback is the haptic steering; this is provided through a motor attached to the steering column that applies torque when the bus drifts too far left or right in the shoulder. The torque strength is kept well below the driver's control threshold. This means that the torque is suggestive only; it is not strong enough to actually control steering of the bus. Feedback warnings are provided in three stages: if the edge of the bus is 6 inches to the edge of the shoulder, the lines on the HUD display turn red; if the bus is 3 inches to the edge of the shoulder, the seat warning is triggered; if the bus is 0 inches to the edge of the shoulder, the steering motor warning is triggered.

Figure 1-1

View of DAS

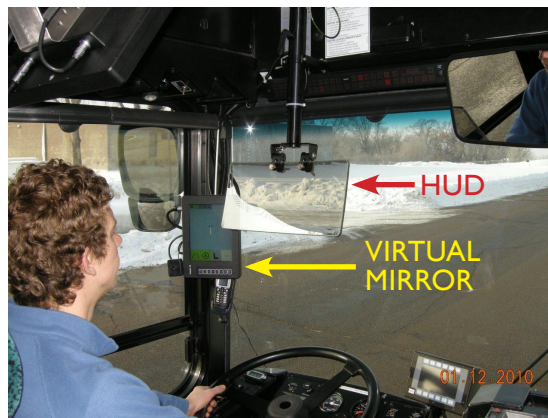
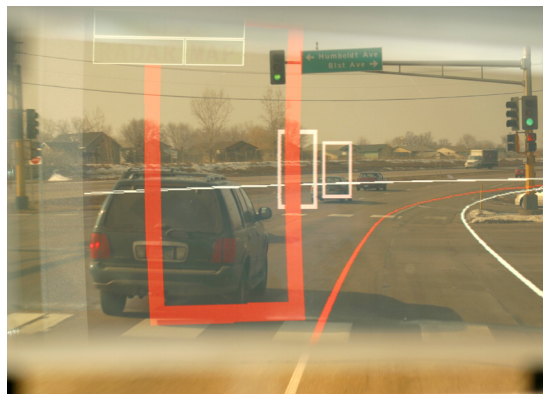


Figure 1-2

View through HUD



DAS Simulator

Real Time Technologies, Inc., of Royal Oak, Michigan, designed and built a DAS simulator for training the drivers. The IV Lab collaborated on the interface between the simulator and the DAS hardware. The simulator includes a mock-up of a bus cabin with all of the same equipment found in a real bus. Video screens placed to the front and sides of the simulator are used to project images of traffic. The DAS simulator is capable replicating numerous traffic scenarios. Two images of the DAS simulator are shown in Figure I-3.

Figure 1-3

DAS Simulator



SECTION 2

Methodology

The DAS-equipped buses operate on Cedar Avenue (Trunk Highway 77), a north-south highway that runs from Apple Valley to Minneapolis. Two test segments were created for the data collection. For the AM period, a northbound test segment was used from the on-ramp at Cliff Road to the southern end of the truss on the Minnesota River Bridge, a distance of 2,760 meters or 1.7 miles. For the PM period, a southbound test segment was used from 71st Street to the beginning of the Minnesota River Bridge, a distance of 2,636 meters or 1.6 miles. Aerial photographs of these two test segments can be found in Appendix B. The segments were chosen based on where the most available shoulder was located and where, historically, the buses used the shoulders most often. Use of the shoulder is left to the discretion of the bus driver. As it turned out, there was only enough data to draw comparisons for the AM northbound direction. Traffic flow improvements brought about by recent construction resulted in less need to use the shoulder in the southbound direction.

From March 5–25, 2011, the DAS was set to passive mode. Lane-position feedback was not available to the driver during this time, but the onboard computer was still collecting lane-position and speed data. From March 26–April 30, the DAS was switched to active mode, and the same data were collected again. To control for differences in driver behavior, comparative data from the two test periods were matched to the same driver. Furthermore, a driver was included in the analysis only if he/she used the shoulder during both periods. This restriction reduced the number of drivers in the analysis from 25 to 6.

A challenge that could not be controlled was the weather. There was more snowfall during the test period when the DAS was in passive mode than there was when it was active. In other words, the weather was at its worst during the time when the DAS was not available to the drivers. This had the potential of skewing the results in favor of the DAS. Closer examination of the data showed this did not occur. The heaviest day of snowfall during the time when the DAS was not available to the drivers was March 23. On that day, 4.1 inches of snow were recorded. Nevertheless, seven of the eight drivers on duty that day used the shoulders and, on average, they used 56 percent of the total available shoulder.

Feedback from the bus drivers was gathered in June 2011, nine months after the DAS began service, via a written survey and two focus groups. All 25 drivers completed the survey. The morning and afternoon focus groups consisted of eight drivers each. Both the survey instrument and the full survey results can be found in Appendix C.

An on-board passenger survey was distributed in June 2011 on the DAS-equipped buses. There were 135 completed surveys from the 457 passengers, resulting in a response rate of 29.5 percent. The response rate was less than hoped for and yielded a confidence interval of +/- 7 percentage points at the 95% confidence level. Both the survey instrument and the full survey results can be found in Appendix D.

Safety was measured by comparing accident data of the DAS-equipped buses for the first six months of operations (November 2010–April 2011) to the same six months of the previous year. Also, the driver survey included a question on safety perception.

SECTION 3

Bus Driver Satisfaction

The primary goal of the DAS, as stated by MVTa, was to enhance driver confidence in the shoulders by providing accurate lane-position feedback. Therefore, an important piece of the evaluation was asking the bus drivers for their opinions of the DAS once they had had sufficient time to use it in the field. The two hypotheses for bus driver satisfaction were:

1. The DAS will generate a positive response from the bus drivers in areas such as ease of use, reduced stress, and improved job performance.
2. The DAS Simulator will adequately prepare bus drivers to use the DAS in revenue service.

Survey Results

In terms of ease of use, 88 percent of the drivers agreed or strongly agreed that the DAS was easy to use. However, only 64 percent agreed or strongly agreed that the DAS made driving in the shoulder less stressful. In the focus groups, many of the drivers described the HUD as “distracting.” In their words, there were too many things going on while driving in the shoulder to be able to focus on the HUD screen. This opinion seems to be confirmed by results from the survey question that asked drivers for their opinions of the various DAS feedbacks. As Table 3-1 shows, 48 percent disagreed or strongly disagreed that the steering wheel feedback was helpful. Although the torque on the steering wheel activator was designed to be mild, drivers complained in the focus groups that they did not like anything having control over the steering besides them. In regards to the HUD, 40 percent disagreed or strongly disagreed that it was helpful. In the focus group, the drivers complained about it being “distracting”. In contrast, the vibrating seat was the most highly regarded.

Table 3-1
*Driver Opinions about
DAS Feedback*

	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)	Total Responses (N)
I find the head-up display helpful.	16	44	20	20	25
I find the steering wheel helpful.	8	44	32	16	25
I find the vibrating seat helpful.	24	56	8	12	25
I find the virtual mirror helpful.	8	56	16	20	25

Table 3-2 shows that 32 percent of the drivers said they were more confident when driving in the shoulder with a DAS-equipped bus, while 60 percent said their confidence was the same. Similarly, 32 percent said they were more confident driving in the shoulder once they had completed DAS training, while 60 percent said their confidence was the same.

Table 3-2
*DAS Impacts on
Driver Confidence*

Question	More Confident (%)	Less Confident (%)	Same (%)	Don't Know (%)	Total Responses (N)
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?	32	0	60	8	25
Are you more or less confident driving in the shoulder now that you've completed simulator and on-the-road training?	32	4	60	4	25

Opinions about the DAS Simulator and overall DAS training were very positive. As Table 3-3 shows, 84 percent agreed or strongly agreed that the simulator helped them to better understand the DAS. Additionally, 100 percent agreed or strongly agreed that the amount of simulator and on-the-road training was sufficient. A comment made by several drivers in the focus groups was that the DAS simulator was an excellent training tool for the newer drivers and that it helped to instill good driving habits.

Table 3-3
*Driver Opinions of
DAS Simulator
and Training*

Question	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)	Total Responses (N)
The amount of DAS simulator training I had was sufficient.	44	56	0	0	25
The amount of DAS on-the-road training I had was sufficient.	52	48	0	0	25
The simulator helped me to better understand the DAS.	32	52	12	4	25

Focus Group Results

The results from the bus driver surveys were reviewed prior to the focus groups and used as a springboard for further discussion. Five topics areas were discussed:

1. Stress levels and perceptions of safety while driving in the shoulders
2. Opinions on the four types of feedback
3. DAS Simulator training
4. DAS impact on the decision to use the shoulder under various weather conditions
5. Overall level of confidence driving in the shoulder

Stress Levels and Perceptions of Safety

In the survey, 36 percent disagreed or strongly disagreed that the DAS made driving in the shoulder less stressful, and 37.5 percent disagreed or strongly disagreed that the DAS made driving in the shoulder safer. Those results could mean one of two things. Either the bus drivers think operating in the shoulder is stressful and unsafe already and the DAS does not improve the situation, or they think the DAS makes conditions more stressful and less safe. The focus group comments indicated that it was a little of both, but primarily the former. Many of the drivers complained about the distracting nature of the HUD. However, there were also complaints about situations in the shoulder that are beyond the control of the DAS. For example, it was repeatedly mentioned how car drivers in the right lane tend to drift into the shoulder during heavy snow conditions. If the road has not been plowed, the car drivers cannot see the lane boundaries. As a result, they simply follow the grooves made in the snow by the cars in front, and many times these grooves cross into the shoulder. Another complaint was about snow piled up on the right side of the shoulder, which forced the operators to steer left. In both examples, the bus driver had to steer to avoid an obstacle, but the DAS prompted him/her to steer back toward the center of the shoulder regardless of the traffic situation.

A word that was used frequently to describe the DAS in general and the HUD in particular was “distracting.” Some of the comments that were made include:

- “We have enough to worry about with the traffic that’s on our left. Now we have the DAS that requires our attention, too.”
- “It’s a distraction I don’t need.”
- “It’s an added distraction to me.”
- “I’ve got too much going on to focus on what’s happening on the monitor.”

Not all of the comments were negative. Some comments were very positive, such as:

- “I used the DAS in a snowstorm. It was amazing.”
- “I think the DAS has helped the newer drivers more.”
- “I think it would be helpful during night driving. The DAS takes getting acclimated to. Refresher training on the simulator would be beneficial. I think the DAS has its place.”

Another driver stated that the DAS simulator helped the newer drivers to develop good habits for driving in the shoulder.

Opinions on the Four Types of Feedback

The main comment about the HUD was that there were too many things going on while driving in the shoulder to be able to focus on the screen. As one driver put it, “If you’re driving in bad weather, you’d better be watching the other drivers, not the DAS.” The bus drivers said it was only necessary to use the HUD under poor visibility. Under clear weather conditions, they say the HUD is not necessary. Another driver complained that the HUD constantly needed to be adjusted because it got knocked around by bumps in the road. This same driver commented that a future version of the DAS would be better if the HUD was incorporated into the windshield. Another driver commented that the column for the HUD obscures some of the warning lights on the Gillig buses.

Comments about the haptic steering were mixed. One driver said, “I like it,” while another said, “I hate it. I don’t like anything having control over the steering wheel.” Another driver commented, “We can see things that the DAS can’t. Sometimes, it’s prompting me to steer when I know I shouldn’t. So I have to fight against the steering.” Several drivers commented that they would like the steering feedback better if the torque was not as strong. Others mentioned the steering activation would catch them by surprise, which is an unusual comment because the steering feedback is the last DAS warning to activate. Prior to the steering activation, the driver will have already been warned via the HUD and tactile seat.

When asked about the virtual mirror, several drivers complained of ghost images or false reads. They said the virtual mirror showed a car to their left when there was none, and vice versa—there was a car to their left that did not appear in the virtual mirror. When asked, no one in the focus groups said they used the virtual mirror to merge back into traffic. Several drivers reported that the size and location of the virtual mirror created a blind spot.

The tactile seat was very well liked by all the focus group participants. One driver commented that he relied on the tactile seat to guide him across the

Minnesota River Bridge when his windows fogged up and he could not see the shoulder boundary. Other positive comments about the tactile seat included:

- “It’s the only thing I use.”
- “It’s not a distraction.”
- “It’s the most helpful.”
- “It doesn’t take your eyes off the road.”
- “It’s the best thing out of all of it.”

Only two negative comments were made about the seat. One driver commented that the seat vibrated sometimes even when he was on a route that was not part of the DAS corridor. This could be a glitch in the DAS. Another driver complained that the seat was uncomfortable because it had less padding. The consensus in the two focus groups was that if MVTA had to do the DAS over again, it would have been better to limit the feedback to the tactile seat and haptic steering (with less torque).

SECTION 4

Customer Satisfaction

On June 22, an on-board survey was conducted of passengers on the DAS-equipped buses. A total of 135 completed surveys were returned from 457 passengers, resulting in a response rate of 29.5 percent. The purpose of the survey was to find out whether the presence of the DAS influenced passengers to switch to transit and whether passengers could detect a change in ride quality when the DAS was used. The two hypotheses/questions for customer satisfaction survey were:

1. Will the DAS facilitate a mode shift to transit?
2. The DAS will generate a positive response from customers in areas such as perception of time savings, service reliability, and smoothness of ride.

Regarding the first hypothesis, Table 4-1 shows the DAS influenced 11.9 percent of the passengers to take transit. While this may seem low, some context is in order.

Table 4-1

*DAS Impacts on
Mode Shift*

Question	YES		NO	
	%	Freq	%	Freq
Did the presence of the driver assistance technology influence your decision to ride this route and trip?	11.9	16	88.1	119

The majority of the passengers (67.4%) had been riding their route for at least a year. An even greater majority (82.6%) were not aware of the presence of the DAS (see Appendix D – Rider Survey). Although the DAS buses were specially wrapped with a “Bus 2.0” design, as shown in Figure 4-1, passengers did not make the connection between the wrap and the presence of driver assist technology.

Figure 4-1

*“Bus 2.0”
Bus Wrap*



Regarding the second hypothesis, the results were mixed. Although 82.6 percent of the riders were not aware of the presence of the DAS, more than 80 percent rated the ride quality in the shoulder as very good or good (see Table 4-2).

Furthermore, more than 95 percent of the riders were very satisfied or satisfied with the travel time reliability and on-time performance of their route (see Table 4-3). What can be said about the results is that the DAS is a positive, albeit invisible presence on board the bus. Had the DAS performed poorly, it is likely the customer feedback would not have been so positive.

Table 4-2
*Customer Comments
on Ride Quality*

How would you rate the quality of each of the following aspects of the ride when the bus is on the shoulder?						
	Very Good (%)	Good (%)	Fair (%)	Poor (%)	Very Poor (%)	Don't Know (%)
Merging in/out of shoulder	52.2	34.3	5.2	1.5	0.0	6.7
Swaying of bus	49.3	35.1	8.2	2.2	0.0	5.2
Accelerating/decelerating	43.6	39.1	9.8	2.3	0.8	4.5
Overall smoothness of ride	49.3	34.3	10.4	0.7	0.7	4.5

Table 4-3
*Customer Comments
about Travel Time
Reliability and On-
Time Performance*

How satisfied are you with the travel time reliability of this route?	%	Freq
Very satisfied	63.0	85
Satisfied	35.6	48
Unsatisfied	1.4	2
Very unsatisfied	0.0	0
Don't know	0.0	0
Total	100.0	135
How satisfied are you with the on-time performance of this route?	%	Freq
Very satisfied	68.7	79
Satisfied	27.8	32
Unsatisfied	3.5	4
Very unsatisfied	0.0	0
Don't know	0.0	0
Total	100.0	115

SECTION 5

Efficiency and Productivity

This part of the evaluation was meant to look at DAS impacts on route performance. Originally, it was hoped that travel times and on-time performance could be compared with and without the availability of the DAS. After extensive discussion with MVTA and the IV lab, it was agreed that this was not possible. The primary reason is because use of the shoulder is left to the discretion of the driver. As a result, it would not be possible to attribute any observed improvements in on-time performance or travel times to the DAS. It would be just as likely, if not more, that observed improvements would be due to improved traffic flow. Indeed, MVTA reported that traffic flow improvements in the vicinity of the Crosstown Commons Highway (I-494) have resulted in shoulders being used less frequently in that area.

Consequently, it was agreed to strictly limit this part of the evaluation to performance measures in the shoulders. Specifically, the three hypotheses were:

1. The DAS will facilitate greater use of the shoulder.
2. The DAS will facilitate higher travel speeds while the bus is in the shoulder.
3. The DAS will facilitate less standard deviation of speed while the bus is in the shoulder.

Impacts of DAS on Shoulder Usage

The performance measure for the first hypothesis was based on a calculation of how much of the total available shoulder was used. For the northbound test segment, there were 2,760 meters of available shoulder. If a bus stayed in the shoulder for all 2,760 meters, it used 100 percent of the shoulder. The logic behind this measure is that the more confident a driver feels in the shoulder, the greater percentage of the shoulder he/she will use. The results were mixed. Only two of the six drivers increased their shoulder usage with the DAS, but it was a large increase. Four of the drivers used less shoulder, but the decrease was minimal for three out of the four. Only one of the drivers used significantly less shoulder with the DAS. Overall, there was a 10.2 percent increase in the percentage of shoulder used.

Table 5-1

*Percentage of
Available Shoulder
Used*

Driver No.	DAS Off (%)	DAS On (%)	Change (%)
1	25.6	24.5	-1.1
2	18.5	65.8	+47.3
3	21.2	59.7	+38.5
4	50.2	48.3	-1.9
5	49.0	30.6	-18.4
6	10.4	7.8	-2.6
Average	29.2	39.4	+10.2

Impacts of DAS on Shoulder Speeds

Increased speeds in the shoulder are another corollary of increased driver confidence. The maximum allowable shoulder speed for the buses is 35 miles per hour (mph). The average shoulder speed without the DAS was already close to 31 mph. Nevertheless, average speeds increased to 34 mph when the DAS was in use. All six drivers who used the shoulders during both time periods drove faster in the shoulder with the DAS active. Two of them increased their speeds by 6 to 7 mph.

Table 5-2

*Average Speeds in
the Shoulder*

Driver	DAS Off (mph)	DAS On (mph)	Change (mph)
1	31.0	37.1	+6.1
2	29.3	32.2	+2.9
3	31.0	33.1	+2.1
4	31.3	31.4	+0.1
5	29.6	37.3	+7.7
6	33.2	34.0	+0.8
Average	30.9	34.2	+3.3

Impacts of DAS on Standard Deviation of Shoulder Speeds

For the third hypothesis, standard deviation was used as a measure of speed fluctuation. There is less fluctuation in speed as the standard deviation approaches zero. The logic behind this measure was that the DAS would lead to less speed fluctuation. Three of the six drivers had slightly less standard deviation of speed, and three had slightly more. Overall, the standard deviation of speed stayed roughly the same at about 4 mph.

Table 5-3
*Standard Deviation
of Speed*

Driver No.	DAS Off (mph)	DAS On (mph)	Change (mph)
1	3.9	3.3	-0.6
2	2.4	3.0	+0.6
3	3.4	1.9	-1.5
4	5.2	5.3	+0.1
5	7.2	5.3	-1.9
6	2.9	3.8	+0.9
Average	4.2	3.8	+0.4

SECTION 6

Technical Performance

The technical performance component of the evaluation compared how well the buses stayed inside the shoulder with and without the assistance of the DAS. The single hypothesis for technical performance was:

1. Runs with the DAS enabled will have less lateral deviation from the shoulder than runs with the DAS disabled.

This part of the evaluation required considerable thought because the DAS is a vehicle assist technology, not an automation technology. This means the driver can choose to ignore the feedback from the DAS and drive at the offset he/she prefers. The driver could also turn off individual DAS feedbacks. In conversations with MVTA and the IV Lab, it was agreed that the two best measures of effectiveness would be:

1. Standard deviation in centimeters from middle of shoulder.
2. Number of steering motor activations per 100 meters while in shoulder.

The standard deviation of offset from the center of shoulder is a measure of the side-to-side movement of the bus. There is less side-to-side movement as the standard deviation approaches zero. Reducing side-to-side movement is important because the average shoulder width is 11 feet while the width of the bus is 9.5 feet from mirror to mirror. That leaves an 18-inch margin of error. As Table 6-1 shows, five of the six drivers had less side to side movement when using the DAS. Overall, side to side movement dropped from 17.8 to 12.3 inches, well below the 18 inch margin of error.

Table 6-1
*Standard Deviation of
Offset from Shoulder
Center*

Driver No.	DAS Off (in.)	DAS On (in.)	Change (in.)
1	17.0	13.9	-3.1
2	17.3	9.6	-7.7
3	20.9	9.7	-11.1
4	13.7	13.9	+0.2
5	17.2	13.2	-4.0
6	20.6	13.5	-7.1
Average	17.8	12.3	-5.5

The steering motor activation messages could not be used for the evaluation. Originally, it was believed that the DAS computer would be able to generate steering motor activation messages even when the DAS was in passive mode. The motor itself would not be activated, but the activation message would be generated and recorded. It appears that was not the case. Consequently, this performance measure could not be included in the evaluation as an accurate indicator of technical performance.

SECTION 7

Maintenance

The intent of the maintenance portion of the evaluation was to measure the level of effort required to maintain and repair the DAS. The original plan was to examine data from the maintenance logs and to conduct a focus group with MVRTA maintenance staff. However, the focus group was dropped after it was learned by the evaluator that all DAS maintenance was handled by the system integrator, the IV Lab at the University of Minnesota. Therefore, the maintenance portion of the evaluation focused on a review of the maintenance log maintained by the IV Lab.

All maintenance repairs listed in the log between the start of DAS service in November 2010 to the end of the evaluation period in April 2011 were reviewed. In the log, each bus was identified by number. The log included a timestamp for when the problem was first reported, a timestamp for when the repair was completed, and notes on the service that was performed. There were a total of 219 repair incidents. Of those, 200 (91.3%) were non-serious in nature, meaning they did not involve the DAS being inoperative. Rather, they pertained to software updates and hard drive swaps that could be accomplished quickly in between revenue service runs. Only 19 (8.7%) of the repair incidents were serious in nature where the feedback from the DAS diminished or was inoperative.

To get a sense of how extensive the repairs were for those 19 incidents, the total number of days the DAS was down for repair was reviewed. This was determined by subtracting the timestamp of when a serious repair was closed from the timestamp of when the problem was first reported. An important note about the maintenance log is that it covers all repairs made between November 2010 and April 2011. However, accurate timestamps for when repair jobs were completed were not entered until after January 21, 2011. Consequently, the first 99 incidents in the maintenance log had an arbitrary completion date of January 21, 2011. Therefore, only repairs completed on or after January 22 were reviewed for the evaluation. That reduced the total number of serious repair incidents that could be measured from 19 to 12.

Table 7-1 shows that the serious repair incidents were limited to 6 of the 10 DAS-equipped buses. Collectively, the 6 buses were inoperative for 57 days between January 22 and April 29, 2011. That translates into the 10-vehicle DAS fleet being operative 91.9 percent of the time during the evaluation period, as shown in Table 7-2.

Table 7-1
Serious DAS Repair Incidents

Bus No.	Repair Incidents	Days Out of Service	Nature of Problem
4733	3	26	No seat feedback
4730	2	12	No seat feedback on right side
4732	2	8	Trimble GPS lost configuration; no seat feedback
4581	2	5	No seat feedback on left side; Trimble GPS lost configuration
4731	2	5	Right side seat controller relay “flakey”
4734	1	1	No steering wheel feedback

Table 7-2
Operative and Inoperative Percentages of the DAS Fleet

Total Out of Service Days	57
Total Test Days*	700
Percent Inoperative	8.1%
Percent Operative	91.9%

*Test period was 70 weekdays (1/22/11–4/29/11).

Total days = 70 days x 10 DAS-equipped buses.

Since the evaluation, the IV Lab has resolved the issues shown in Table 7-1. The loss of seat feedback was due to the connection being broken between the seat motors and the controller. The IV Lab fixed this problem by changing the connectors and the controllers on all 10 buses. The loss of Trimble GPS configuration was traced to pre-trip operator procedures. The operators run the bus for a short time to bring the brakes up to pressure and then shut the bus off to bleed the brakes down. Whenever the ignition was turned on, the GPS would start to configure. Shutting off the ignition before the GPS could finish caused configuration file to become corrupted (similar to what happens to a personal computer if the boot process is interrupted). To fix the problem, the IV Lab installed a timer that keeps the GPS system from booting unless the bus runs for at least five minutes. This was done on all 10 buses.

SECTION 8

Safety

According to MVTA, the accident rate for buses operating in the shoulder is already low. Nevertheless, the evaluation examined the impacts of the DAS on safety. The two hypotheses for this part of the evaluation were:

1. The DAS will facilitate safe operations in the shoulder.
2. Bus drivers will perceive driving in the shoulder to be as safe or safer with the DAS.

The first hypothesis was tested by comparing the accident data of the DAS-equipped buses for the first six months of operation (November 2010 to April 2011) to the same six months from the previous year. The data confirm that bus shoulder operations were and continued to be safe. There were zero accidents in the shoulder during both time periods. Although there were eight accidents in the pre-deployment period and four accidents in the post-deployment period, none of them had anything to do with shoulder operations. Rather, they included incidents such as a bus being rear-ended in downtown Minneapolis, two passengers slipping when getting off buses, and a complaint made about a bus driving in the far left lane of Cedar Avenue and slowing traffic.

The second hypothesis was tested via the driver survey. As shown in Table 8-1, 62.5 percent agreed or strongly agreed that the DAS made driving in the shoulder safer. Based on the focus group discussions mentioned in the previous section, the main source of negativity was the distracting nature of the HUD.

Table 8-1
*Impacts of DAS on
Perceptions of Safety*

Question	Strongly Agree	Agree (%)	Disagree (%)	Strongly Disagree (%)	Total Responses (N)
The DAS makes driving in the shoulder safer.	12.5	50.0	20.8	16.7	24

Lessons Learned

Since other transit agencies may consider using Vehicle Assist and Automation (VAA) technology similar or identical to the MVTA's DAS, it was important to collect information from MVTA on lessons learned. On June 20, 2011, Mr. Michael Abegg, MVTA's Transit Planning Manager and project manager for the DAS, was interviewed, covering several topic areas.

Institutional Obstacles

The only institutional issue cited by Mr. Abegg was that, initially, some of the drivers questioned the need for the DAS. By limiting the DAS rollout to 10 buses, it did not become a big issue. Had MVTA decided to implement the DAS system-wide, the objections might have been stronger. MVTA management told the drivers that if they were not interested in going through the DAS training, they should not bid on the DAS routes. It should be noted that MVTA uses a private company, Schmitt and Sons Transit, to operate the routes, and the drivers are not unionized. This gave MVTA more flexibility in writing up the work rules for the DAS routes. When asked if the Minnesota Department of Transportation (MnDOT) or the State Highway Patrol raised any objections to the DAS, Mr. Abegg said no, because all of the technology was on the bus and not the road. It might have been different if the DAS required making modifications to the shoulder or adding RFID (Radio Frequency Identification) equipment to the side of the shoulder.

Insurance Liability Issues

As a government agency, MVTA is protected with a liability cap. As a private entity, Schmitt and Sons Transit does not enjoy that benefit. Although Schmitt and Sons initially had no objections to the DAS, they began to raise concerns about liability as MVTA moved closer to conducting training and installing the DAS on the buses. Several safety incidents at transit agencies nationwide over the last several years have put risk management more in the spotlight. Schmitt and Sons were concerned that in the event of an accident related to the DAS, they would become the target of expensive civil lawsuits. Mr. Abegg said it was an education process to convince them to accept the DAS. MVTA invited the insurance underwriters to visit and test-drive the DAS simulator and go out on the road with a DAS bus. Once MVTA showed Schmitt and Sons and their insurance provider that the driver would always be in control of the steering, they were okay with the DAS. Mr. Abegg added that having a well-thought-out training program also helped convince that insurance provider. If he had to do it all over again, he said he would have involved the insurance company earlier on in the process.

Involvement of Bus Drivers in DAS Design

When asked if any bus drivers were involved in the DAS design, Mr. Abegg responded no. The DAS interfaces already existed on the prototype “techno bus” that was designed for Metro Transit. The components had been improved upon, but the interfaces were the same. MVTA training staff provided feedback to the IV Lab on the placement of the feedback components, but there was never any discussion regarding the value of any given component. However, even if the training staff had questioned the need for one or more of the components, MVTA management would still likely have pursued all four. The reason is that, at that time, there was a body of research that had been done on using the DAS with snow plows in Alaska, which showed that all four DAS components (HUD, virtual mirror, haptic steering, and tactile seat) provided valuable feedback. If there was a lesson to be learned here, it is that transit shoulder operations are not the same as snow plow operations.

Restrictions on Which Drivers Can Bid on DAS Routes

The only restriction that MVTA placed on bidding for DAS routes is that the driver must be willing to undergo DAS training. Also, if a driver subsequently refused to use the DAS, he/she was prevented from bidding on DAS routes the next time around.

Level of Satisfaction with DAS

From a technical perspective, Mr. Abegg stated he was very satisfied with the DAS because it does what it promised to do. Furthermore, the DAS training was beneficial because it encouraged Schmitt and Sons to make their training more formalized. Mr. Abegg stated that his biggest frustration with the DAS has been that the drivers did not seem to make much use of it because Minnesota UPA has resulted in traffic flow improvements. Many of the shoulder locations that were used quite frequently are no longer used as much.

Advice for Other Transit Agencies Considering Using the DAS

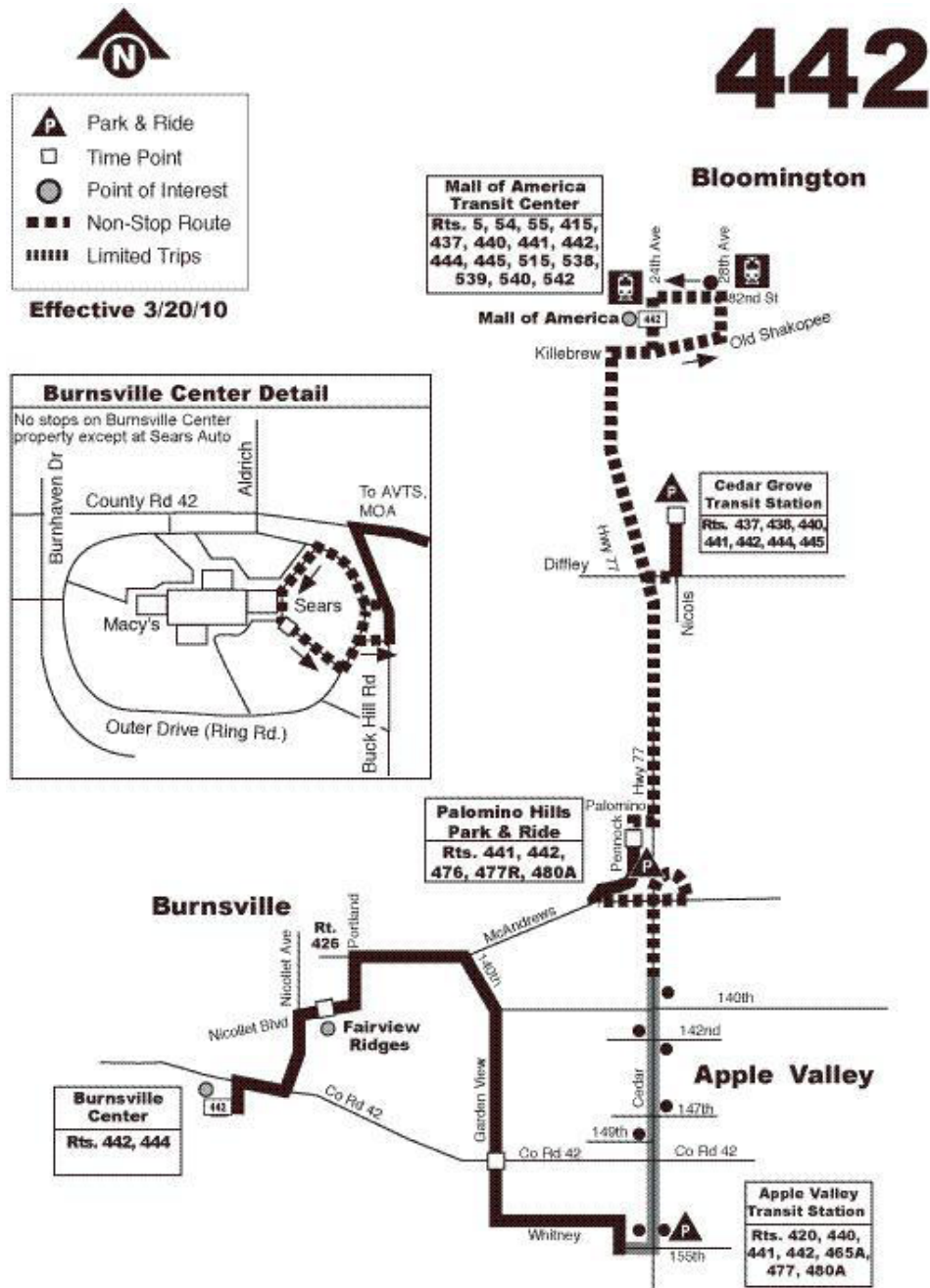
Mr. Abegg’s advice to other agencies was to design the system so that it puts the drivers first. It needs to be made clear to drivers that control of the bus is not being taken from them; it is about providing them with a tool to help them do their job better.

APPENDIX

A

DAS Route Maps

Appendix A contains the route maps published by Minnesota Valley Transit Authority for the three DAS-equipped routes: Route 442 (local) and Routes 476 and 477 (express).

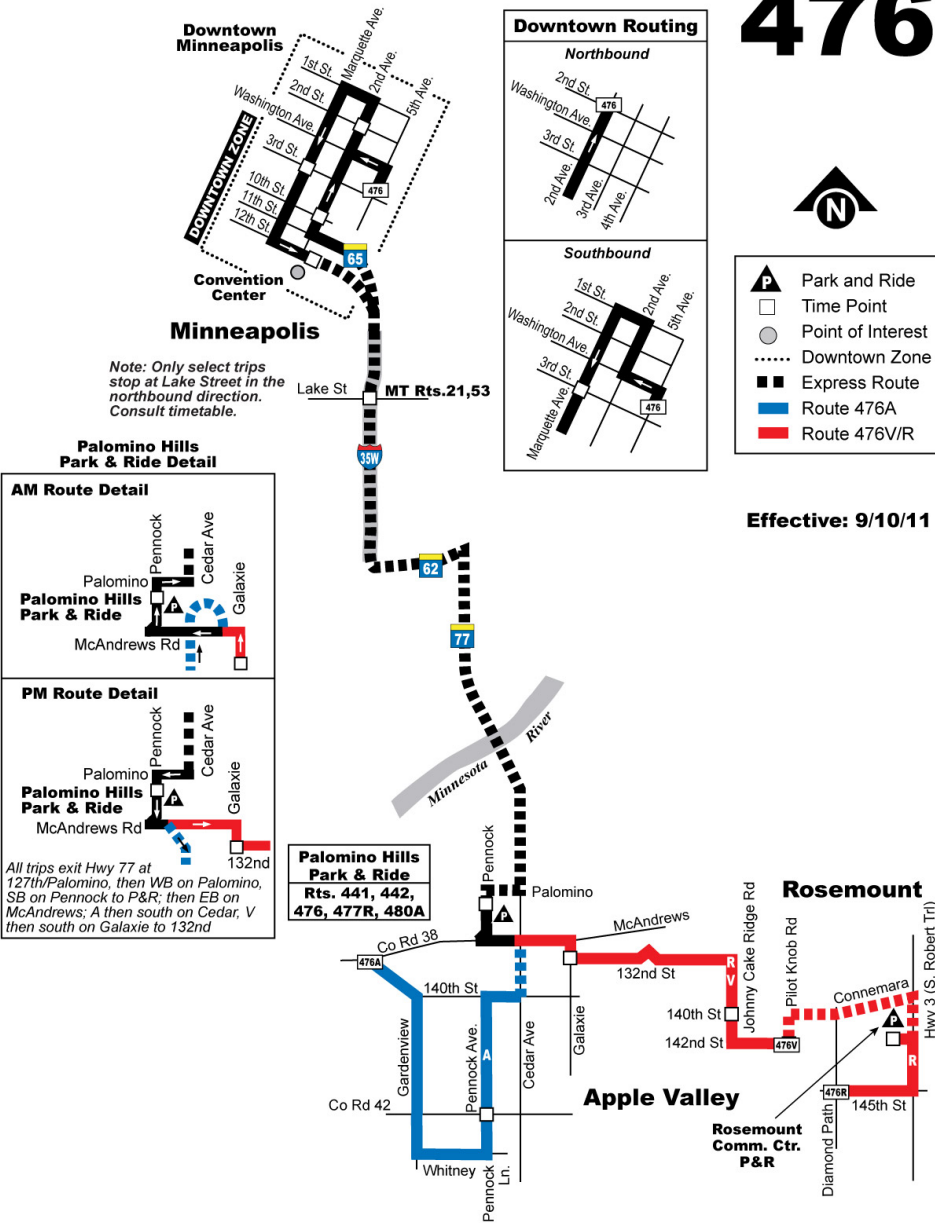


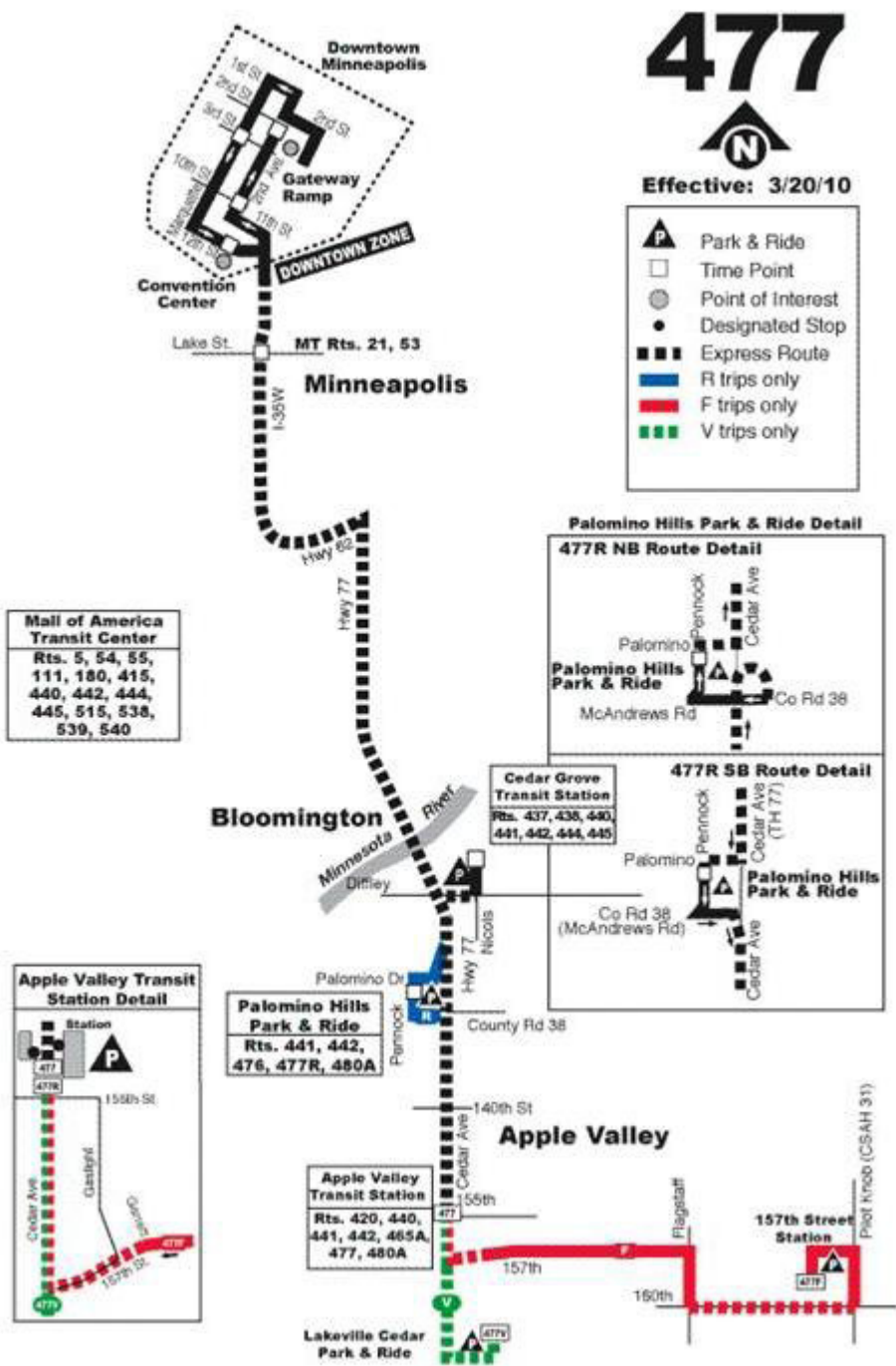
476



- Park and Ride
- Time Point
- Point of Interest
- Downtown Zone
- Express Route
- Route 476A
- Route 476V/R

Effective: 9/10/11





APPENDIX B

Test Segments

Following are aerial photographs of the two test segments used in the evaluation. For the AM period, a northbound test segment was used from the on-ramp at Cliff Road to the southern end of the truss on the Minnesota River Bridge, a distance of 2,760 meters or 1.7 miles. For the PM period, a southbound test segment was used from 71st Street to the beginning of the Minnesota River Bridge, a distance of 2,636 meters or 1.6 miles.

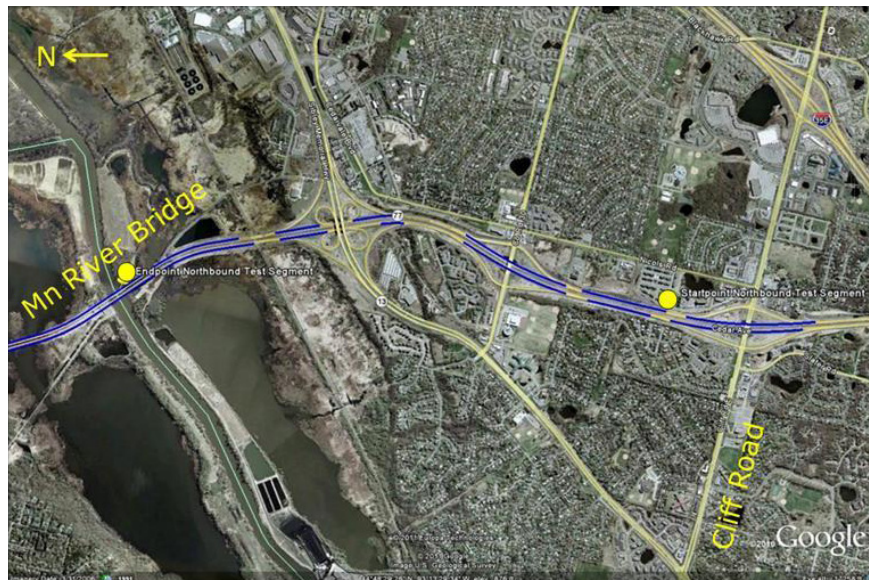
Southbound Test Segment

2,636 meters or
1.6 miles



Northbound Test Segment

2,760 meters or
1.7 miles



APPENDIX C

Bus Driver Survey and Responses

Following is the survey questionnaire administered to the DAS-trained bus drivers and their responses. The questionnaire asked for their opinions on DAS feedbacks, the DAS Simulator, and their level of confidence using the DAS.

MVTA Driver Assist System (DAS) Survey



MVTA Driver Assist System (DAS) Survey

The Center for Urban Transportation Research at the University of South Florida is conducting an evaluation of the MVTA's Driver Assist System (DAS), and we'd like to hear your comments. The survey is strictly anonymous. Your feedback will be used to help make any necessary improvements to the DAS and to help other transit agencies that are considering similar technology for their buses. Please complete the survey and return it to the dispatcher.

Please check the response that you feel is most accurate. Choose one response only.

	Strongly Agree	Agree	Disagree	Strongly Disagree
1. The amount of DAS simulator training I had was sufficient.				
2. The amount of DAS on-the-road training I had was sufficient.				
3. The simulator helped me to better understand the DAS.				
4. The DAS is easy to use.				
5. The DAS makes driving in the shoulder less stressful.				
6. The DAS makes driving in the shoulder safer.				
7. With the DAS, I am more likely to use the shoulder during:				
Clear Days				
Snow				
Rain				
Fog				
8. I find the feedback from the head up display helpful.				
9. I find the feedback from the steering wheel helpful.				
10. I find the feedback from the vibrating seat helpful.				
11. I find the feedback from the virtual mirror helpful.				

12. 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?

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

13. Are you more or less confident driving in the shoulder now that you've completed simulator and on-the-road training (regardless of whether the bus has DAS or does not have DAS)?

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

Driver Survey Responses

	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)	Total Responses (N)
General opinions about the DAS					
Amount of DAS simulator training I had was sufficient.	44.0	56.0	0.0	0.0	25
Amount of DAS on-the-road training I had was sufficient.	52.0	48.0	0.0	0.0	25
Simulator helped me to better understand the DAS.	32.0	52.0	12.0	4.0	25
DAS is easy to use.	36.0	52.0	8.0	4.0	25
DAS makes driving in the shoulder less stressful.	12.0	52.0	20.0	16.0	25
DAS makes driving in the shoulder safer.	12.5	50.0	20.8	16.7	24
Opinions about using the shoulder under various weather conditions					
With the DAS I am more likely to use the shoulder during ...					
Clear Days	7.1	42.9	28.6	21.4	14
Snow	27.3	68.2	0.0	4.5	22
Rain	15.0	70.0	10.0	5.0	20
Fog	22.7	68.2	4.5	4.5	22
Opinions about individual DAS feedbacks					
I find the feedback from the head-up display helpful.	16.0	44.0	20.0	20.0	25
I find the feedback from the steering wheel helpful.	8.0	44.0	32.0	16.0	25
I find the feedback from the vibrating seat helpful.	24.0	56.0	8.0	12.0	25
I find the feedback from the virtual mirror helpful.	8.0	56.0	16.0	20.0	25
	More Confident (%)	Less Confident (%)	Same (%)	Don't Know (%)	Total Responses (N)
Changes in driver confidence levels while driving in the shoulders					
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?	32.0	0.0	60.0	8.0	25
Are you more or less confident driving in the shoulder now that you've completed simulator and on-the-road training?	32.0	4.0	60.0	4.0	25

Transit Rider Survey and Responses

Following is the survey questionnaire administered to transit riders on the DAS routes and their responses. The questionnaire asked riders if they were aware of the presence of the DAS on the bus, to rate the ride quality in the shoulder, and whether they perceived any difference in bus performance.



Cedar Avenue Bus Rider Survey

Hello. The bus you are riding is equipped with special technology that helps the bus driver while in the shoulder. We'd like your feedback on how it's affected your ride. The Driver Assist System provides lane guidance to the driver when operating on the shoulder along Cedar Avenue. Through the use of visual and physical feedback, the driver is warned if he/she starts to drift out of the shoulder. We're curious if you've noticed any changes to your ride.

1. How long have you been riding this bus route (not just this specific trip)?

☐ First time riding	☐ 6 months to 1 year
☐ Less than 6 months	☐ 1 to 5 years ☐ More than 5 years

2. Approximately how many days a week do you ride this bus route (again, not just this specific trip)?

☐ 4-5 days per week	☐ Less than one day per week
☐ 1-3 days per week	☐ Very infrequently

3. Did the presence of the driver assistance technology influence your decision to ride this route *and* trip?

☐ Yes	☐ No
------------------------------	-----------------------------

4. If you ride regularly, do you notice when a Driver Assist System (DAS) bus is operating on your trip?

☐ Yes	☐ No
------------------------------	-----------------------------

Cedar Avenue Bus Rider Survey

cont'd.

5. How would you rate the quality of each of the following aspects of the ride when the bus is on the shoulder? Please circle the number that best reflects your opinion.

	Very Good	Good	Fair	Poor	Very Poor	Don't Know
Merging in/out of the shoulder	5	4	3	2	1	0
Swaying of the bus	5	4	3	2	1	0
Accelerating/decelerating	5	4	3	2	1	0
Overall smoothness of the ride	5	4	3	2	1	0

6. How satisfied are you with the travel time reliability of this route? Reliability is the day to day consistency in time it takes this bus to get you to your destination.

Very Satisfied	Satisfied	Unsatisfied	Very Unsatisfied	Don't Know
4	3	2	1	0

7. How satisfied are you with the on-time performance of this route? In other words, how well does this bus pick you up and drop you off according to the schedule?

Very Satisfied	Satisfied	Unsatisfied	Very Unsatisfied	Don't Know
4	3	2	1	0

8. If you ride regularly, do you notice a difference in ride quality, reliability, and/or on-time performance on days when a bus equipped with the Driver Assist System is operating on your trip?

Seems Better	No Difference	Seems Worse	Don't Know if a DAS Bus is Operating
3	2	1	0

Thank you very much for your time. Please return your completed questionnaire to the driver as you exit the bus, or on your next trip.

Transit Rider Survey Responses

	Frequency	Percent
How long have you been riding this bus route?		
First time riding	4	3.0
Less than 6 months	25	18.5
6 months to 1 year	15	11.1
1 to 5 years	39	28.9
More than 5 years	52	38.5
Total	135	100.0
Approximately how many days a week do you ride this bus route?		
4–5 days	110	82.1
1–3 days	15	11.2
Less than one day per week	3	2.2
Very infrequently	6	4.5
Total	134	100.0
Did the presence of the driver assistance technology influence your decision to ride this route and trip?		
Yes	16	11.9
No	119	88.1
Total	135	100.0
If you ride regularly, do you notice when a Driver Assist System (DAS) bus is operating on your trip?		
Yes	23	17.4
No	109	82.6
Total	132	100.0

	Very Good (%)	Good (%)	Fair (%)	Poor (&)	Very Poor (%)	Don't Know (%)	N
How would you rate the quality of each of the following aspects of the ride when the bus is on the shoulder?							
Merging in/out of shoulder	52.2	34.3	5.2	1.5	0.0	6.7	134
Swaying of bus	49.3	35.1	8.2	2.2	0.0	5.2	134
Accelerating / decelerating	43.6	39.1	9.8	2.3	0.8	4.5	133
Overall smoothness of ride	49.3	34.3	10.4	0.7	0.7	4.5	134

Transit Rider Survey Responses

cont'd.

	Frequency	Percentage
How satisfied are you with the travel time reliability of this route?		
Very satisfied	85	63.0
Satisfied	48	35.6
Unsatisfied	2	1.4
Very unsatisfied	0	0.0
Don't know	0	0.0
Total	135	100.0
How satisfied are you with the on-time performance of this route?		
Very satisfied	79	68.7
Satisfied	32	27.8
Unsatisfied	4	3.5
Very unsatisfied	0	0.0
Don't know	0	0.0
Total	115	100.0
If you ride regularly, do you notice a difference in ride quality, reliability, and/or on-time performance on days when a bus equipped with the Driver Assist System is operating on your trip?		
Seems better	22	19.5
No difference	40	35.4
Seems worse	2	1.8
Don't know if a DAS bus is operating	49	43.4
Total	113	100.0



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