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Vehicle Assist and Automation (VAA) Demonstration Evaluation Report

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PREPARED BY

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U.S. Department of Transportation
Federal Transit Administration

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DECEMBER 2012

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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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This report summarizes an evaluation of a vehicle assist and automation (VAA) system used by Lane Transit District in Eugene, Oregon, for its Emerald Express (EmX) Bus Rapid Transit (BRT). The 1.5-mile demonstration involved the use of magnetic sensors for precision docking at three stations and lane guidance between the stations. The VAA system was evaluated in six broad areas: bus driver satisfaction, customer satisfaction, efficiency/productivity, technical performance, maintenance, and safety. Data were collected from a variety of sources, including customer surveys, driver surveys and focus groups, accident reports, maintenance reports, and lane position data from the VAA on-board computer system. Key findings indicated that the VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform. The VAA was widely praised by the bus operators and passengers for it precision docking at the station platforms.

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ABSTRACT

This report summarizes an evaluation of a vehicle assist and automation (VAA) system used by Lane Transit District in Eugene, Oregon, for its Emerald Express (EmX) Bus Rapid Transit (BRT). The 1.5-mile demonstration involved the use of magnetic sensors for precision docking at three stations and lane guidance between the stations. The VAA system was evaluated in six broad areas: bus driver satisfaction, customer satisfaction, efficiency/productivity, technical performance, maintenance, and safety. Data were collected from a variety of sources, including customer surveys, driver surveys and focus groups, accident reports, maintenance reports, and lane position data from the VAA on-board computer system. Key findings indicated that the VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform. The VAA was widely praised by the bus operators and passengers for it precision docking at the station platforms.

EXECUTIVE SUMMARY

In 2008, the California Department of Transportation (Caltrans) was awarded $1.9 million by the Federal Transit Administration (FTA) and the Intelligent Transportation Systems Joint Program Office (ITS JPO) for the "Pilot Program to Demonstrate the Benefits of Vehicle Assist and Automation Applications for Full-Size Public Transit Buses." In addition to the $1.9 million, Caltrans provided a $1.5 million match. The Caltrans partners included Alameda-Contra Costa County Transit District (AC Transit) in California, Lane Transit District (LTD) in Oregon, California Partners for Advanced Transportation Technology (PATH) at the University of California (UC) Berkeley, and three private sector companies, ContainerTrac, Integrated Motion, Inc., and Bob McGee's Machining Company, Inc.

The objective in the original Caltrans proposal was to test lateral guidance/control on a stretch of a high occupancy vehicle (HOV) lane and through a toll booth on AC Transit's M Line and to test lateral guidance/control and precision docking on LTD's Emerald Express (EmX) Bus Rapid Transit (BRT). The AC Transit M line connects Castro Valley, Hayward, and Union City with San Mateo and Santa Clara counties, crossing the San Mateo-Hayward and Dumbarton bridges. The EmX is an 11.8-mile BRT system. The original EmX route was 4 miles and operated east–west between downtown Eugene and downtown Springfield. In 2011, the 7.8-mile Gateway Extension was opened, which runs north–south on Pioneer Parkway from the Springfield Station and provides service to the Gateway Mall and Sacred Heart Medical Center. The VAA was tested on a 1.5-mile segment of the original route, and the VAA application used two sensing technologies—magnetic markers as the primary system and differential Global Positioning System (GPS) with inertial navigation sensors as the secondary back-up system.

Originally, the project was expected to be completed by March 2011. However, there were numerous delays from the beginning, most of which stemmed from institutional, contractual, and liability issues. The longest delay was for one year and was sparked by a Caltrans internal review that added requirements to the contract between Caltrans and UC. By the time the contractual issues were resolved, the subcontract with AC Transit had expired. Consequently, AC Transit dropped out of the demonstration. Therefore, this report is limited to the findings for LTD.

The demonstration of the VAA in revenue service at LTD began on June 10, 2013. The project was suspended from October 2013 to October 2014 due to the contractual and liability issues between Caltrans and UC. Revenue service started again in October 2014 and ended in February 2015. Altogether, 10 months' worth of data were collected with the VAA enabled.[1]

[1]The 10 months include June–October 2013, September–November 2014, and January–February 2015.

The National Bus Rapid Transit Institute (NBRTI) of the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) evaluated the VAA system 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 focus groups, accident reports, maintenance reports, and lane position data from the VAA on-board computer system. The key findings for the six evaluation areas are listed in Table ES-1 and are described in greater detail in the paragraphs immediately below. Lessons learned from the project are discussed in Section 9 of the report.

Related to technical performance, the VAA system kept the bus better centered in the busway while it was in motion, and it consistently docked the bus closer to the station platform. The largest recorded offset from the lane center with the VAA enabled was 11.06 centimeters (cm). When the VAA was disabled, it was as high as 44.34 cm. When docking at the stations, the maximum reported deviation from the platform with the VAA was 1.94 cm; without the VAA, it was 11.08 cm.

The evaluation found that lateral acceleration is an area of improvement that needs to be addressed. Lateral acceleration, the g-force that throws vehicle passengers sideways in a turn, was consistently higher on several of the lane segments when the steering was under automated control. In interviews conducted with bus operators and in surveys of riders, many reported that the ride experience felt "jerky." This finding suggests a need to strike a balance between tight lane control and ride comfort when designing the magnetic pathway.

Related to efficiency and productivity, the bus operators in general drove slightly slower when using the VAA, with speed differences varying from segment to segment. When the VAA was enabled, the speeds ranged from 4.08 mph slower to 1.96 mph faster, which translated into slightly longer travel times with the VAA enabled. However, the difference was of such small magnitude (about 3.37 seconds longer within the 1.5-mile test segment) that it was not likely to have been noticed by the riders. This finding suggests that bus operators are more cautious with their speed when yielding control of the steering to the VAA.

In terms of system availability, the VAA was operational 100% of the time during the evaluation period, with the exception of August and September 2013; the problem in those months was not the VAA but rather a bad alternator and battery. In terms of maintenance, the VAA-equipped bus had two reported work orders for bent wheels (wheels damaged by side impact collisions with the station platforms) during the evaluation period, but neither could be traced to the 1.5-mile VAA test segment. The first incident of damage was discovered during a routine inspection by one of LTD's maintenance technicians, and the second was reported in the vicinity of the Springfield Station (not on the VAA test segment).

In regards to comparable safety-related incidents within the 1.5-mile test segment, there was only one occurrence of a bus striking the station platform (a non-VAA bus). One safety-related incident occurred with the VAA-equipped bus: in December 2012, the VAA bus was on a training run with the steering under VAA control when it hit a bump causing it to jump the curb of the busway. VAA operations were suspended for six months while PATH investigated and corrected the problem, which was determined to be a failure of the primary controller to detect a fault. Consequently, PATH modified the safety software so there was full fault detection redundancy in both the primary and secondary controllers. Service with the VAA resumed in June 2013, after which there were no safety-related incidents or collisions with the VAA-equipped bus during the evaluation.

Table ES-1

Six Core Evaluation Areas and Key Findings

Evaluation Area	Key Findings
Bus Driver Satisfaction	• Drivers very positive about precision docking. • Drivers less positive about lateral control due to "jerky" sensation.
Customer Satisfaction	• High praise for precision docking. • Some criticism of "jerky" sensation while in motion.
Efficiency/Productivity	• Speeds up to 4 mph slower with VAA enabled; may reflect cautiousness on part of bus drivers (although speed differences were inconsistent or higher with VAA enabled in some route segments). • Speed and travel time differences not likely to have been noticeable to riders.
Technical Performance	• Tight lateral control with VAA; max lateral deviation from lane center 11.06 cm; without VAA, was 44.34 cm. • Precise docking with VAA; max deviation from the platform was 1.94 cm; without VAA it was 11.08 cm. • Lateral acceleration (g force) higher with VAA on 7 of 18 travel segments; contributed to "jerky" ride sensation. • VAA available 100% of time except for 2 months; problem due to bad alternator and battery, not VAA.
Maintenance	• VAA-equipped bus had 2 bent wheel orders during evaluation; neither traced to 1.5-mile VAA test segment.
Safety	• 1 incident occurred during VAA operations early in demonstration and was corrected; no further incidents occurred.

SECTION 1

Vehicle Assist and Automation (VAA) Project

Background

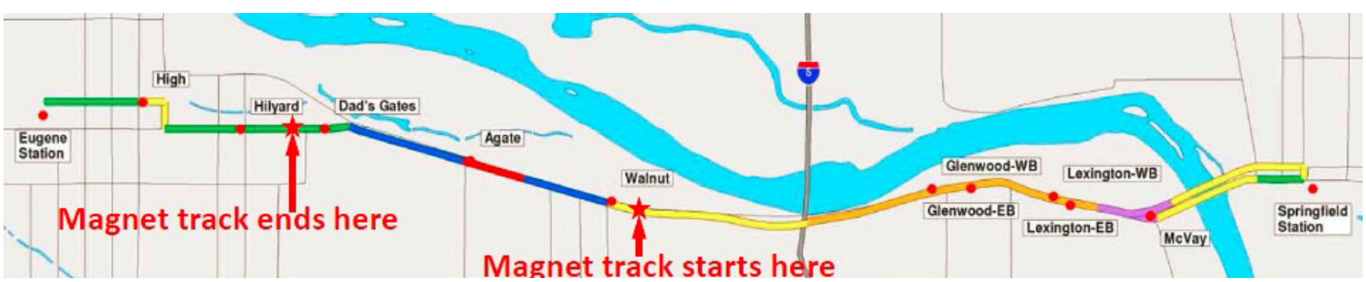
In 2008, the California Department of Transportation (Caltrans) was awarded $1.9 million by the Federal Transit Administration (FTA) and the Intelligent Transportation Systems Joint Program Office (ITS JPO) for a "Pilot Program to Demonstrate the Benefits of Vehicle Assist and Automation Applications for Full-Size Public Transit Buses." In addition to the $1.9 million, Caltrans provided a $1.5 million match. The Caltrans partners included Alameda-Contra Costa County Transit District (AC Transit) in California, Lane Transit District (LTD) in Oregon, California Partners for Advanced Transportation Technology (PATH) at the University of California (UC) Berkeley, and three private sector companies, ContainerTrac, Integrated Motion, Inc., and Bob McGee's Machining Company, Inc. The objective in the original Caltrans proposal was to test lateral guidance/control on a stretch of a high occupancy vehicle (HOV) lane and through a toll booth on AC Transit's M Line and to test lateral guidance/control and precision docking on LTD's Emerald Express (EmX) Bus Rapid Transit (BRT). However, due to unresolved contractual and liability issues, AC Transit dropped out of the project in Fall 2014, leaving only LTD and EmX.

The EmX is an 11.8-mile BRT system that began service in 2007 as a 4-mile east-west route between downtown Eugene and downtown Springfield. In 2011, the 7.8-mile Gateway Extension opened, which runs north–south on Pioneer Parkway from the Springfield Station and provides service to the Gateway Mall and Sacred Heart Medical Center (see EmX route map in Appendix A.) The EmX was an ideal choice for the VAA demonstration from both technical and operational standpoints because it uses 60-foot articulated buses and the route has multiple lane types/alignments and curves, as illustrated in Figure 1-1.

Figure 1-1

EmX route configurations

The original plan was to demonstrate the VAA on the 4-mile length between downtown Eugene and downtown Springfield, which included 10 stations. Because costs were greater than originally projected, the project limits were reduced to a 1.5-mile test segment and 3 stations. Figure 1-2 shows a map of the original EmX route with the various lane types/alignments, and Figure 1-3 is a map of the test segment and the three stations (Dad's Gate, Agate, and Walnut).



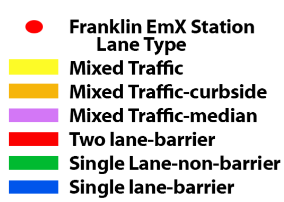


Figure 1-2

EmX Route, Franklin

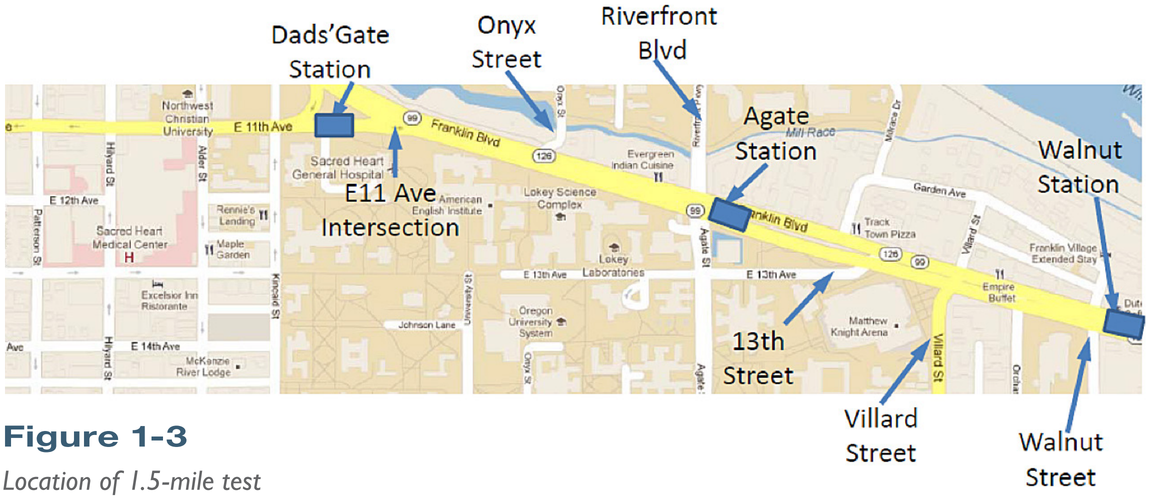


Figure 1-3

Location of 1.5-mile test

As noted, the EmX corridor in general is very curvy; the test segment includes 36 curves (19 in the westbound direction and 17 in the eastbound direction). Of those 36 curves, 8 have a radius of less than 100 meters. The eastbound approaches to Agate Station and Walnut Station require multiple lane changes within short distances. Aerial photos of the three stations are shown in Figures 1-4, 1-5, and 1-6.

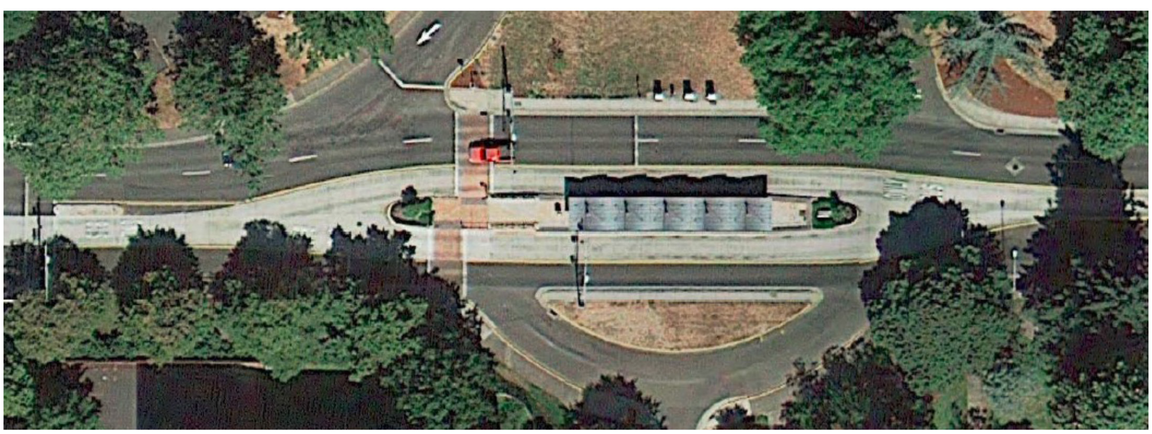


Figure 1-4

Dad's Gate

Figure 1-5

Agate Station

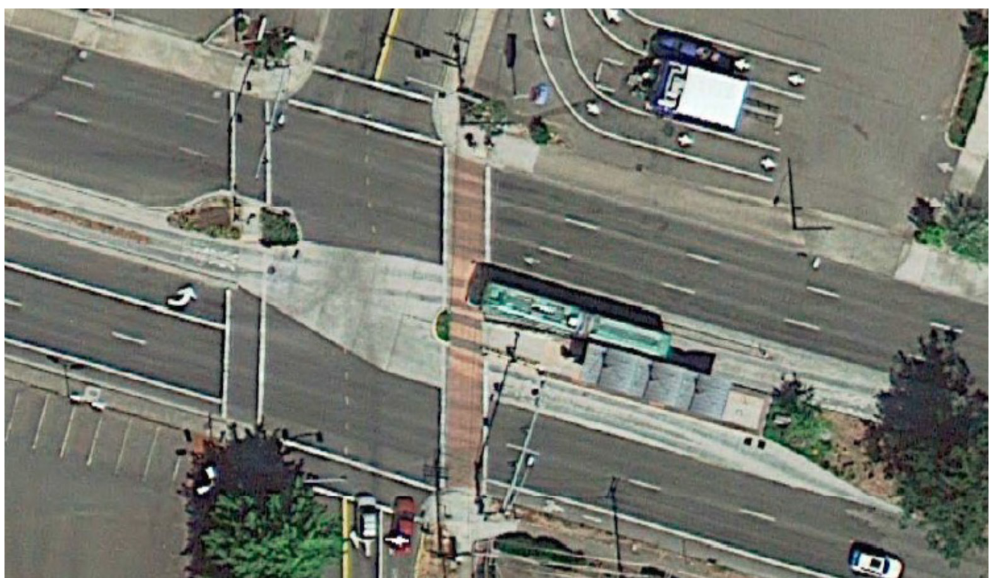


Figure 1-6

Walnut Station

Implementation Issues

Originally, the project was expected to be completed by March 2011; however, there were numerous delays from the beginning. In December 2012, during a training run of the VAA-equipped bus while it was under VAA control, the bus hit a bump, causing it to jump the curb of the busway and go into the opposing traffic lane. The bus driver retook control of the steering, as trained, and there were no damages or injuries. However, LTD suspended the use of the VAA for six months, until June 2013, while PATH investigated and corrected the problem. It was determined that the mishap was caused by a failure of the primary controller to detect a fault. Consequently, PATH modified the safety software so there was full fault detection redundancy in both the primary and secondary controllers. Service with the VAA resumed in June 2013.

The longest project delay was for one year and was sparked by a Caltrans internal review that added requirements to the contract between Caltrans and UC. The VAA project was suspended from October 15, 2013, to October 10, 2014. By the time the contractual issues were resolved, the subcontract with AC Transit had expired. Consequently, AC Transit dropped out of the demonstration. Other delays were caused by failed contract negotiations with TRW, Inc., the original intended supplier of the steering actuator, and turnover of key engineering staff at PATH.

VAA Components

The VAA system automates the steering function while the bus operator controls the acceleration and braking. The key components of the VAA system include a steering actuator, magnetic sensor modules, a differential Global Positioning System (GPS)/inertial navigation system (INS) module, control computers, and a human-machine interface (HMI).

The steering actuator provides the steering control functions. Originally, this was to be supplied by a private company, TRW. However, no agreement could be reached after months of legal negotiations. Consequently, PATH designed a prototype steering actuator, which was fabricated by Bob McGee's Machining Company, Inc.

The magnetic sensor modules measure the lateral position of the bus with respect to the magnetic track. One LTD VAA-equipped 60-foot articulated bus had two sensor bars, one in front of the front wheels and the other about 5 meters behind (under the middle door). Single rare-earth magnets embedded in the lane about 3–4.25 feet apart indicate the lane center. Alternating the magnetic polarities of the markers (north-up vs. south-up) creates a binary code that indicates roadway characteristics. The magnetic sensors mounted under the bus measure the magnetic fields on three axes. A Pentium computer processes the magnetic field data to derive lateral and longitudinal position measurements and to decode the binary information.

The DGPS/INS serves as a secondary sensing system.[2] Its integration software converts the global position estimates to lateral deviations from the lane centerline by comparing the global position estimates with the surveyed positions

[2]The LTD VAA implementation used a mid-range GPS receiver with a Wide Area Augmentation System (WASS) correction (i.e., did not require support from local base stations).

of the magnets installed along the center of the bus lane. The DGPS/INS was not used for control, but only as a secondary, independent source of measurement and location referencing.

The VAA system incorporates two controller computers, each with its own power supply, for purposes of redundancy. They serve as the brain of the VAA system by performing sensor fusion, lateral control, fault detection, and management. The HMI module provides information to and takes commands from the bus driver. It features redundant audio and visual feedback and is connected to both computer controllers.

Figure 1-7 shows the VAA system components. The LED lights, buzzer, and control switches/buttons are located near the dashboard and driver control panel. When the VAA system is activated, lateral control is done by the steering actuator. However, the acceleration and braking are controlled by the bus operator.

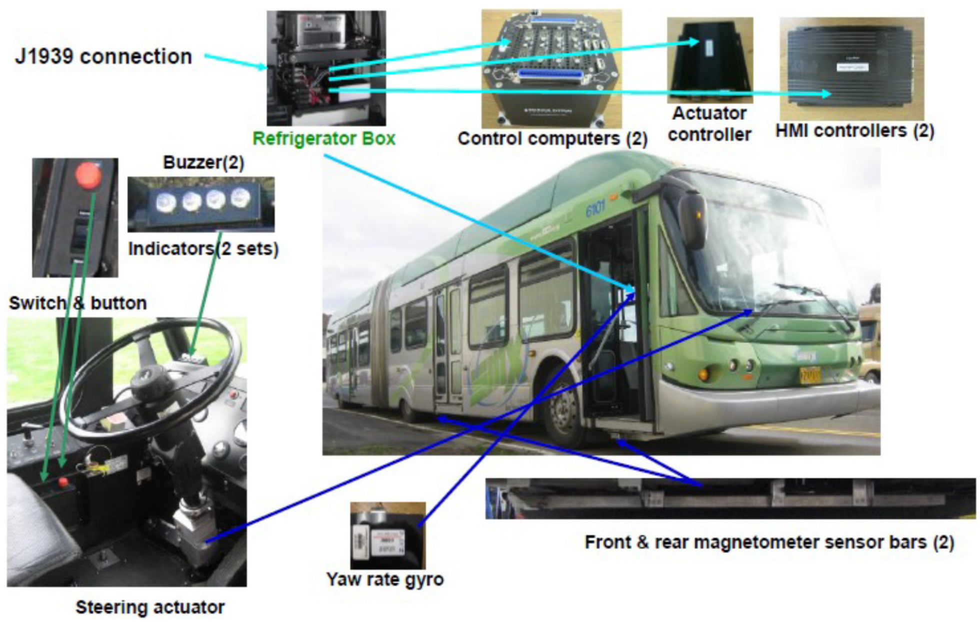


Figure 1-7

VAA system components on 60ft New Flyer LTD

SECTION

2

Methodology

The operational test plan was divided into two phases: VAA operation without passengers and VAA operation with passengers. The former was done in May 2013 to accustom the drivers to using the VAA system. Revenue service with the VAA commenced in June 2013 and continued until October 2013 when it was suspended due to contractual issues between UC and Caltrans. Revenue service resumed a year later, in October 2014, and the evaluation ended in February 2015.

The original intent was to conduct a "with and without" approach. Several months of baseline data were to be collected with the bus drivers operating in manual mode (i.e., without the VAA). Subsequent data were to be collected from these same drivers with the VAA enabled to control for variations in driver behavior. Unfortunately, this approach proved to be impractical due to a number of issues, including the inability to have operators consistently engage the VAA system, driver absenteeism and vacations, and extended project delays, during which time there were driver reassignments. Therefore, the data were not aggregated by individual driver. As a result, there were limitations to the conclusions that can be made from the data results. Table 2-1 shows how the data outputs from the VAA system were aggregated.

Table 2-1

VAA System Technical Performance Measures

Measure of Effectiveness	Data matched to individual driver?	How are data grouped?	Are data categorized by VAA status (enabled vs. disabled)?
Avg. operating speed	No	By lane segment	For Jan and Feb 2015 only; other months are combined data
Avg. running time	No	By lane segment	For Jan and Feb 2015 only; other months are combined data
Offset from lane center	No	By lane segment	Yes
Docking accuracy	No	By station	Yes
Lateral acceleration	No	By lane segment	Yes

For the evaluation of customer satisfaction, the original plan was for LTD to establish a customer volunteer group that would provide feedback on the VAA over the course of the evaluation. This was to be accomplished via surveys, focus groups, and trip journals. Initially, a Customer Volunteer Group (CVG) was established, but because of the various project delays, the customer satisfaction component of the evaluation was modified to be a single focus group consisting of 13 individuals who worked for LTD, the City of Eugene, Lane County, the City of Springfield, the Oregon Department of Transportation, and the Lane

Council of Governments. NBRTI staff met with the focus group on April 3, 2015. Participants were given an orientation of the VAA followed by a field trip on the EmX. On the outbound trip, they rode an EmX bus from Eugene Station to Walnut Station in manual mode (without the VAA). On the return inbound trip, they rode an EmX bus with the VAA enabled. Participants were asked to pay attention to different aspects of ride quality such as the side-to-side movement of the bus and the alignment of the bus at stations. They also were asked to consider how the bus with the VAA compared to regular bus performance. After the field trip, the participants were given a survey, and a group discussion followed.

Similar to the evaluation of customer service satisfaction, the evaluation of bus operator satisfaction was to be conducted through surveys, interviews, and ongoing reporting via journals throughout the evaluation. Their opinions and perceptions were to be sought regarding the VAA's ease of use and accuracy as well as how it impacted their driver stress and performance. This evaluation procedure also had to be adapted due to project delays—LTD trainers communicated with participant operators, and NBRTI staff conducted individual operator interviews throughout the demonstration period.

SECTION

3

Bus Operator Satisfaction

The hypothesis for bus operator satisfaction was that the VAA system would generate a positive response in areas such as ease of use, reduced stress, improved job performance, and perceived VAA system performance. This part of the evaluation consisted of interviews with seven EmX bus operators to capture their opinions and experiences with the VAA system and seek their recommendations for improvements. To facilitate consistency in the interviews, a multi-point interviewer guide was used, which included the following discussion areas:

- Introductions/general purpose of evaluation
- Length of time as an operator
- Length of time operating VAA
- Overall impression
- Benefits
- Issues/concerns
- Operations in runway, curves
- Operations at station precision docking
- Adequate training
- Ride quality
- Performance reliability
- Ease of use, helps operate, benefits to you
- Safety enhanced
- Design assessment
- Overall opinions/comments regarding demonstration
- Recommendations

Overall Impression of VAA System

The EmX operators overwhelmingly reported a positive impression of the VAA system—in particular, the performance of the precision docking at the three stations. The perceived benefits included improved safety with consistent docking alignment at stations, the ability to better focus on platform activity and riders when approaching stations without the competing stress of concentrating on aligning the position of the bus, and the safety and accessibility provisions for riders alighting and boarding precision-docked doorways. All operators recognized that the consistent performance of the precision docking eliminated collisions with station platforms and damage to the bus body, tires, wheels, and axles.

Several areas of concern were articulated by the operators. First, they indicated that there was an initial hesitation to “trust” the system by letting go of the wheel. There was also a predominant opinion that the automated steering was “jerky” and rough in the runway between the stations, specifically during curves approaching stations. There were a few comments about the “stiffness” that occurred when manually retaking control of the steering from the VAA system.

Throughout the demonstration, PATH engineers tweaked the steering track from the permanently-embedded roadway magnets to smooth out the ride and jerky steering. However, most operators advised that the magnets should have been positioned based upon an actual maneuvering pattern of a good driver.

The following are several paraphrased comments by the operators during the individual interviews:

- I definitely like it; precision docking is safe; it was hard to let go of the steering wheel at first; the position design of the “on/off” and kill buttons should be addressed (PATH addressed this issue by installing a cover over the “on/off” switch); benefits include customers, back door alignment, use of the wheelchair ramp.
- Precision docking made driving more relaxing to neck and shoulders; it is not as tiring to align at stations; I like the chirping signals; training was good.
- I don't know what to do with my hands when automation is engaged; I stayed ready to grab steering wheel if necessary.
- I like the system; I was a little concerned at first how the vehicle swung out at the Agate Station; wheelchair customers noticed precision alignment the most.
- This system is not the answer to everything; I’m not comfortable with automation in between stations and curves; manual driving is preferred between stations, but precision docking is good; engineers could design better automation steering on curves.
- Hands-free driving impacts the torso by having to hold hands ready; there is still a way to go with the technology; it is not a smooth ride; good precision docking; training should be modified to emphasize warnings and readiness to take over manually.
- I experienced a growing confidence in the VAA system and thought it was cool and fun.
- When under VAA control, I tended to slow down my speed at curves; steering felt jerky; took time for me to trust system.
- Precision docking reduces wear on tires and station platforms.
- Training was good and allowed me to know what to expect, but actually using the VAA was interesting.

- I could feel lateral movement of VAA as a driver, but customers did not feel or notice it.
- It would be much better to have had VAA system precision docking at all stations and not have to worry about turning the system on and off.
- Precision docking allowed me to focus more on pedestrians, bicycles, and cars.

Most operators recommended that precision docking be expanded to all EmX stations. They also suggested that the magnet locations be adjusted to create a better replication of manual steering to address their concerns about the jerky motions.

In summary, there was a positive response to the system performance of the VAA by the bus operators, who regarded it as a valuable tool for safe and effective docking and believed it contributes personally to lower stress when docking.

SECTION

4

Customer Satisfaction

The hypothesis for the customer satisfaction portion of the evaluation was that the VAA would improve customer perceptions of a smooth ride, safety, service reliability, vehicle control, etc. For the evaluation, customer satisfaction was measured via a selected group of 13 riders. On April 3, 2015, NBRTI staff led this group on a field trip of the EmX route to compare the ride quality with and without the VAA. The group included individuals from LTD and various government agencies (City, County, Council of Governments, Oregon Department of Transportation). On the outbound portion of the field trip, participants rode a regular EmX bus without VAA, and on the return trip they rode an EmX bus with VAA enabled. They were asked to pay attention to different aspects of the ride quality such as the side-to-side movement of the bus and the alignment of the bus at stations and to consider how the bus with VAA compared to regular bus performance. After the field trip, the group members were given a survey to complete.

This approach differed from the original plan, which was to recruit riders who would provide feedback on the VAA over the course of the evaluation via surveys, focus groups, and trip journals. This was made difficult because of the various project delays. Nevertheless, the use of the 13-person customer service group and field trip offered at least one advantage over the approach that was used in the FTA-sponsored evaluation of VAA in Minnesota.[3] In that evaluation, an on-board passenger survey was conducted, and 82.6% of the passengers were not aware of the presence of the VAA. Although the survey results from the EmX field trip are not statistically significant, they are still meaningful.

The survey findings are shown in Tables 4-1 and 4-2. A full list of coments is provided in Appendix B – Rider Survey. It was clear from the survey that the precision docking feature was favored over the lane guidance feature. In regard to the latter, many people in the survey group commented how the side-to-side movement of the bus seemed "jerky" when it was under the control of the VAA.

Table 4-1

Rating of Ride Quality with VAA

Aspect of Ride Quality	Mean Score	No. of Responses
Steering between stations	3.75	12
Minimal swaying of bus	3.33	12
Overall smoothness of ride	3.58	12
Speed of bus	4.42	12

Survey scale: 5 Very Good, 4 Good, 3 Fair, 2 Poor, 1 Very Poor, 0 Don't Know.
Mean score does not include 0 Don't Know responses.

[3]See "Cedar Avenue Driver Assist System Evaluation Report," FTA Report No. 0010, http://www.nbrti.org/docs/pdf/FTA_Report_No%20_0010_Cedar_Avenue_DAS_Evaluation_Report.pdf.

Table 4-2

Rating of Precision Docking with VAA

Aspect of Precision Docking	Mean Score	No. of Responses
Accuracy of aligning to station	4.91	11
Ease of boarding and alighting	4.92	12
Safety	4.73	11
Assistance to bus driver	4.60	10

Survey scale: 5 Very Good, 4 Good, 3 Fair, 2 Poor, 1 Very Poor, 0 Don't Know.
Mean score does not include 0 Don't Know responses.

Sample comments included the following:

- I was a little surprised it was not smoother.
- For docking, I think it's a wonderful system. For the swaying and jerkiness of the steering between stations, it is less than "friendly."
- The docking at the stations was good, very consistent, but the bus felt very jerky and not very smooth.
- The best part of the technology is consistent docking. During the ride, it was a bit jerky in some curves at higher speeds.

SECTION

5

Efficiency and Productivity

The efficiency and productivity part of the evaluation looked at how the VAA impacted route performance. The hypothesis was that VAA would reduce route running time and lead to higher speeds. To exclude when the bus was stopped at intersections and stations, speed and running time data were collected by lane segment. There were 8 travel segments in the westbound direction and 10 in the eastbound direction. There was a plan to include a hypothesis about the VAA reducing station dwell time also; however, it was eliminated because the VAA-equipped stations are located near signalized intersections, and there was a risk that traffic signal delay could interfere with the evaluation results.

The monthly averages were intended to be grouped by segment, direction, and VAA status (i.e., enabled vs. disabled). However, due to a miscommunication between PATH and NBRTI, much of the data was not grouped by VAA status. Most of the monthly averages were combined figures (i.e., combined averages for VAA enabled and disabled runs). The only exceptions were January and February 2015, the last two months of the evaluation, when PATH was able to parse the data according to VAA status. Consequently, this part of the evaluation focused on these two months.

Contrary to what was expected, the bus operators drove slightly slower when using the VAA (see Table 5-1). This was true even on the eastbound approaches to Walnut Station and Agate Station, which generally are considered the most challenging by bus operators. The speed differences (VAA-enabled vs. VAA-disabled) ranged from 4.08 mph slower (eastbound Onyx St. to Riverfront Blvd.) to 1.96 mph faster (eastbound Villard St. to Orchard St.). This means that the average running times were slightly longer when the VAA was enabled, although they were small in magnitude. As shown in Table 5-2, the difference in run time within the 1.5-mile segment with the VAA enabled ranged from 3.37 seconds longer (westbound 11th Ave. to Dad's Gate Station) to 1.84 seconds shorter (westbound 13th St. to Agate Station). Such small differences were not likely to have been noticeable to the riders.

Table 5-1

Average Speed (MPH) by Lane Segment

Lane Segment	VAA Enabled		VAA Disabled		Difference*	
	Jan 2015	Feb 2015	Jan 2015	Feb 2015	Jan 2015	Feb 2015
Westbound						
Beginning of WB magnet track to Walnut Station	19.00	21.28	21.58	20.87	-2.58	0.41
Walnut Station to Orchard St	11.95	11.40	12.98	12.41	-1.03	-1.01
Orchard St to Villard St	21.45	21.62	25.20	23.21	-3.75	-1.59
Villard St to 13th St	25.58	24.62	29.01	26.41	-3.43	-1.79
13th St to Agate Station	22.53	22.99	21.80	21.86	0.73	1.13
Agate Station to Onyx St	15.91	15.21	18.33	16.17	-2.42	-0.96
Onyx St to E11 Ave	26.84	26.28	30.59	29.65	-3.75	-3.37
E11 Ave to Dad's Gate Station	14.25	13.03	14.00	14.96	0.25	-1.93
Eastbound						
Beginning of EB magnet track to Dad's Gate Station	13.23	12.35	13.06	13.56	0.17	-1.21
Dad's Gate Station to E11 Ave	6.39	7.38	8.30	8.80	-1.91	-1.42
E11 Ave to Onyx St	20.16	19.78	23.04	22.14	-2.88	-2.36
Onyx St to Riverfront Blvd	23.68	22.01	27.76	22.74	-4.08	-0.73
Riverfront Blvd to Agate Station	9.56	10.04	10.68	10.06	-1.12	-0.02
Agate Station to 13th St	18.17	18.16	18.57	17.69	-0.40	0.47
13th St to Villard St	18.54	19.17	20.19	17.96	-1.65	1.21
Villard St to Orchard St	19.09	19.92	19.71	17.96	-0.62	1.96
Orchard St to Walnut St	23.65	23.67	25.31	23.67	-1.66	0.00
Walnut St to Walnut Station	9.01	8.49	9.16	9.48	-0.15	-0.99
Total Samples VAA-Enabled EB, WB	42, 38	54, 60	42, 38	54, 60	42, 38	54, 60
Total Samples VAA-Disabled EB, WB	60, 62	55, 46	60, 62	55, 46	60, 62	55, 46

* Since hypothesis was that speeds would be greater with VAA enabled, difference calculated as VAA-enabled speed minus VAA-disabled speed.

Table 5-2

Average Running Time (seconds) by Lane Segment

Lane Segment	VAA Enabled		VAA Disabled		Difference*	
	Jan 2015	Feb 2015	Jan 2015	Feb 2015	Jan 2015	Feb 2015
Westbound						
Beginning of WB magnet track to Walnut Station	10.69	9.46	10.12	10.10	0.57	-0.64
Walnut Station to Orchard St	10.06	11.05	9.92	10.15	0.14	0.90
Orchard St to Villard St	5.72	5.56	5.12	5.44	0.60	0.12
Villard St to 13th St	5.70	6.16	5.22	5.85	0.48	0.31
13th St to Agate Station	10.89	10.76	12.73	12.15	-1.84	-1.39
Agate Station to Onyx St	16.20	17.58	14.61	16.88	1.59	0.70
Onyx St to E11 Ave	7.83	8.61	6.94	7.37	0.89	1.24
E11 Ave to Dad's Gate Station	10.29	12.05	11.13	8.68	-0.84	3.37
Eastbound						
Beginning of EB magnet track to Dad's Gate Station	10.12	11.01	11.71	9.84	-1.59	1.17
Dad's Gate Station to E11 Ave	12.72	11.26	10.23	8.91	2.49	2.35
E11 Ave to Onyx St	11.54	11.94	10.24	10.69	1.30	1.25
Onyx St to Riverfront Blvd	10.82	12.33	9.18	11.36	1.64	0.97
Riverfront Blvd to Agate Station	7.45	6.66	4.47	7.05	2.98	-0.39
Agate Station to 13th St	11.94	12.03	12.47	12.46	-0.53	-0.43
13th St to Villard St	6.85	6.57	7.05	7.05	-0.20	-0.48
Villard St to Orchard St	6.82	6.29	7.11	7.59	-0.29	-1.30
Orchard St to Walnut St	4.56	4.73	4.52	4.72	0.04	0.01
Walnut St to Walnut Station	5.39	5.74	6.02	5.30	-0.63	0.44
Total Samples VAA-Enabled EB, WB	42, 38	54, 60	42, 38	54, 60	42, 38	54, 60
Total Samples VAA-Disabled EB, WB	60, 62	55, 46	60, 62	55, 46	60, 62	55, 46

* Since hypothesis was that running times would be less with VAA enabled, difference was calculated as VAA-enabled running minus VAA-disabled running time.

The limited data on the slower reported speeds when the VAA was enabled were backed up by some of the comments that were made by the bus operators in Section 3, Bus Operator Satisfaction. Two comments in particular stand out:

- This system is not the answer to everything; I'm not comfortable with automation in between stations and curves; manual driving is preferred between stations, but precision docking is good; engineers could design better automation steering on curves.
- When under VAA control, I tended to slow down my speed at curves; steering felt jerky; took time for me to trust system.

SECTION

6

Maintenance

There were two hypotheses for the maintenance portion of the evaluation. The first hypothesis was that the VAA would reduce maintenance costs for materials and equipment at the stations, on the runways, and on the vehicles, such as tires and station curbing. The second hypothesis was that the VAA system itself would be easy to maintain. Since NBRTI did not have access to the VAA maintenance data (such as costs expended by PATH), the evaluation focused instead on the first hypothesis by examining LTD maintenance logs.

High numbers of tire work orders are a unique problem for the EmX route due to its many tight turns. According to a 2011 internal LTD report, the EmX accounted for 9.1% of the LTD fleet but 17.7% of tire work orders[4] (see Table 6-1).

Table 6-1

2011 EmX Bus Call Analysis

	Total Buses	% of Fleet	Total Work Orders in 2011	% of Work Orders
Gillig 40 ft.	95	78.5%	287	65.8%
New Flyer 60 ft.	15	12.4%	72	16.5%
EmX	11	9.1%	77	17.7%

Historically, excessive sidewall scrub and hard impacts have been the main source of EmX tire repairs. The 2011 LTD internal report noted that in 2011, EmX vehicles consumed five wheels due to impact damage, which accounted for 67% of the wheel costs for LTD's entire fleet.

Table 6-2 shows that there were 23 "bent wheel" work orders for the 11-vehicle EmX fleet during the evaluation. These are work orders were for repairs due to the bus striking the station platform. Bus Number 6101, the VAA-equipped bus, had two work orders. Both incidents occurred to the left rear outside tire, indicating that it occurred at a median station. However, neither incident was traceable to the 1.5-mile VAA test segment. The first incident of damage was discovered during a routine inspection by one of LTD's maintenance technicians; therefore, the geographic location of where the damage occurred is unknown. The second incident was reported by the bus driver in the vicinity of the Springfield Station, which is not part of the VAA test segment.

[4]Bill Bradley, Journeyman Tire Specialist, LTD, EmX Tire Program Analysis, 2011.

Table 6-2

EmX Fleet Bent Wheel Instances (May 2013 to February 2015)

Bus No.	Bent Wheel Instances	Wheel Position
6101*	2	Left rear outside
6102	1	Left rear outside
6103	1	Left rear outside
6104	1	Left rear outside
6105	2	Left rear outside
6106	1	Left rear outside
9101	0	Left rear outside
9102	2	Left rear outside
9103	7	Left rear outside
9104	5	Left rear outside
9105	1	Left rear outside
Total	23	

* Bus 6101 is VAA-equipped bus.

SECTION

7

Safety

Hypothesis

The hypothesis for the safety portion of the evaluation was that the VAA would reduce vehicle path deviation, thus reducing the number and severity of side collisions and safety-related accidents. There were two measures of effectiveness: precision control performance level in the running path and the number and severity of collisions and accidents. Since precision control also relates to the system performance evaluation area, it is addressed in Section 8, Technical Performance.

LTD provided data on all EmX collisions and safety-related incidents from 2013 to 2015. It was able to refine the data search to include only those collisions and incidents that occurred inside the 1.5-mile test segment, as shown in Table 7-1. Of the 18 total events, there was one occurrence of a non-VAA equipped EmX bus involved in a side impact collision (which would not have been prevented by VAA) and one occurrence of non-VAA equipped bus striking the station platform (VAA-preventable). None of the 18 events involved the VAA-equipped bus (No. 6101). One safety-related incident occurred prior to 2013. This is the incident that occurred in December 2012, which was discussed in Section 1 of the report. Although it was a serious event, it appears that the fault was addressed since no other safety incidents or collisions were reported with Bus 6101 over the next two years.

Table 7-1

EmX Accidents and Safety Incidents within Test Segment, 2013–2015

Bus No.	No. of Incidents	Nature of Incidents
6101*	0	
6102	0	
6103	3	Hard stop to avoid collision Hard stop to avoid collision Passenger fall
6104	3	Struck station platform Hard stop to avoid collision Passenger fall
6105	0	
6106	1	Passenger fall
9101	3	Side impact collision Bus on bus collision/fender bender Hard brake with passenger fall
9102	2	Passenger fall
9103	0	
9104	4	Passenger fall Rear-ended Passenger caught arm in door Passenger jumped through door as it was closing
9105	2	Struck by mower in median Hard stop to avoid collision
Total	*18*	

* Bus 6101 is VAA-equipped bus.

SECTION

8

Technical Performance

The technical performance component of the evaluation compared how well the buses aligned with the station platform when docking and the lane centerline when in transit. The hypothesis was that runs with the VAA-enabled bus would achieve a closer alignment with the station platform, would stay closer to the centerline of the running path, and have a smoother ride.

Lateral Guidance

The EmX buses are 8.5 feet wide, and the bus lane is 10 feet wide, leaving a maximum allowable deviation from the lane center of 0.75 ft. (22.8cm). The performance goal of the VAA for the lateral tracking was that the error with respect to the lane center would be kept to within 50–60% of the maximum allowable deviation of 0.375 feet (11.43 cm) to 0.45 feet (13.72 cm). That performance goal was met. In fact, the largest recorded offset with the VAA enabled was only 11.06 cm, recorded for the westbound approach to Walnut Station where the westbound magnet track begins. The largest recorded offset with the VAA disabled was 44.34 cm, recorded at the eastbound approach to Dad's Gate Station.

Figure 8-1 compares the standard deviation of offset from the lane center in the westbound direction for VAA-enabled and disabled trips. Figure 8-2 shows the same data for the eastbound direction. For analysis purposes, the 1.5-mile test track was divided into 8 segments in the westbound direction and 10 segments in the eastbound direction. The results in Figures 8-1 and 8-2 show that the VAA's performance goal was achieved in every segment in both directions

Figure 8-1

Lateral deviation from center line (westbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

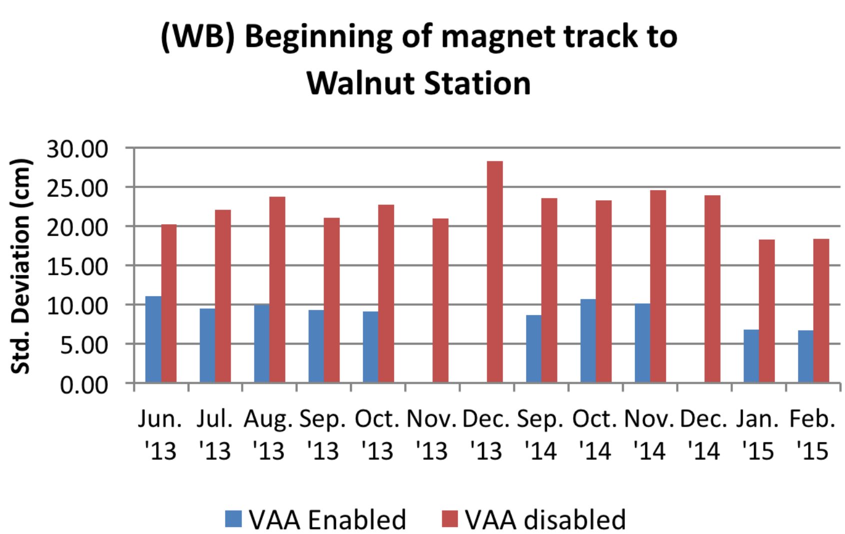
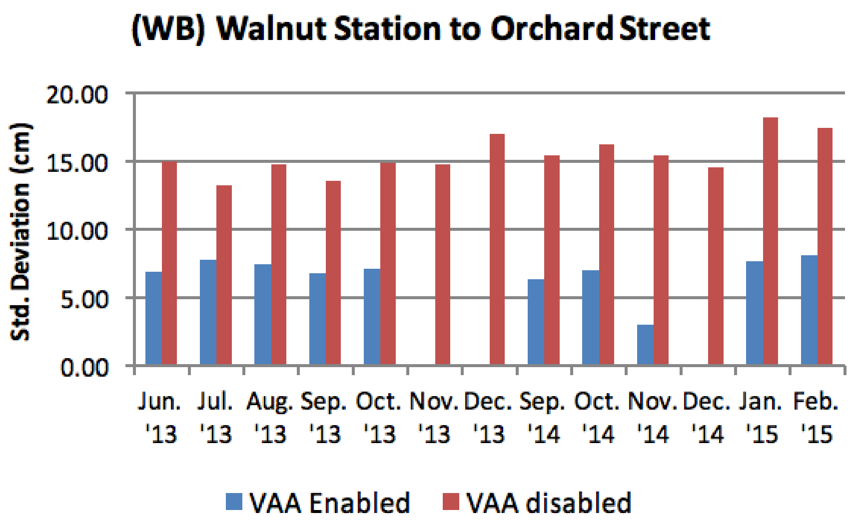
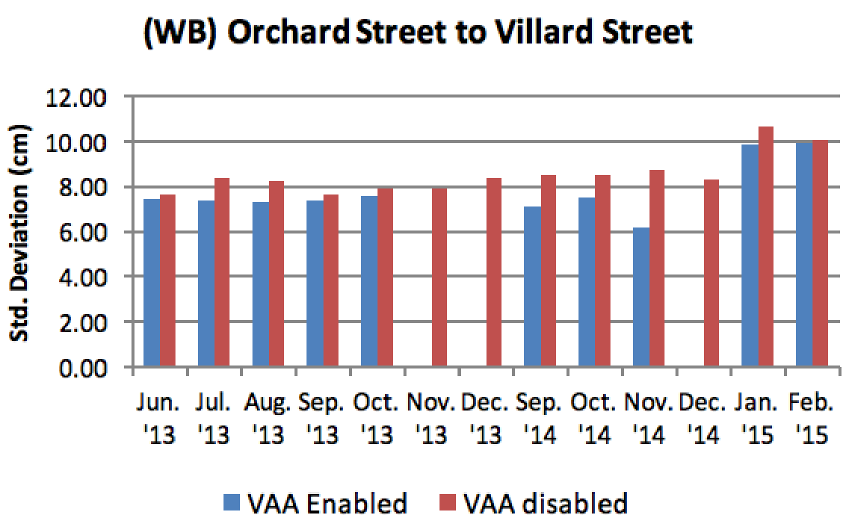


Figure 8-1 (cont.)

Lateral deviation from center line (westbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





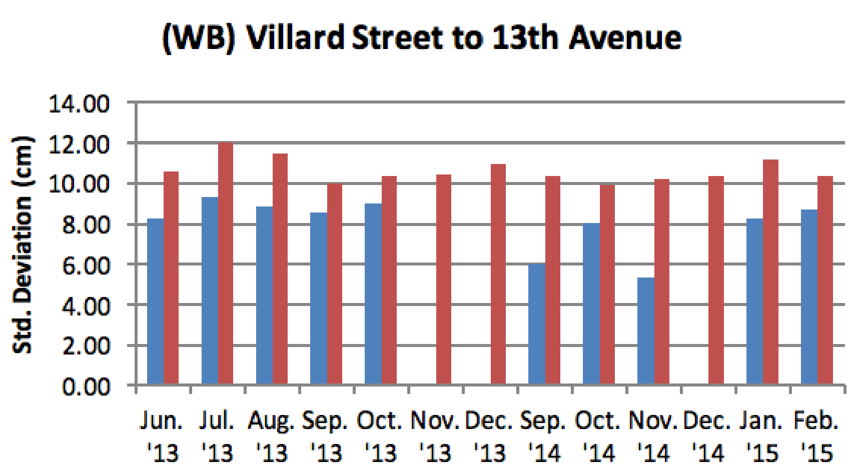


Figure 8-1 (cont.)

Lateral deviation from center line (westbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

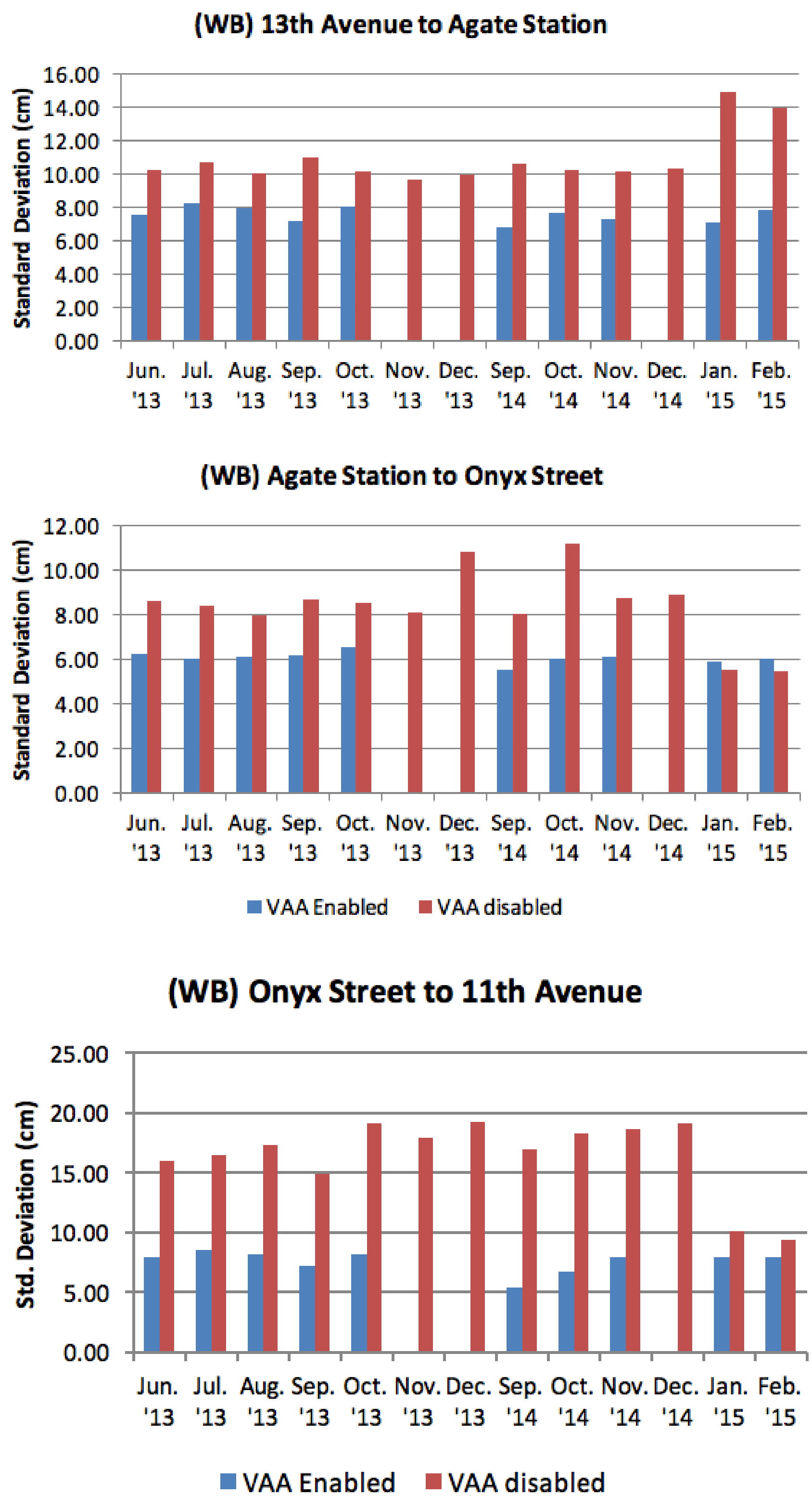


Figure 8-1 (cont.)

Lateral deviation from center line (westbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

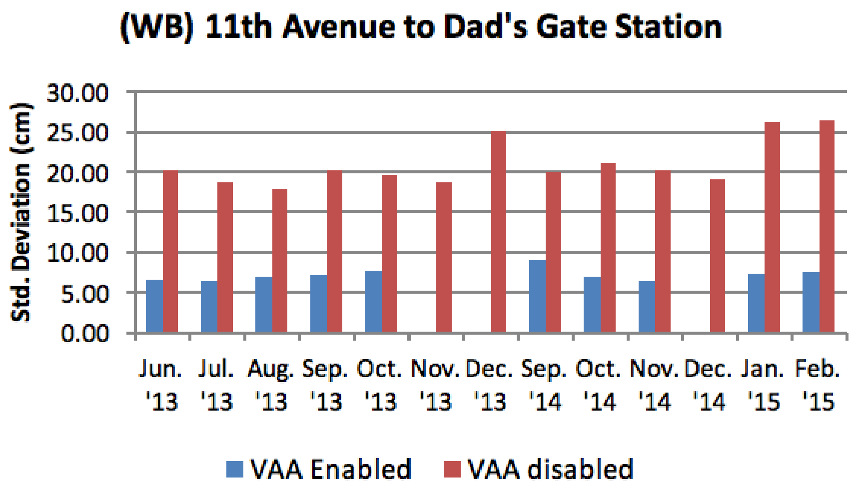
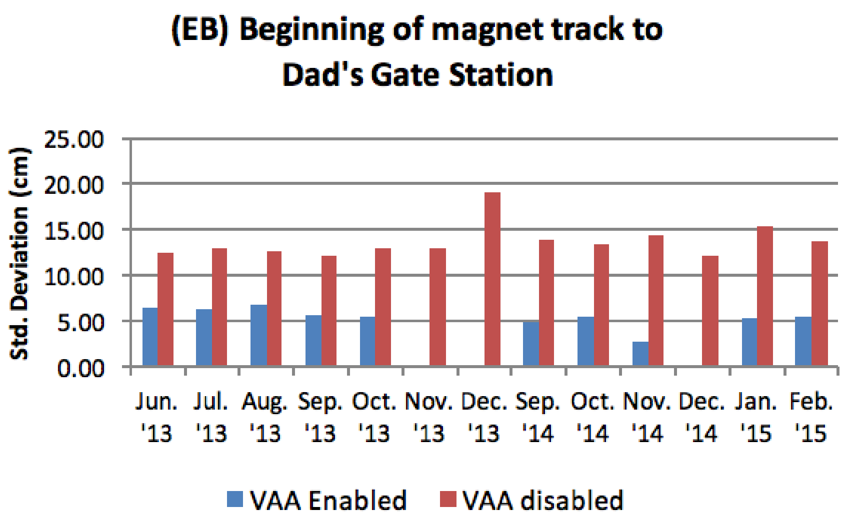


Figure 8-2

Lateral deviation from center line (eastbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014,.



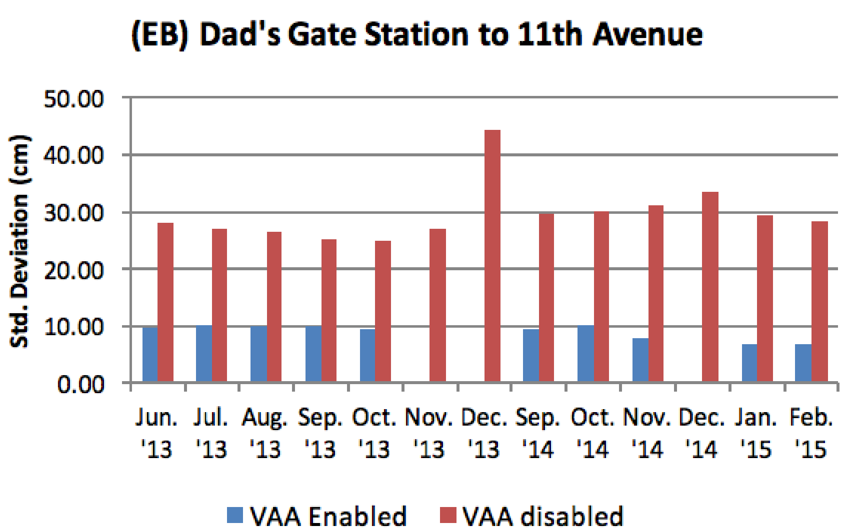


Figure 8-2 (cont.)

Lateral deviation from center line (eastbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

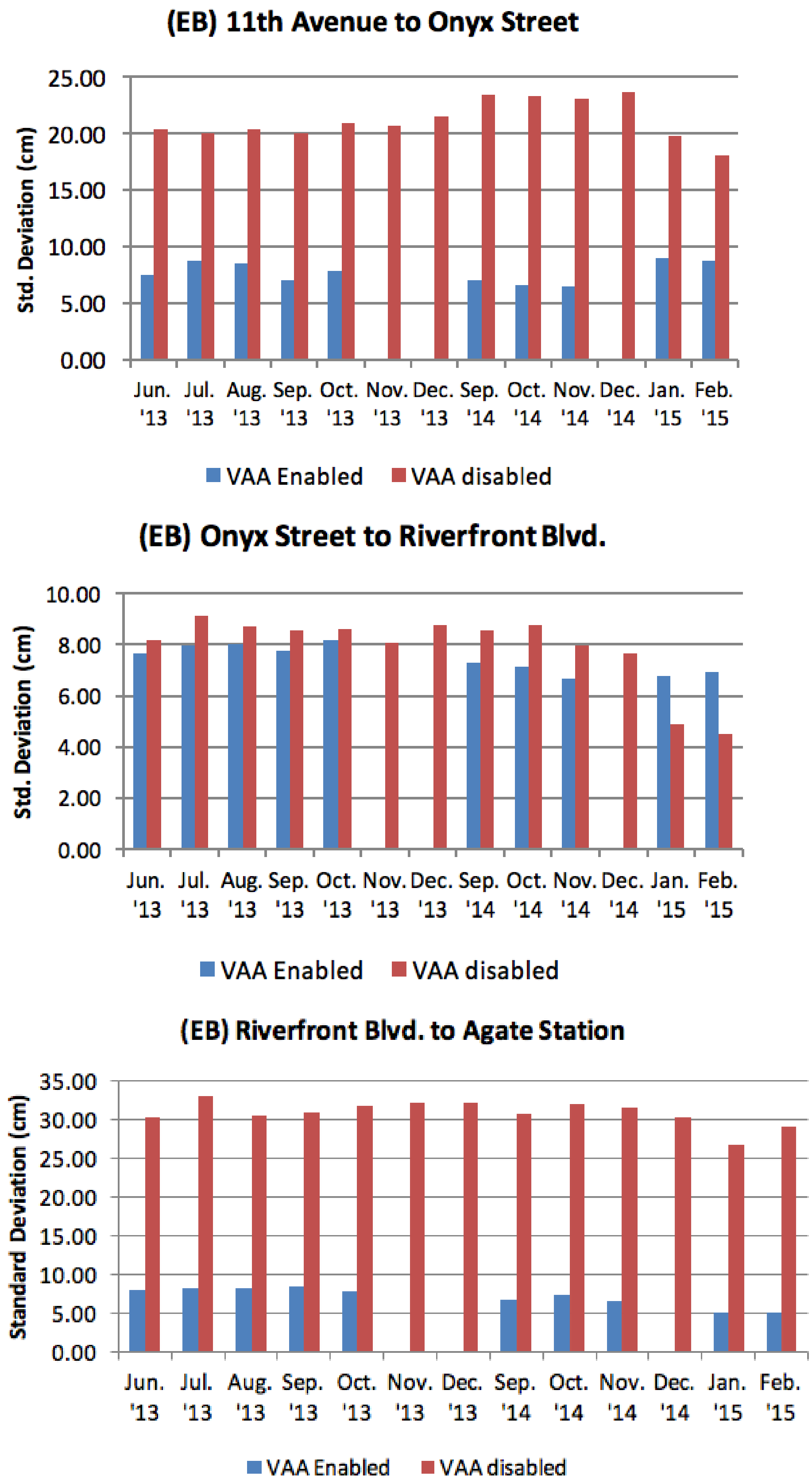
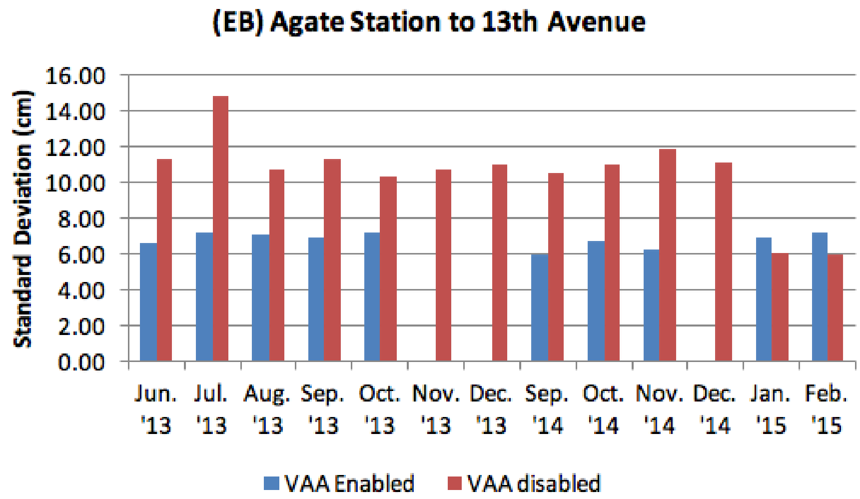
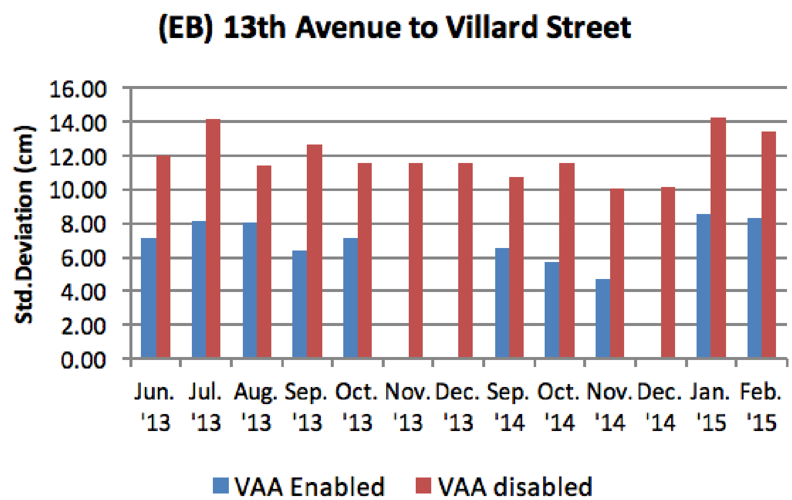


Figure 8-2 (cont.)

Lateral deviation from center line (eastbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





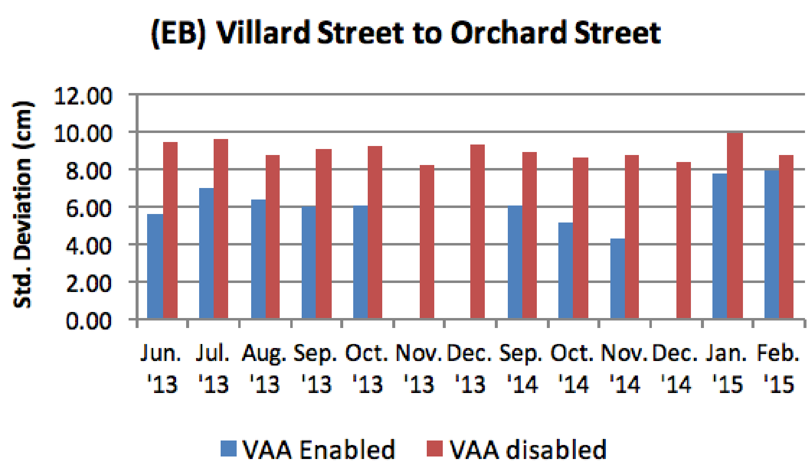
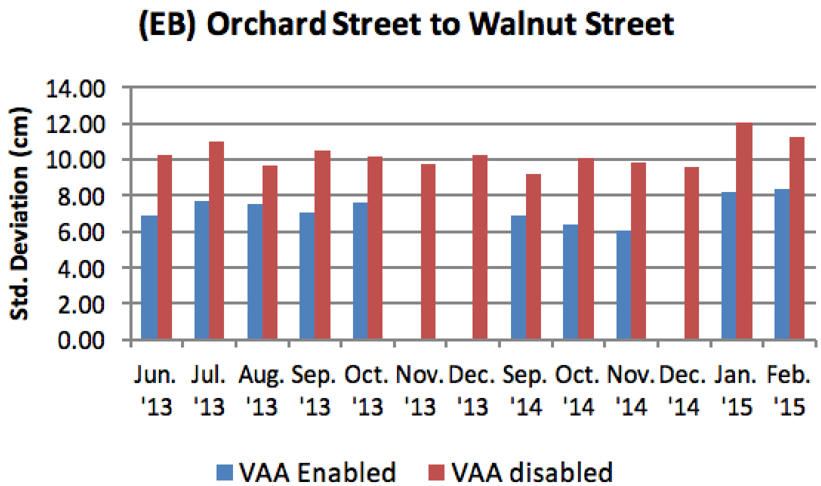
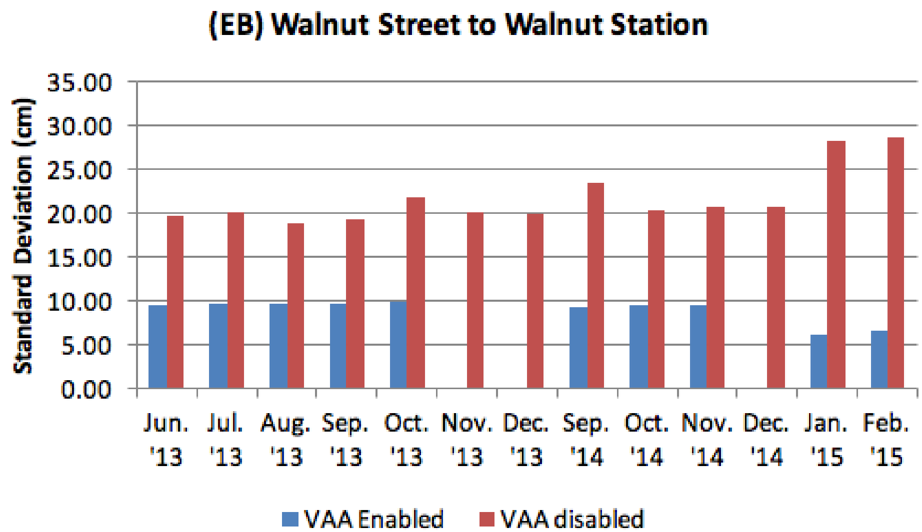


Figure 8-2 (cont.)

Lateral deviation from center line (eastbound)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





The VAA performed exceptionally well at keeping the bus centered on the eastbound approach to Agate Station. This segment is identified in Figure 8 2 as (EB) Riverfront Blvd. to Agate Station. Here, the bus had to make more than 2 lane changes within 223 feet. (An aerial photo of Agate Station is shown in Figure 1 5.) Without the VAA, the bus deviated from lane center by as much as 33.08 cm. With the VAA enabled, the maximum deviation was 8.33 cm. Another segment in which the VAA performed exceptionally well at keeping the bus centered was 11th Avenue to Onyx Street in the eastbound direction. This segment includes a sharp turn to the right as the bus leaves 11th Avenue and returns to Franklin Blvd. Without the VAA enabled, the bus deviated from the center line by as much as 23.63 cm. With the VAA enabled, the maximum deviation was 8.94 cm.

Precision Docking

A sample photo of the EmX precision docking is shown in Figure 8-3. EmX stations include a yellow polyethylene guide strip along the side of the platform to prevent damage to bus tires. For precision docking, the magnetic track was laid to achieve a target horizontal gap of 4 cm between the vehicle floor and the guide strip. The results for the precision docking at Walnut Station, Agate Station, and Dad's Gate Station are shown in Figures 8-4, 8-5, and 8-6, respectively. These figures show the standard deviation in centimeters from the point in the pavement that the bus needed to be to achieve a 4 cm gap as measured from the front magnetometer. A standard deviation of zero means that the edge of vehicle is exactly 4 cm from the guide strip.

Figure 8-3

Precision docking

Figure 8-4

Precision docking, Walnut Station

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

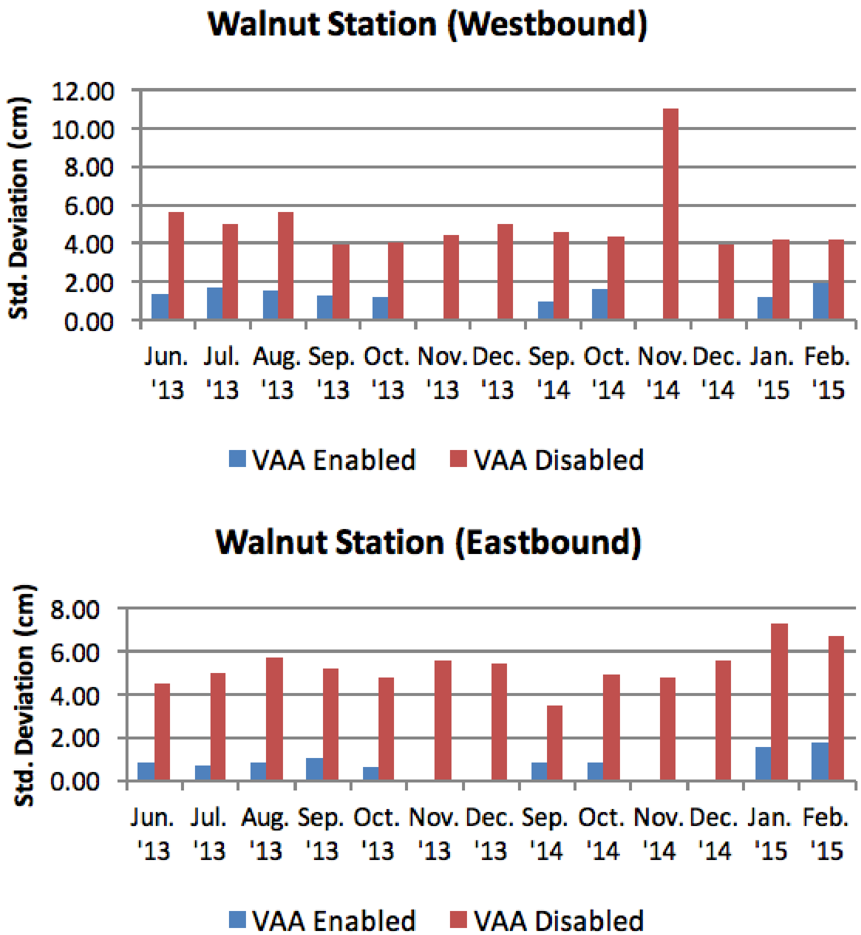


Figure 8-5

Precision docking, Agate Station

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

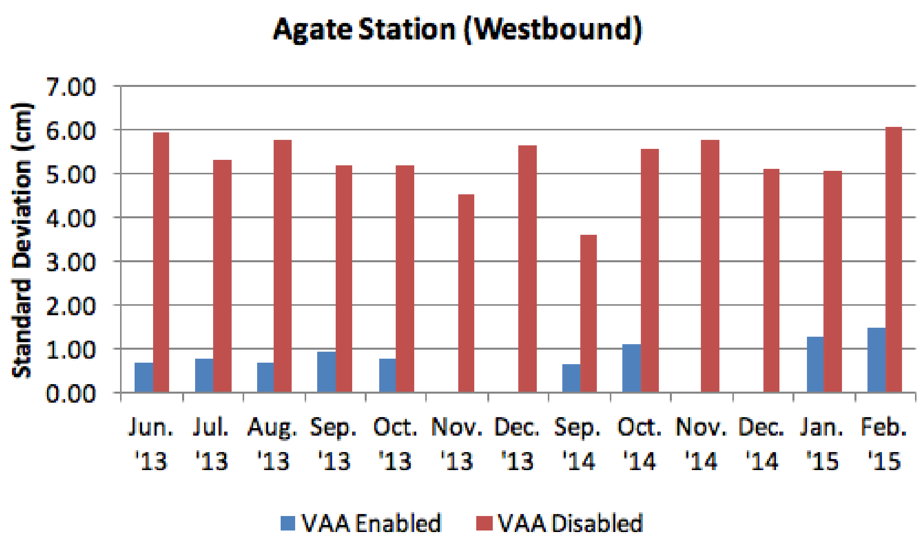


Figure 8-5 (cont.)

Precision docking, Agate Station

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

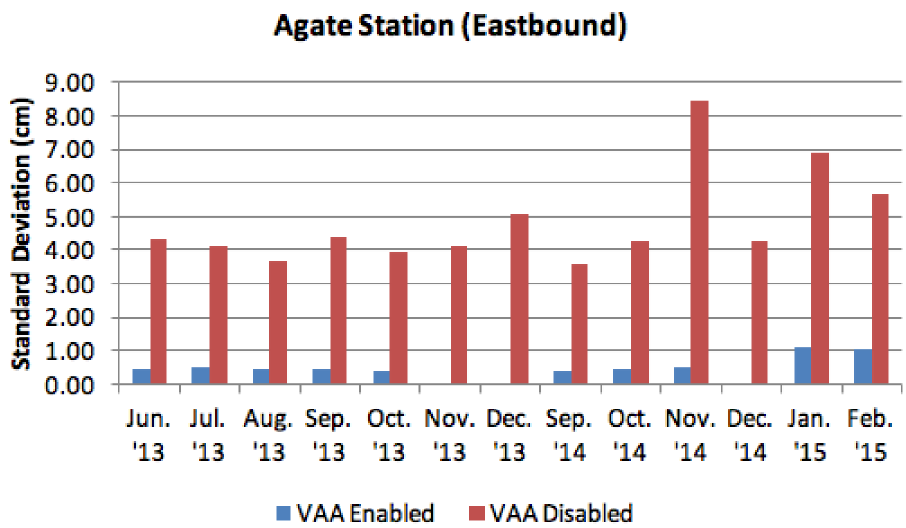
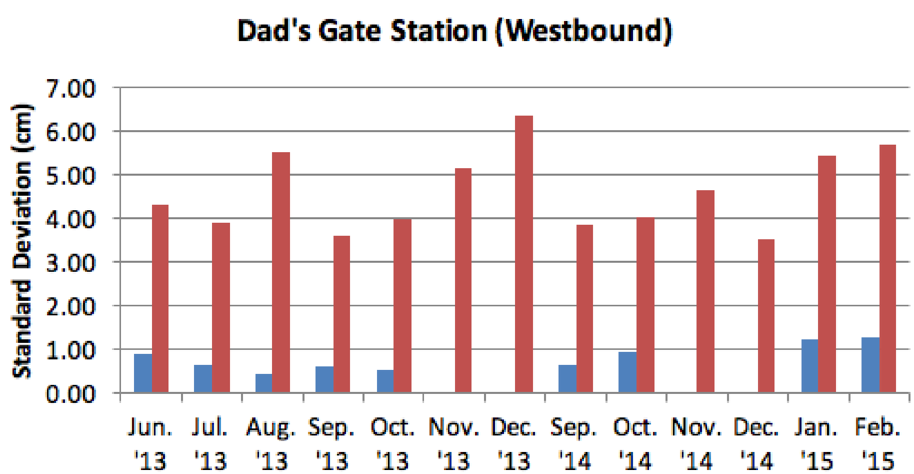
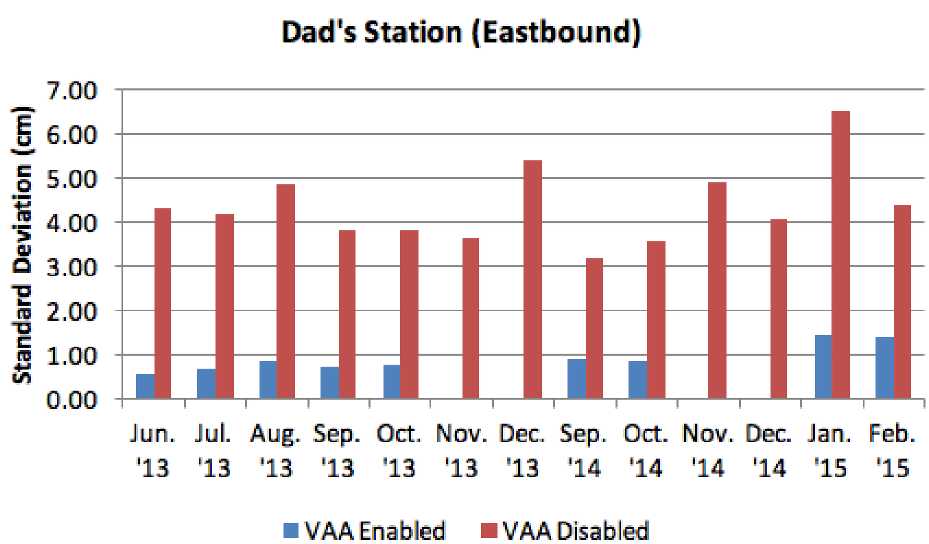


Figure 8-6

Precision docking, Dad's Gate Station

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





The bus docked closer to the platform with the VAA enabled. Overall, the maximum reported deviation at all three stops was only 1.94 cm, which occurred at the westbound platform of Walnut Station in February 2015. The maximum reported deviation with the VAA disabled was much higher, 11.08 cm, which also occurred at the westbound platform of Walnut Station in February 2015 (see Figure 8-4). Another observation was that the gap distance was more consistently the same when the VAA was enabled. The deviation in centimeters for each station from month to month was close to the same when the VAA was enabled; there was more variation in the deviation from month to month when the VAA was disabled.

Of particular note is the improved docking performance at the eastbound platform of Agate Station. As reported, the eastbound docking at this station is difficult because the bus is required to make more than 2 lane changes within 223 feet. When the VAA was not used, the maximum reported deviation was 8.48 cm; when the VAA was enabled, the maximum dropped to 1.09 cm (see Figure 8-5).

Lateral Acceleration

Lateral acceleration is the force that throws vehicle passengers sideways in a turn. The standard unit of measure for lateral acceleration is g-force. Comparisons were made of the g-force while the steering was under control of the VAA to when the steering was under manual control. The VAA report by Caltrans and PATH stated that the lateral acceleration was slightly smaller under automated steering than under manual steering. The report concluded, "This comparison indicates that the automated steering provides a slight advance in ride comfort to the passengers as well."[5] However, the report provided results only for the entire length of the test track. When looking at the g force data by individual segment, the results are not as straightforward. Figure 8-7 shows the exhibited g force with and without VAA for the 8 westbound segments, and Figure 8-8 shows it for the 10 eastbound segments. In the westbound direction, the segments from Orchard Street to Villard Street and from Agate Station to Onyx Street consistently showed higher g force values under automated steering. The same was observed in the eastbound direction for the following segments: the beginning of magnetic track to Dad's Gate Station, from Onyx Street to Riverfront Blvd., from Riverfront Blvd. to Agate Station, from Agate Station to 13th Avenue, and from 13th Avenue to Villard Street.

The VAA system is designed to follow the magnetic track with a high degree of precision. However, a balance needs to be struck between lane position accuracy and ride comfort. If the lane keeping control is too "tight," the riders will experience a more "jerky" ride. The report notes that the EmX corridor is very curvy, and the test track has a total of 36 curves (19 in the westbound

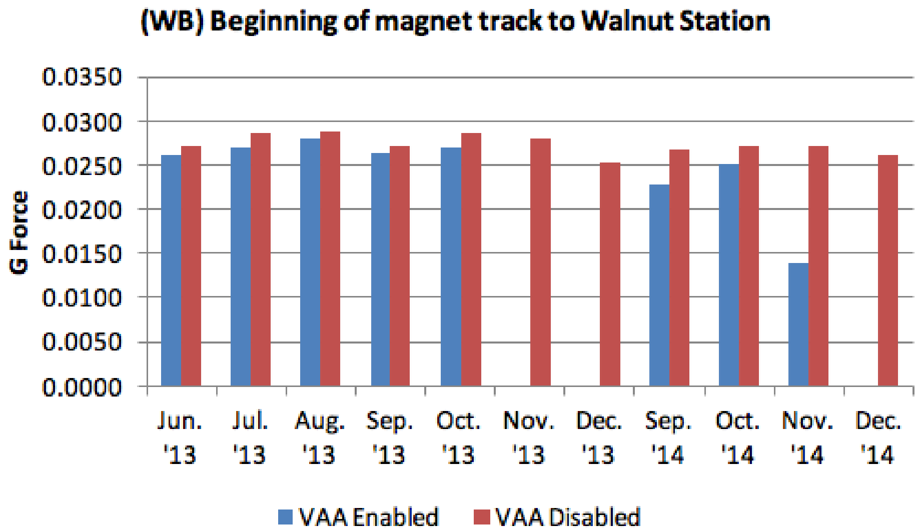
[5]Han-Shue Tan and Jihua Huang, "Vehicle Assist and Automation Demonstration: Final Report," FTA Project No. CA-26-7080.

direction and 17 in the eastbound direction). Of those 36 curves, 8 have a radius of less than 100 meters; the smallest radius is 46.6 meters. The report states that the VAA system was re-tuned in July 2012 after a demonstration run to tolerate larger lateral deviations. During that demonstration, drivers and passengers reported experiencing jerkiness on the ride. The results in Figures 8-7 and 8-8 show, and the customer comments from Section 4, confirm that the VAA system needs further fine-tuning.

Figure 8-7

Lateral acceleration (westbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.



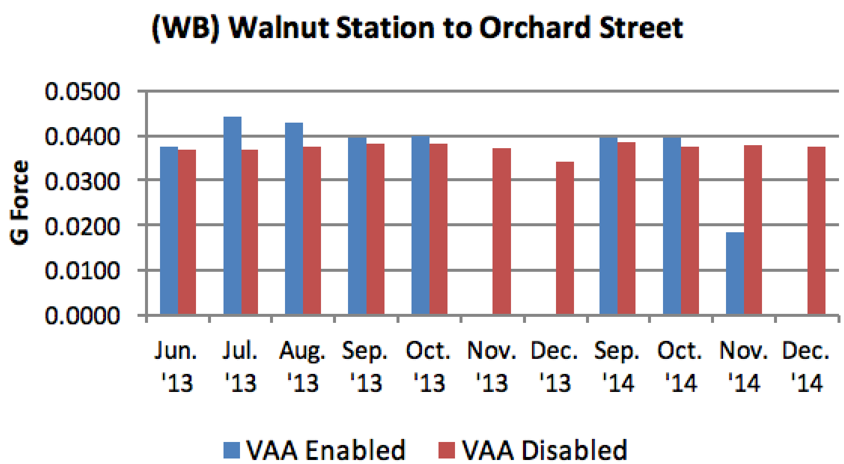
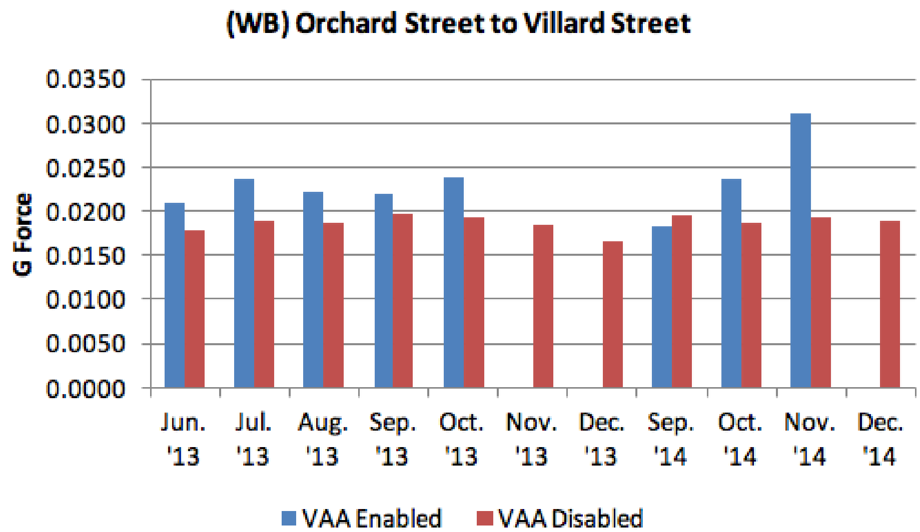
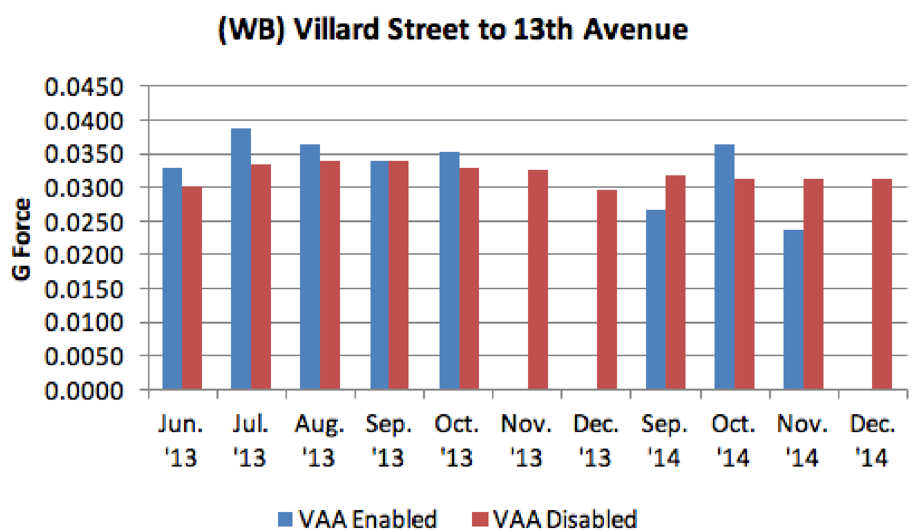


Figure 8-7 (cont.)

Lateral acceleration (westbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





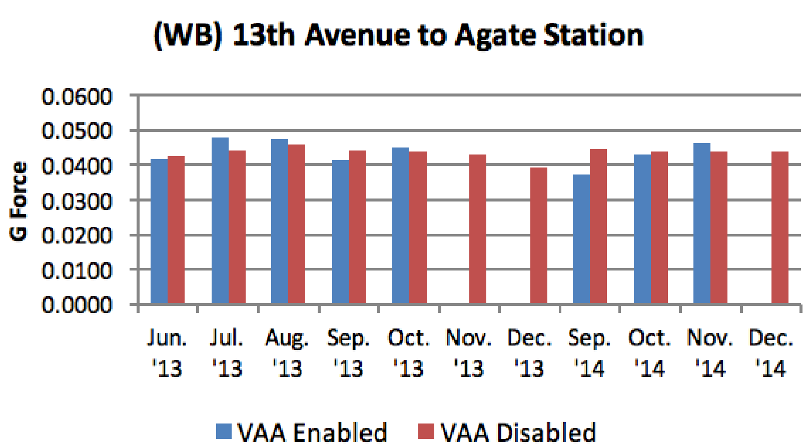
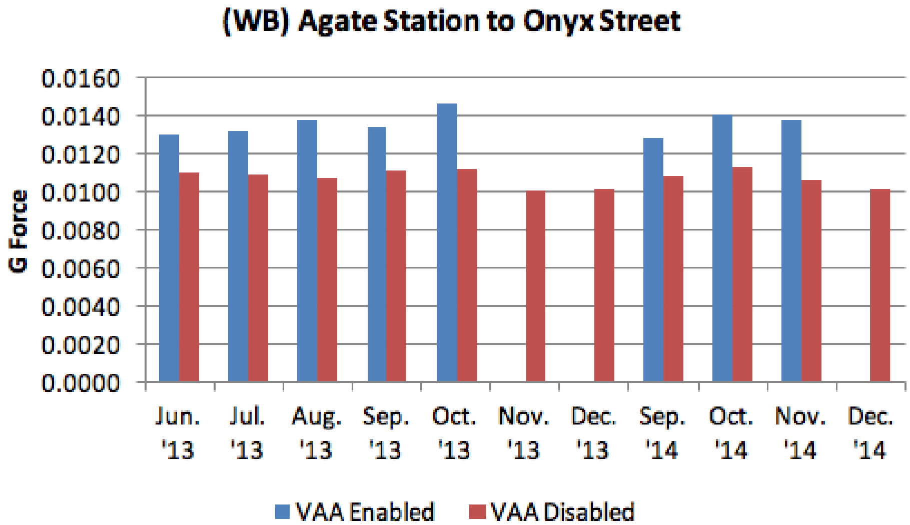
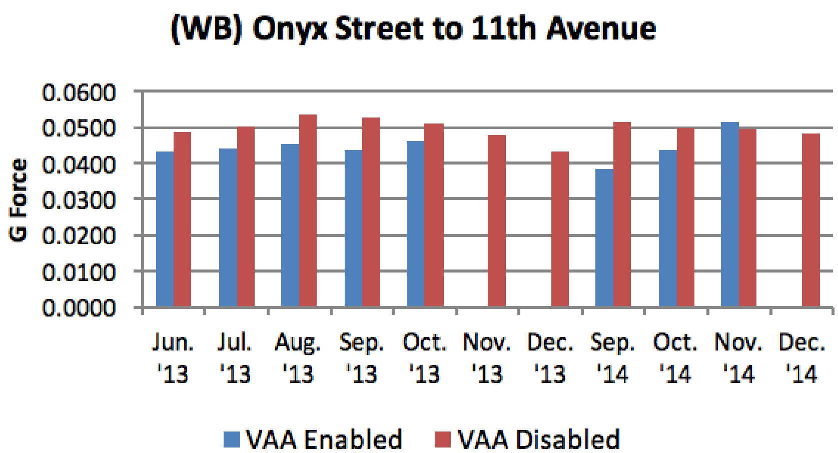


Figure 8-7 (cont.)

Lateral acceleration (westbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





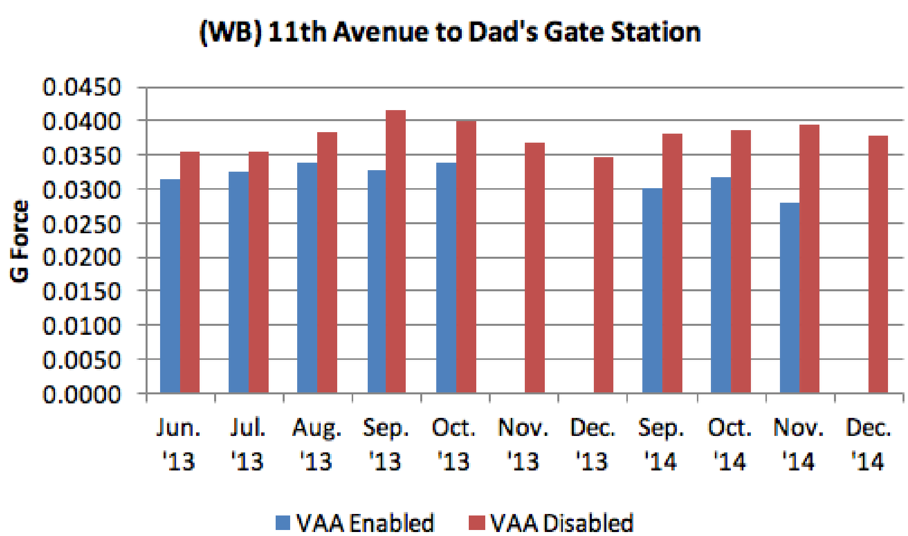


Figure 8-8

Lateral acceleration (eastbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.

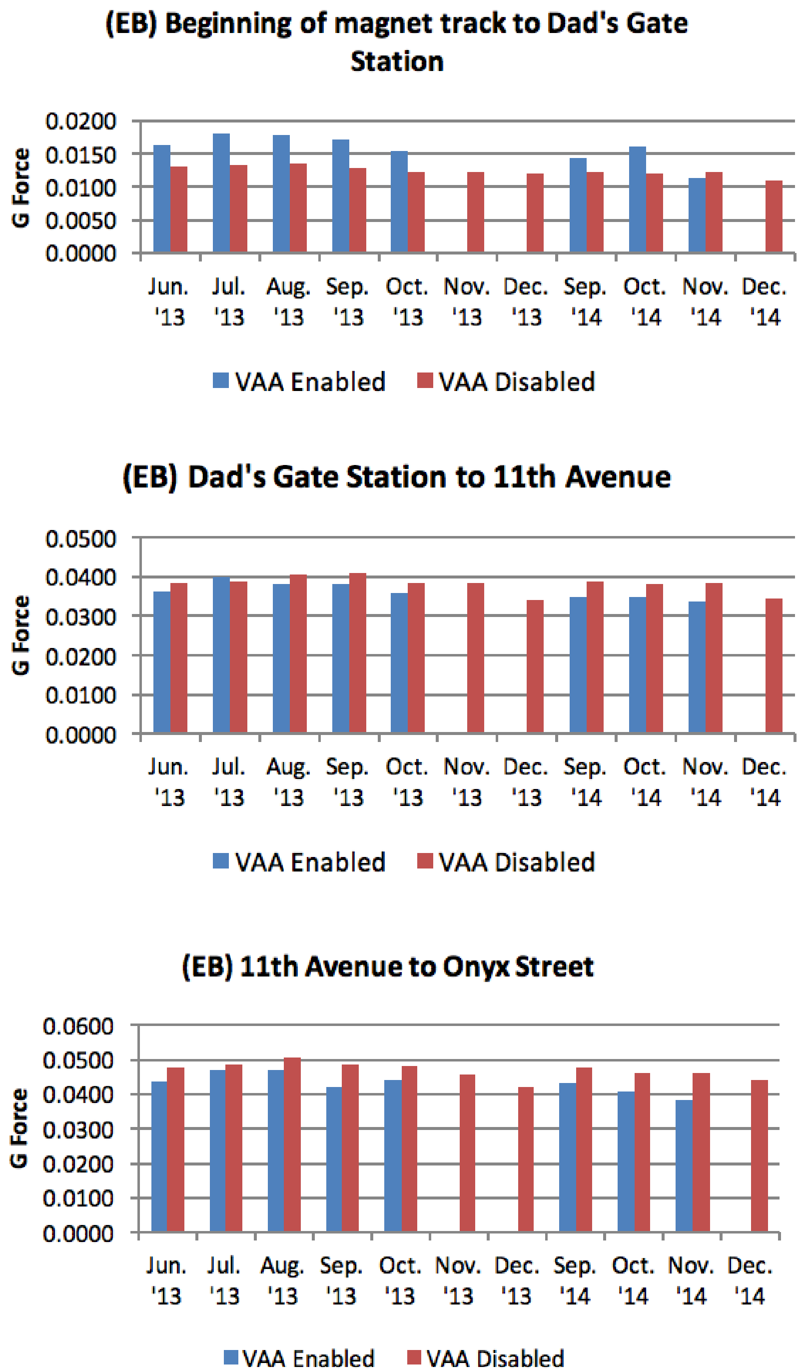
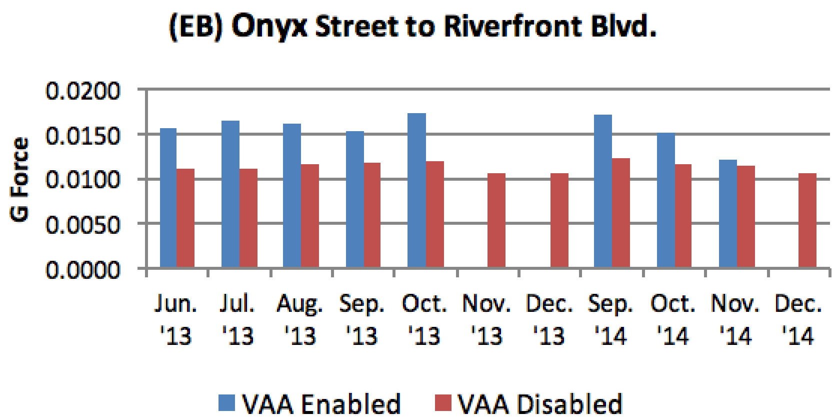
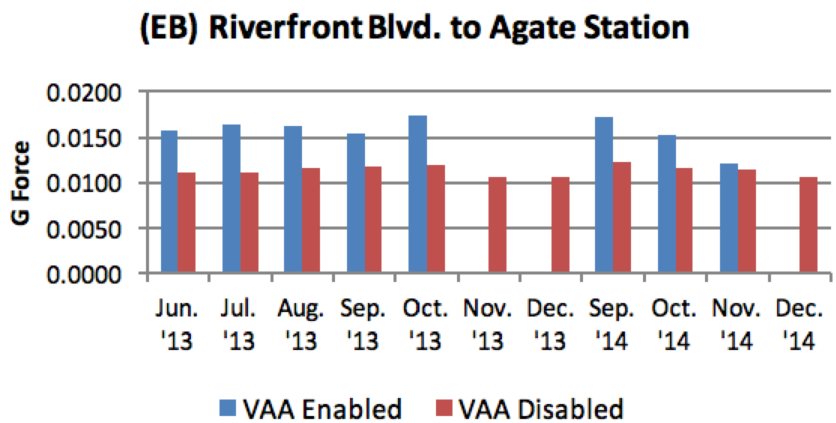


Figure 8-8 (cont.)

Lateral acceleration (eastbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





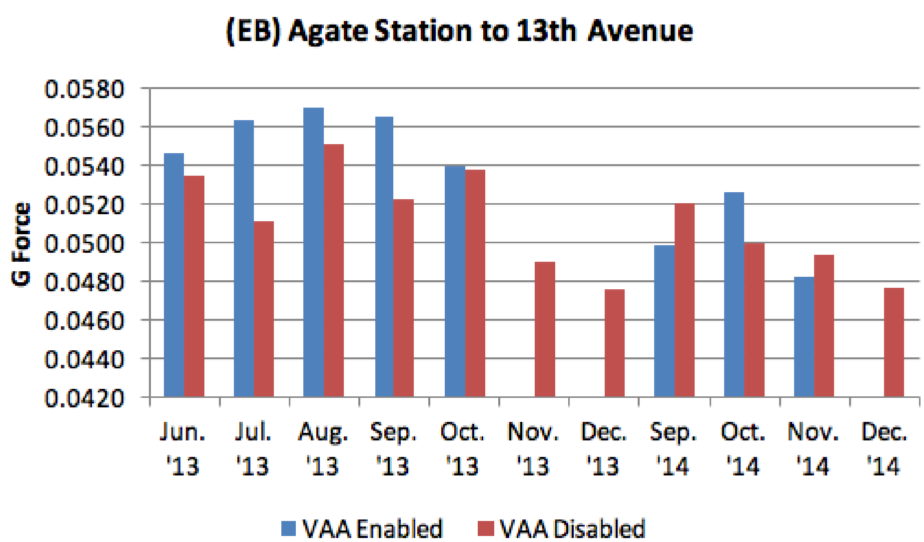
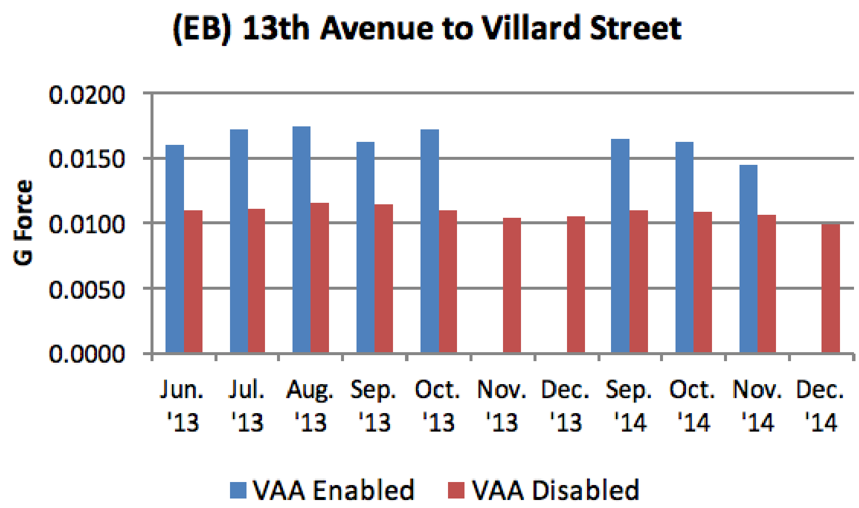
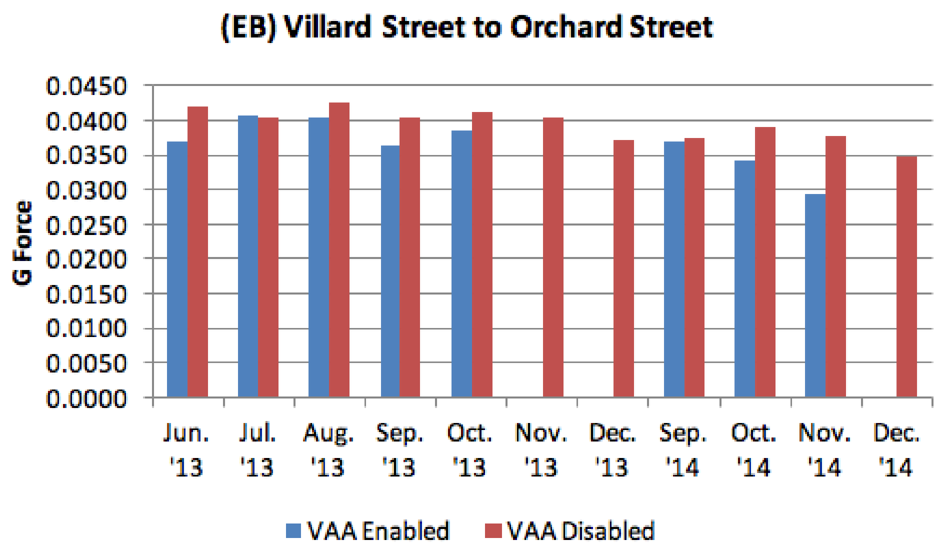


Figure 8-8 (cont.)

Lateral acceleration (eastbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.





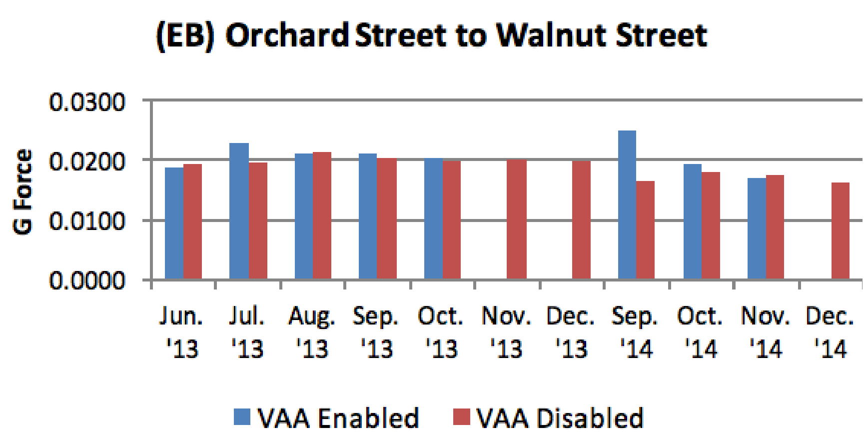
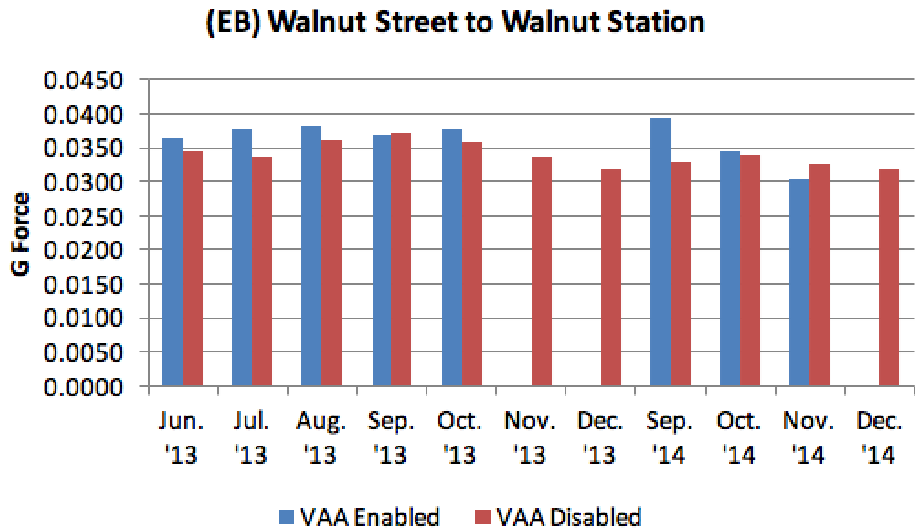


Figure 8-8 (cont.)

Lateral acceleration (eastbound segments)

Note: No VAA-enabled data were collected in November or December 2013 or December 2014.



Other System Performance Measures

In addition to lateral guidance, precision docking accuracy, and lateral acceleration, the evaluation looked at several other measures of VAA system performance, including system availability, fault management events, and driver overrides. In terms of system availability during the evaluation period, the VAA was operational 100% of the time, with the exception of August and September 2013, when it was operational only 66.7% and 80% of the time, respectively, because use of the VAA was temporarily suspended. The source of the problem was not the VAA system but rather a bad alternator and battery. The problem was first detected in June 2013 when the VAA controller detected faults in the bus's controller area network (CAN) communications and the magnetic sensor bars. This occurred twice in June, three times in July, and twice in August (seven times total). In two of the instances, the bus was under automated steering. The VAA system provided an audible warning to the driver, and the driver resumed manual steering. In the other five instances when the bus was under manual steering, the VAA system alerted the bus driver via red LED lights. Consequently, use of the VAA was temporarily suspended between August 20 and September 8 while PATH and LTD investigated the problem. After discovering that the source of the problem was a bad alternator and battery, these components were replaced, and use of the VAA was resumed. Despite the temporary drop in system availability, this occurrence demonstrated that the VAA's fault detection management system worked properly. Furthermore, these were the only fault indications during the course of the evaluation; there were zero VAA-related fault indications during revenue operations.

SECTION

9

Lessons Learned

Lessons-learned information was gathered via interviews with the key project participants, each of whom provided insights from a different perspective. LTD staff provided insights from an operational perspective (i.e., the impact of the VAA system on bus revenue service). Faculty engineers from PATH provided insights from a designer and developer perspective, as they constructed, tested, implemented, and monitored the system. Caltrans and AC Transit staff provided insight on lessons learned from a project management perspective.

To maintain consistency in the conduct of the interviews, an interview guide was used that included the following topical questions:

1. In general, would you consider the VAA Demonstration to be successful? Why? Why not?
2. What were the most challenging issues relative to the design, development, implementation, and evaluation phases of the VAA system on EmX?
3. What, if any, design changes occurred during the testing and implementation of the VAA system?
4. What specific benefits, if any, do you believe the VAA system will have on maintenance of vehicles and infrastructure?
5. To your knowledge, please list the lessons learned from the conceptual start of the VAA system to its actual in service demonstration
6. What specific benefits, if any, do you believe the VAA system will have on safety of the EmX service?
7. What specific benefits, if any, do you believe the VAA system will have on bus operators and service operations?
8. What specific benefits, if any, do you believe the VAA system will have on transit customers/riders?
9. Aside from answering the previous questions above, are there any other questions, observations, or opinions you would like to share toward evaluating the success and potential future of utilizing the VAA technology?
10. Aside from the technical perspective, are there any institutional issues learned or that may come into play for future implementation of this technology?

What follows are some of the key findings grouped by topic area. For a complete list of the comments in bulleted form, see Appendix C, Stakeholder Interviews.

General Findings

The unanimous response from all local project partners was that the VAA demonstration was a success. A recurring theme heard during the close-out interviews was that the demonstration project proved that VAA technology can work successfully in bus revenue service. The precision docking was recognized as the most successful element of the demonstration.

Technical Lessons Learned

An important technical lesson was learned in the early part of the demonstration. One of the computer controllers failed, and the redundant backup computer controller did not take over as it should have because a test version of the software was incorrectly installed. This caused the demonstration bus to move off track and required the bus operator to manually retake control of the steering. This early incident had an initial impact on how the bus operators trusted the system and caused LTD to be concerned with VAA system's performance and safety. PATH engineers addressed the issue with enhanced safety measures (e.g., added software interlock mechanism and fault detection redundancy at system level), and the demonstration continued with in-service testing that proved both reliable and safe. After that point, the VAA system did not experience any system or component failures during revenue service operations. The technical lesson learned was the importance of full fault detection redundancy in the primary and secondary computer controllers. As stated by one of the interviewees, safety design in VAA systems is a complex and iterative process in which the following factors are all very critical: redundancy, fault detection and warning, degraded-mode controls, and fault test procedures.

A second technical lesson learned pertains to the use of GPS. Originally, the project was going to test both magnetic marker sensing and GPS technologies. However, it was discovered later that this GPS was not precise enough to be used as the primary control. Therefore, the project only included magnetic maker sensing as the primary controller. The GPS was used only as a backup source of measurement and location referencing.

A few other technical lessons were learned. The epoxy sealant for the magnets had to be reapplied a second time because of rainy weather in Eugene. The lesson learned was the importance of checking the weather ahead of time. It was discovered that the magnetic sensors bars needed more insulation for better durability (e.g., to seal them sufficiently to withstand road and environment hazards, as well as bus cleaning). There was a comment that the original dashboard lights were inadequate and that the warning tones should be more distinctive for system failure. Finally, the design of the magnetic pathway on some of the curves and approaches to the stations should be reevaluated to reduce the "jerky" sensation that was widely reported when the bus was in motion.

Operational Lessons Learned

Several of those interviewed commented that the test track installed in the LTD bus yard was a critical piece of the project. Not only did it provide a place for the PATH engineers to integrate the VAA components and refine the software, it also provided a place for the trainers and operators to develop a trust and familiarity with the system before using it on the road. Related to this comment, another operational lesson learned that was mentioned by LTD staff was the importance of training. PATH conducted detailed training sessions on the VAA with several LTD instructors, and their feedback was incorporated into a training procedure for the operators, who were subsequently trained by the LTD instructors.

Institutional Lessons Learned

The most significant institutional lesson learned pertained to liability and indemnification requirements. This demonstration project involved multiple agencies (state and local), each with its own contract requirements. A disagreement between the University of California and Caltrans over the liability language in the contract caused a one-year project suspension. Similarly, the University's procurement rules impeded partnerships with private organizations. TRW, the company originally anticipated to supply the steering actuator, dropped out of the project as a subcontractor after months of failed negotiations with the University. The lesson learned is the need for more flexibility in procurement rules for technology research compared to procurement for typical professional services and products.

At the outset of the project, there was hope by the project partners that the successful implementation of the VAA in revenue service would lead to its commercialization. Although some of those interviewed felt that the demonstration provided a significant step forward in that regard, others felt that an opportunity had been lost due to turnover in the engineering staff at PATH and the lack of documentation on the software development.

APPENDIX

A

EmX Route Map

Appendix A contains the LTD route map for the EmX. The test track for the VAA demonstration was located between Dad's Gate Station and Walnut Station.

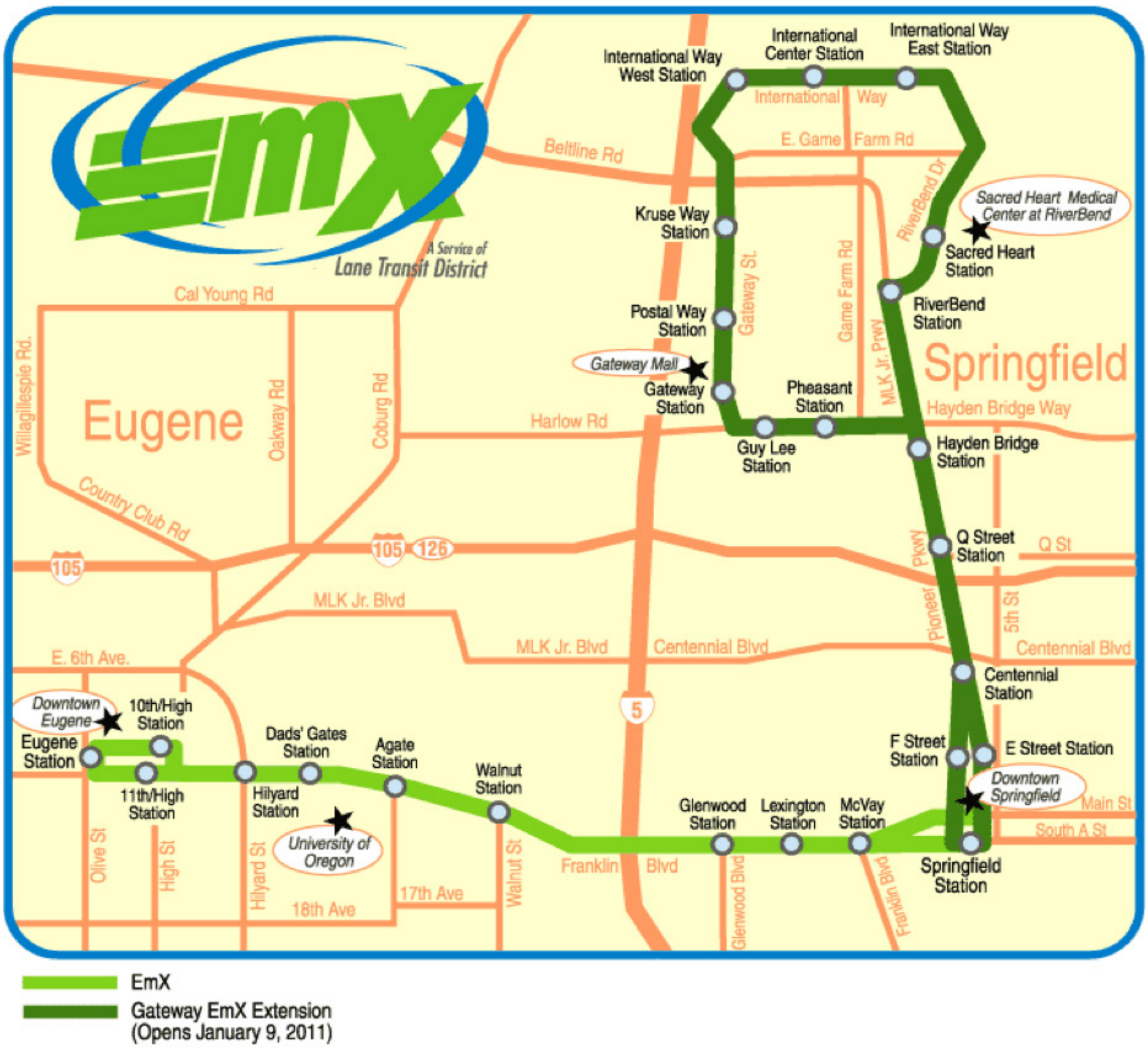


Figure A-1

EmX LTD route map

APPENDIX

B

Rider Survey

Appendix B includes the survey questionnaire administered to the customer service group and their responses. The questionnaire asked customers to rate various aspects of the ride quality and the precision docking performance and also included three open-ended questions that asked for their overall opinion of the VAA technology, what they thought was the most important benefit of the VAA, and what their thoughts were on the future use of VAA technology.

National BRT Institute

Vehicle Assist and Automation
Customer Evaluation Survey

Hello. The vehicle you rode today is equipped with special technology that helps the bus driver operate the vehicle in an automated mode from Walnut Station to Dad's Gate Station on the EmX route. This technology called Vehicle Assist and Automation (VAA) keeps the vehicle on a "magnetic track" and performs precision docking at the stations. We'd like your feedback on how the VAA affected your ride. Thank you for being a Customer Evaluator. Please answer the following questions and provide comments in the space provided.

1. Have you used the EmX service previously? If so, how long have you been riding this bus route?

   ☐ First time riding ☐ Less than 6 months
   ☐ 6 months to 1 year ☐ 1 to 3 years ☐ More than 3 years

2. Approximately how many days a week do you ride the EmX?

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

3. How would you rate each of the following aspects of the ride quality when the bus is running in the automated mode? Please circle the number that best reflects your opinion.

	Very Good	Good	Fair	Poor	Very Poor	Don't Know
Steering between stations	5	4	3	2	1	0
Minimal swaying of bus	5	4	3	2	1	0
Overall smoothness of ride	5	4	3	2	1	0
Speed of the bus	5	4	3	2	1	0

4. How would you rate the precision docking performance of the VAA system?

	Very Good	Good	Fair	Poor	Very Poor	Don't Know
Accuracy of aligning to station	5	4	3	2	1	0
Ease of boarding and alighting	5	4	3	2	1	0
Safety	5	4	3	2	1	0
Assistance to bus driver	5	4	3	2	1	0

5. What is your overall opinion of this Vehicle Assist and Automation (VAA) Technology?

6. What do you think are the most important benefits of VAA, if any?

7. Your thoughts on future use of VAA technology?

How long have you been riding this bus route?		
	Frequency	*Percentage*
First time riding	0	0%
Less than 6 months	2	17%
6 months to 1 year	0	0%
1 to 3 years	3	25%
More than 3 years	7	58%
Total	*12*	*100%*

Approximately how many days a week do you ride the EmX?		
	Frequency	*Percentage*
4–5 days	0	0%
1–3 days	3	25%
Less than 1 day per week	6	50%
Very infrequently	3	25%
Total	*12*	*100%*

On a scale of 1 to 5, how would you rate the following aspects of the ride quality when the bus is running in the automated mode?							
	1 = Very Good	*2 = Good*	*3 = Fair*	*2 = Poor*	*1 = Very Poor*	*0 = Don't know*	*Mean Score*
Steering between stations	17% (2)	50% (6)	25% (3)	8% (1)	0% (0)	0% (0)	3.75
Minimal swaying of bus	0% (0)	42% (5)	50% (6)	8% (1)	0% (0)	0% (0)	3.33
Overall smoothness of ride	8% (1)	42% (5)	50% (6)	0% (0)	0% (0)	0% (0)	3.58
Speed of bus	42% (5)	58% (7)	0% (0)	0% (0)	0% (0)	0% (0)	4.42

How would you rate the precision docking performance of the VAA system?							
	1 = Very Good	2 = Good	3 = Fair	2 = Poor	1 = Very Poor	0 = Don't know	Mean Score
Accuracy of aligning to station	83.3% (10)	8.3% (1)	0% (0)	0% (0)	0% (0)	8.3% (1)	4.91
Ease of boarding and alighting	91.7% (11)	8.3% (1)	0% (0)	0% (0)	0% (0)	0% (0)	4.92
Safety	66.7% (8)	25.0% (3	0% (0)	0% (0)	0% (0)	8.3% (1)	4.73
Assistance to bus driver	50.0% (6)	33.3% (4)	0% (0)	0% (0)	0% (0)	16.7% (2)	4.60

Note: One of the 12 group members did not complete a survey. The mean scores exclude those who chose "Don't know."

What is your overall opinion of this Vehicle Assist and Automation (VAA) Technology?

- I thought the experience was good. The bus was packed so it was difficult to see everything but overall it was a good experience. I was a little surprised it was not smoother.
- For docking, I think it's a wonderful system. For the swaying and jerkiness of the steering between stations, it is less than "friendly."
- I am impressed with the technology and its potential to improve safety and provide consistent docking. I did not feel that it made the ride more like a LRT or Street Car.
- The docking at the stations was good very consistent, but the bus felt very jerky and not very smooth.
- Has great potential.
- Positive for the precision docking. Neutral for the lane keeping.
- Great technology/potential.
- Seems to provide great benefit in docking and managing the space between the station. That is not always the case w/other EmX. May cause some hesitation from drivers who aren't comfortable w/the assistance. They may turn it off, but this defeats the benefit.
- Seems like a good system, although we had a good driver on the way out. I've seen other drivers park much farther from the docking station.
- The best part of the technology is consistent docking. During the ride it was a bit jerky in some curves at higher speeds.
- Best suited to docking and tight corner approaches to stations (like Walnut where non-assisted drivers sometimes bump wheels against curbs). Did not notice much difference along the guideway sections.

- Between stations the "smoothness" of the guidance "line" likely needs improving. Seemed to work very well at docking. In both cases, but particularly docking, I can see a strong benefit in consistent operations among a variety of driver skill levels and desires.

What do you think are the most important benefits of VAA, if any?

- The ability to consistently dock the bus to the platform. Large gaps are a real issue for safety.
- Docking. I've been on many EmX's that dock a foot or more away and it is frightening. I can't imagine being alter-abled and trying to make sure I could get across the gap safely.
- Consistent docking; safety
- Docking is very consistent. It will help prevent some shoulder issues that we have with drivers. Save money on tires and structure of stations.
- Consistency. Gap between vehicle and platform looked to be the same at stations where VAA was employed. Safety to passengers. i.e. minimum gap to cross. Reduced maintenance, vehicle and platform.
- Precision docking – ability to get close to the platform.
- Consistency in docking improves safety for drivers. Improved experience for riders – smoother ride.
- Precision docking to improve boarding and safety of boarding. Potentially a smoother ride. However, I felt a little bouncing back and forth as the bus corrected itself.
- Docking
- Safe, consistent boardings
- Consistent docking spacing
- At this point it seems like docking and consistency of ride, both docking and travelling in the situations where drives are variable (some fast, slow, better, not so much).

Your thoughts on future use of VAA technology?

- I think future use of the VAA technology may help control the smoothness of the ride especially for those standing. Maybe there can be a connection to speed and not only navigation resulting in a smoother ride.
- If we could utilize it on all EmX, docking, it would increase the safety and likeability of the system.
- I hope that the technology improves to provide a smoother ride that works more like LRT or other rail options and makes BRT more attractive to cities as a cheaper and more adaptable rail alternative. It is a lot easier to install and relocate magnets than rails.

- I worry about the driver not paying attention to his surrounding while he is driving.
- Hopefully, it has a future. Private sector needs to offer a [unreadable] of the hardware and software to implement the technology. Liability concerns need to be addressed. Need robust components that will last. Operator confidence in systems reliability/safety need to be established. Very cool potential.
- I support its use for precision docking.
- Improved safety for routes and docking. Could make ride smoother if alignment enhanced. The movement in the back of the bus could be minimized.
- Curious what the cost is to implement. Does it provide enough benefit to balance out inconsistencies of drivers including costs for training.
- Perhaps start w/docking and then phase into the rest of the route later.
- With this or similar technology in all vehicles, not just buses, I think safety would increase tremendously.
- May be useful (more useful) if speed control can be coordinated with steering control for optimal ride quality.
- Has strong promise for fixed guideway deployments. Presumably the technology is not “fixed” but is being reworked and improved upon over time. As the tech improves, the utility of this system should also improve. It is also going to take time for drivers in general to grow comfortable operating the bus w/o use of hands. I think it will be important to stay with the tech over time to see its evolution and more fully realize the potential of this system.

Stakeholder Interviews

At the conclusion of the project, NBRTI conducted close-out interviews with key project staff from LTD, PATH, and Caltrans to gather information on lessons learned. Their comments are paraphrased and listed below.

- Very successful demonstration of technology and ability to conduct research in a real live service environment.
- Disappointment that good practices were lacking in software development and documentation.
- Precision docking most impressive and significant.
- This demonstration took the development of VAA technology a step further beyond proof of concept and confirmed its feasibility and benefits.
- There were significant institutional issues related to contracting, liability, and insurance that delayed the project; this is something that needs to be addressed for research of this nature.
- System reliability was established with no component failures experienced.
- Design and engineering staff turnover impacted the project's continuity and delayed progress.
- The design and durability of the sensor bars were enhanced with insulation modifications.
- The design of the magnetic runway at curves and approaches to the stations should be reevaluated and be based on good driver patterns.
- Installation issues and support necessary for roadway mobilization and installation phase were critical for the success of the demonstration.
- The physical layout of the VAA controls in the bus cabin needs to account for differences in bus operator body physique (specifically placement of the on/off engagement switch and steering wheel interface).
- Power supply failures were addressed.
- There was substantial new development of hardware and software for improved reliability and safety deployment issues such as project delivery, as well as infrastructure, maintenance and operational preparation.
- Significant complexities in contractual arrangements with transit agencies and multiple industrial partners were experienced.
- Safety design is the first and foremost design consideration for deploying an automated bus in a public roadway, and safe operation is the prerequisite for transit agencies to adopt any automated control technologies into a bus for revenue service.

- Safety design in vehicle automated control is a complex and iterative process in which the following factors are all very critical: redundancy, fault detection and warning, degraded-mode controls, and fault test procedures.
- The VAA system maintains a consistent docking performance, and initial comments from the operators suggest the VAA system does reduce operators' stress with improved performance.
- The warning system worked in a system failure event.
- More than one bus should have been utilized, and the test segment should have included Hilyard Station.
- Original dashboard lights were inadequate; the warning tones should be more distinctive for system failure.
- No difference in front and back as smoothness to observer.
- It was a good test as a proof of concept but not of its long term sustainability (i.e., life cycle).

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