GEORGIA DOT RESEARCH PROJECT 11-13

FINAL REPORT

FEASIBILITY STUDY FOR USING VIDEO DETECTION SYSTEM DATA TO SUPPLEMENT AUTOMATIC TRAFFIC RECORDER DATA

Georgia Department of Transportation

OFFICE OF RESEARCH
15 Kennedy Drive
Forest Park, GA 30297-2534

1.Report No.: FHWA-GA-15-1113	**2. Government Accession No.:**	**3. Recipient's Catalog No.:**

4. Title and Subtitle: Feasibility Study for Using Video Detection System Data to Supplement Automatic Traffic Recorder Data	**5. Report Date:** December 2013 **6. Performing Organization Code:**
7. Authors: Angshuman Guin, Ph.D., Michael Hunter, Ph.D., Wonho Suh, Ph.D., James Anderson	**8. Performing Organ. Report No.:** 11-13
9. **Performing Organization Name and Address**: School of Civil and Environmental Engineering Georgia Institute of Technology 790 Atlantic Dr. Atlanta, GA 30332-0355	**10. Work Unit No.:** **11. Contract or Grant No.:** 0010406
12. Sponsoring Agency Name and Address: Georgia Department of Transportation Office of Research 15 Kennedy Drive Forest Park, GA 30297-2534	**13. Type of Report and Period Covered**: Final; May 2011–December 2013 **14. Sponsoring Agency Code:**

15. Supplementary Notes:
Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract:
The objective of this study was to determine the feasibility of incorporating Georgia NaviGAtor traffic volume data with Georgia Department of Transportation (GDOT) traffic volume data to enhance federal reporting. Some of the pertinent conclusions from this study are:

1. Accuracy of video detection system (VDS) counts varied from site to site and lane to lane.
2. Accuracy for VDS with gantry-mounted cameras was not significantly better than that of pole-mounted VDS sites.
3. Accuracy of VDS sites with cameras mounted on 36 ft. offset poles was marginally lower than units with cameras mounted on 24 ft. offset poles.
4. Accuracy of counts from VDSs and remote traffic microwave sensors (RTMSs) is sensitive to site-specific deployment characteristics.
5. There is a likely limit to the number of lanes that may be accurately counted by a single VDS unit.
6. Counts aggregated over all lanes provide the highest accuracy.
7. Given the variability in data quality across detection stations, the use of VDS data to supplement GDOT data should be considered on a detector-by-detector basis (i.e. the data from a detector need to be individually checked for quality against ground truth data before they are used for federal reporting purposes).

17. Key Words: Video Detection System, Highway Performance Monitoring System, Automatic Traffic Recorders	**18. Distribution Statement:**

19. Security Classification (of this report):	**20. Security Classification (of this page):**	**21. Number of Pages:**	**22. Price:**
Unclassified	Unclassified	61	

Form DOT 1700.7 (8-69)

GDOT Research Project No. 11-13

Final Report

Feasibility Study for Using Video Detection System Data to Supplement Automatic Traffic Recorder Data

By

Angshuman Guin, Ph.D. (PI)

Michael Hunter, Ph.D. (Co-PI)

Wonho Suh (Research Engineer)

James Anderson (Graduate Research Assistant)

School of Civil and Environmental Engineering
Georgia Institute of Technology

Contract with

Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

December 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Georgia Department of Transportation (GDOT) Office of Transportation Data (OTD) collects continuous traffic data using permanently installed in-pavement sensors and related telemetry traffic data collection equipment, which are referred to as automatic traffic recorders (ATRs). GDOT's Office of Traffic Operations (OTO) collects traffic data primarily from the video detection system (VDS), remote traffic microwave sensor (RTMS), and ramp meter sensors (in-pavement loops) as part of its NaviGAtor intelligent transportation system (ITS) network. Currently, these different sources of traffic volume data are not integrated into a unified database. The objective of this project was to determine the feasibility of incorporating navigator traffic volume data with OTD traffic volume data to enhance federal reporting. This project evaluated the accuracy of the VDS and ATR data collection systems and investigated the performance of the VDS detectors under various conditions, including mounting styles and offsets. This project focused on freeway mainline data collected from the VDS and ATR systems. The data from both systems were selectively compared with ground truth manual vehicle counts performed at each location. Even though the data quality from the VDS varied across stations, the overall results provided positive evidence toward the feasibility of incorporating navigator traffic volume data with OTD traffic volume data, in order to enhance federal reporting. Since the results are based on the limited sample stations, additional study and cross-checking will be needed before navigator traffic volume data can be incorporated with OTD traffic volume data. However, given the variability in data quality across detection stations, it would not be appropriate to accept or reject data from the entire detection network as a whole for use in supplementing OTD data. The use of VDS data to supple-

ment OTD data should be considered on a detector-by-detector basis (i.e., the data from a detector need to be individually checked for quality against ground truth data before they are used for federal reporting purposes).

ACKNOWLEDGMENTS

The authors of this report thank the Georgia Department of Transportation for its support and assistance throughout this effort, in particular the efforts of David Jared, Mark Demi-dovich, Scott Knight, and Scott Susten.

INTRODUCTION

State departments of transportation (DOTs) collect continuous traffic data using permanently installed in-pavement sensors and related telemetry traffic data collection equipment, commonly referred to as automatic traffic recorders (ATRs). These ATR traffic data provide continuous traffic count coverage at selected locations. In addition to providing direct measurement of average annual daily traffic (AADT) counts at these locations, the data from ATRs are also used to develop seasonal or monthly, day-of-week, and growth factors that are then used to adjust short coverage counts to generate estimated AADT counts at other sites [1].

Obtaining accurate continuous traffic count data is essential for state DOTs to report the AADT for the federal Highway Performance Monitoring System (HPMS). State DOTs are responsible for traffic counting programs that cover all Interstate, Principal Arterial System (PAS), other National Highway System (NHS), and HPMS sample sections. Whenever possible, state DOTs are expected to have at least one continuous counter on each major PAS/NHS highway route. At a minimum, each continuous counter should have at least two full days of data for each day of the week for each month [1]. These continuous traffic counts are also essential for planning purposes, since the 30^{th} highest hour factors are typically determined based on permanent ATR station counts.

The Federal Highway Administration (FHWA) recommends state DOTs use ATR data to generate appropriate factors to apply to short-term counts for obtaining estimates of AADT [1]. However, continuous ATR count data can become unavailable due to several factors, including pavement rehabilitation, construction, and maintenance. FHWA encourages state DOTs to use statewide factors if there are insufficient ATR data and to have a comprehensive quality assurance program that includes data collection, the conversion of traffic counts into current year AADT values, routine equipment testing provisions, and routine traffic count calibration procedures. As an alternative, this paper explores the potential of using data collected for real-time traffic monitoring purposes by other non-invasive technologies, including video detection system (VDS) and remote traffic microwave sensor (RTMS) on a short-term basis to supplement ATR traffic count data for federal reporting when ATR data are not available.

Short-term, 48-hour traffic data are typically collected using road tubes and portable traffic data collection devices. The Georgia Department of Transportation (GDOT) Office of Traffic Operations (OTO) collects traffic data primarily from the VDS, RTMS, and ramp meter sensors (in-pavement loops) as part of its NaviGAtor intelligent transportation system (ITS) network. In the current system, the different sources of traffic volume data are not integrated into a unified database.

This research project will (1) evaluate the accuracy of the VDS, RTMS, and ATR data collection systems; (2) investigate the performance of the VDS detectors under various conditions, including mounting styles and offsets; and 3) determine the feasibility of incorporating NaviGAtor traffic volume data with GDOT's Office of Transportation Data (OTD) traffic volume data to enhance federal reporting. This research project focuses on freeway mainline data collected from the VDS, RTMS, and ATR systems. The data from both systems are selectively compared with ground truth manual vehicle counts performed at each location.

Existing data collection systems are typically expensive, and manufacturer claims of accuracy and robustness often assume ideal conditions and are far from the results that can be obtained in real-world installations. Hence, a comparison of the data from the data collection systems can provide GDOT a better understanding of the data accuracy with respect to the possibility of data integration across data collection systems.

LITERATURE REVIEW

Traffic counts are one of the fundamental data sources for a variety of transportation applications, ranging from assessment of current transportation system conditions to future transportation planning and forecasting [2–8]. At this time, automated traffic counts are collected mostly by ATR (using inductive loop detectors), RTMS, and VDS-based systems. While the abundance of traffic count data offers new opportunities for better transportation planning and forecasting, the quality of the data is not uniform across technologies and deployments. Thus, an assessment of the suitability of the data for the given use is critical.

Traffic count quality is a critical part of transportation monitoring and planning. However, obtaining accurate traffic count data in high-volume urban areas using intrusive technologies is often challenging from an equipment setup and maintenance standpoint [9]. Nonintrusive technologies have evolved over the years and have been deployed to provide traffic data [9–13]. The overall accuracy of those data collection technologies has been well documented [13–17]. However, the variability of each technology and its sensitivity under different deployment conditions has not been studied in detail. The Federal Highway Administration established general principles to ensure that traffic data are analyzed and summarized in a consistent manner [12]. Understanding and identifying variability in the accuracy of the data collection technologies will assist transportation practitioners in making decisions using traffic count data.

Numerous studies have investigated the accuracy of ATR, RTMS, and VDS detection technologies. Overall, researchers consider ATR to be the most accurate [12]. FHWA also listed the accuracy of inductive loop detectors and RTMS as excellent and fair, respectively, for VDS detectors [12]. In that study, researchers noted that VDS detectors have poor performance in high-density locations or bad weather conditions. Also, they list occlusion and light conditions as possible reasons for reduced accuracy of VDS detectors. Knowing there are errors in the data collection technologies, FHWA [12] recommended a general rule of thumb to follow to check if data collection equipment is working properly. According to these recommendations, the data collection equipment is considered working properly when a comparison manual count is within ±2% of inductive loop sensor counts, ±10% of road tube and vehicle classifier automatic counts, and ±15% of weigh-in-motion automatic counts.

Another report by the Federal Highway Administration [11] documented accuracy of ATRs from multiple case studies: a 4.4% mean absolute percentage error (MAPE) in a Texas case study, a 4% MAPE in a Pennsylvania case study, and a 0.89% MAPE in an Ohio case study. To ensure the quality of the traffic data, the report developed a framework for data quality measurement based on six fundamental measures: accuracy, completeness, validity, timeliness, coverage, and accessibility [11].

Numerous studies have investigated the accuracy of traffic count data collection technologies. However, most studies provided overall average percentage error and did not specifically explore the variability of the data generated by these technologies, especially with different operating and deployment conditions including mounting styles and offsets. This is of particular interest in urban freeway environments where deployments are intensive but equipment setups are often suboptimal due to capital and maintenance resource constraints. Understanding the variability of different data collection technologies will assist transportation practitioners in understanding the limitations and strengths of the data for measuring performance and thereby in making decisions based on analysis using traffic count data from different technologies.

This research project compares the traffic count data from the VDSs under various conditions, including mounting styles and offsets. Understanding the variability of the data collection technologies will provide a better understanding about the data accuracy and assist GDOT in making decisions regarding traffic count data.

RESEARCH APPROACH

The objective of this research is to investigate the variability of data collection technologies in freeway environments. For this study, researchers adopted a strategy for obtaining manual counts that would allow for count verification and thereby reduce the potential for inaccuracies in collecting the baseline comparative counts. The research team recorded over 1400 lane-hours of video from pan-tilt-zoom (PTZ) freeway surveillance cameras near selected ATR, VDS, and RTMS locations (study sites) around the Metro Atlanta area from 6AM–10AM and 3PM–7PM in 2011 and 2012. The video was manually processed using a tablet-based traffic counting application [18] to generate baseline manual counts. The baseline manual counts were then compared with the ATR, VDS, and RTMS data to evaluate the accuracy of each set of data.

TABLET-BASED TRAFFIC COUNTING APPLICATION

To ensure accuracy of the baseline manual counts and reduce human processing error, researchers at the Georgia Institute of Technology have developed a tablet-based traffic counting application. This application allows the data collectors to manually count vehicles on a tablet from videos recorded from traffic-monitoring cameras. To record counts on the tablet, the data collector taps on the screen when the vehicle crosses the designated count location (lane specific) set as part of the program initialization for that site. The data collectors can stop and play the videos at their convenience. This application also allows the data collectors to replay and toggle through the video to review and correct counts. Whenever tapped, the detector location highlights, and the highlight is recalled when the video is reviewed. This feature allows different data collectors to review and correct other users' count while replaying the video. Figure 1 presents a snapshot of the application. A detailed discussion of the accuracy and use of the tablet-based counting application is available in the report by Toth et al. [18]. For all sites in this study, unless otherwise noted, the baseline counts used for evaluation of the ATR and VDS technology were collected manually from PTZ video streams using the tablet-based traffic counting application. Numerous days of PTZ video feeds were recorded to allow for the elimination of days in which the video was not usable because of changes made to the PTZ video angle by a system operator in GDOT's Transportation Management Center in order to detect or monitor incidents.

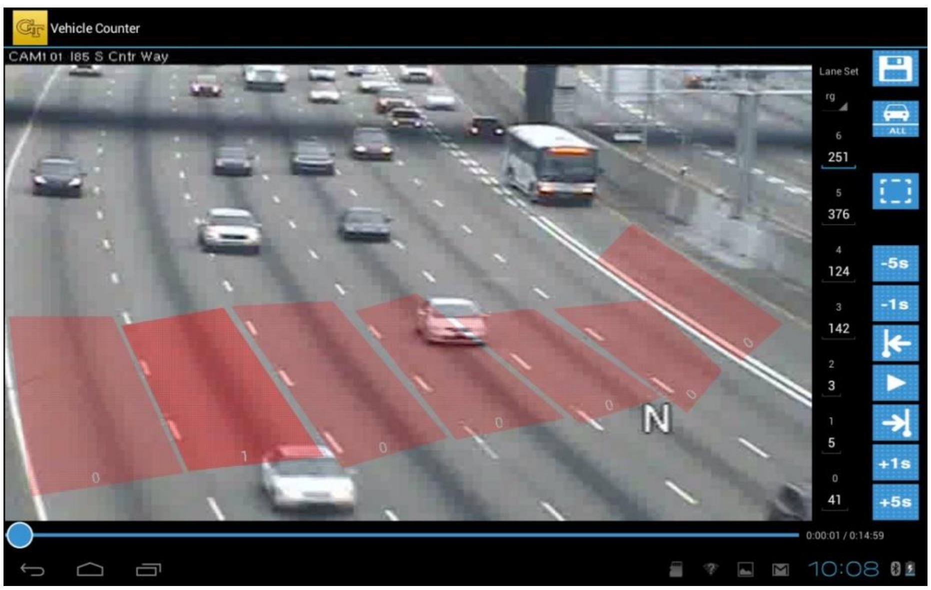


Figure 1: Tablet-based Traffic Counting Application

DATA COLLECTION AND PROCESSING – FIRST ROUND

To investigate the accuracy of ATR and VDS, baseline traffic counts were compared with counts from ATR and VDS on I-285 at Orchard Road near Smyrna, Georgia. This location was chosen for the first-round data collection as both gantry-mounted VDS and pole-mounted VDS deployments are available near this ATR site (067-2373), with no entry or exit ramps in between to affect total vehicle counts. Additionally, PTZ cameras are available near these stations that could be leveraged to facilitate video data collection for generating baseline data. Video streams from the PTZ cameras were recorded regularly during peak and off-peak periods to enable collection of baseline counts by post-processing the recorded videos. Figure 2 illustrates the location of the data collection site.

At first, ATR and VDS data availability in November 2011 was investigated (Table 1). The researchers found that data for nine non-consecutive days were not available for the ATR station. For the VDS station 285-0210, northbound near Cumberland Parkway, data were missing for 10 consecutive days between November 1 and 10 due to local detection/communication failure at this station. The other three VDS stations' data were available for all 30 days in November. Additionally, it was discovered that some of the PTZ camera views that were recorded were not suitable for manual traffic counts. Figure 3 shows example PTZ camera views that were suitable for data collection and not suitable,. The view in Figure 3a was suitable as it allowed the data collectors to count vehicles at a location that is close to the location of the installed detectors with a low probability of vehicles changing lane between the viewable location and the detector location. Figure 3b shows a view where the camera was zoomed in to a location close to the exit ramp. This location is not only farther from the installed detector location, it also increases the probability of vehicles changing lanes due to the presence of the exit ramp. Thus, the view in Figure 3b was not suitable for baseline data collection. Additionally, Saturday/Sunday and days during Thanksgiving week were excluded from the data collection time period. After checking all the data availability, weekend/holiday schedule, and view suitability criteria, the researchers selected for processing more than 380 lane-hours of video from PTZ cameras on weekdays during time periods of 6AM–10AM and 3PM–7PM in November 2011. The videos from the PTZ camera were counted by using the traffic counting application. The Results section of this report provides a comparison of the baseline, VDS, and ATR counts.

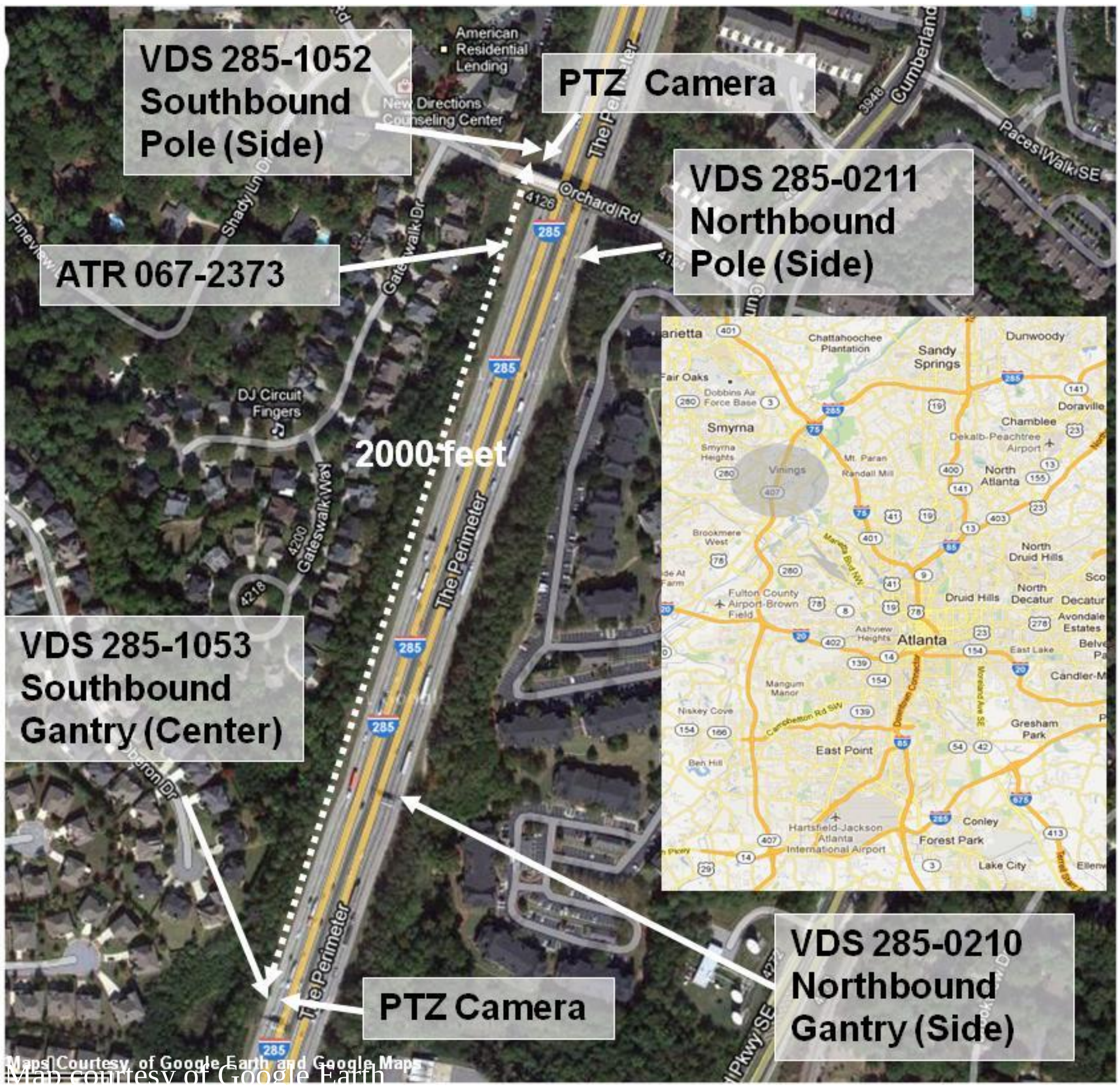


Figure 2: First Round Data Collection Site

Table 1: Data Availability Matrix for Phase-I (November 2011)

Date	Day	ATR data	VDS 2850210	VDS 2850211	VDS 2851052	VDS 2851053	PTZ Video	PTZ 111 AM	PTZ 111 PM	PTZ 109 AM	PTZ 109 PM
11/1	Tuesday	N/A	N/A	OK	OK	OK	OK		OK		Low Quality
11/2	Wednesday	OK	N/A	OK	OK	OK	OK	zoomed on ramp	zoomed on ramp	Low Quality	Low Quality
11/3	Thursday	OK	N/A	OK	OK	OK	OK	zoomed on ramp	zoomed on ramp	Accident	OK
11/4	Friday	OK	N/A	OK	OK	OK	OK	zoomed on ramp	zoomed on ramp	OK	OK
11/5	Saturday	OK	N/A	OK	OK	OK	OK	zoomed on ramp	zoomed on ramp	OK	OK
11/6	Sunday	N/A	N/A	OK	OK	OK	OK	zoomed on ramp	Can't see left side	OK	Stalled Car
11/7	Monday	OK	N/A	OK	OK	OK	OK	Can't see left side	Can't see left side	Low Quality	Low Quality
11/8	Tuesday	OK	N/A	OK	OK	OK	OK	Stalled Car	Stalled Car	OK	OK
11/9	Wednesday	OK	N/A	OK	OK	OK	OK	OK	OK	OK	Low Quality
11/10	Thursday	N/A	N/A	OK	OK	OK	OK	OK	OK	Low Quality	Low Quality
11/11	Friday	N/A	OK	OK	OK	OK	OK	OK	OK	Low Quality	OK
11/12	Saturday	N/A	OK	OK	OK	OK	OK	OK	OK	OK	OK
11/13	Sunday	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
11/14	Monday	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
11/15	Tuesday	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
11/16	Wednesday	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
11/17	Thursday	N/A	OK	OK	OK	OK	OK	OK	OK	OK	Accident
11/18	Friday	N/A	OK	OK	OK	OK	OK	OK	OK	Can't see left side	off highway
11/19	Saturday	OK	OK	OK	OK	OK	OK	OK	OK	All off highway	All off highway
11/20	Sunday	OK	OK	OK	OK	OK	OK	OK	OK	All off highway	All off highway
11/21	Monday	OK	OK	OK	OK	OK	OK	Fog for 20 minutes	Low angle zoom	Low Quality	Zoomed in
11/22	Tuesday	OK	OK	OK	OK	OK	OK	OK	camera angle change	OK	OK
11/23	Wednesday	OK	OK	OK	OK	OK	OK	OK	OK	OK	First 15 min is unusable
11/24	Thursday	N/A	OK	OK	OK	OK	OK	OK	OK	OK	OK
11/25	Friday	OK	OK	OK	OK	OK	N/A	OK		OK	
11/26	Saturday	OK	OK	OK	OK	OK	N/A				
11/27	Sunday	OK	OK	OK	OK	OK	N/A				
11/28	Monday	OK	OK	OK	OK	OK	N/A				
11/29	Tuesday	N/A	OK	OK	OK	OK	N/A				
11/30	Wednesday	OK	OK	OK	OK	OK	N/A				

(a)

(b)

Figure 3: PTZ Camera View: (a) Usable for Baseline Manual Counts, (b) Not Usable for Baseline Manual Counts

DATA COLLECTION AND PROCESSING – SECOND ROUND

As a follow-up to the first round, researchers collected data at four additional locations: (1) gantry-mounted VDS on I-285 near US-78, (2) pole-mounted VDS with 36 ft. offset on I-285 near Cascade Road, (3) RTMS on US-78, and (4) pole-mounted VDS on the I-75/85 Connector. More than 700 lane-hours of video from PTZ cameras were collected during weekdays 6AM–10AM and 3PM–7PM in 2012. Table 2 and Figure 4 show the data collection locations with their site-specific characteristics. The videos from the PTZ camera were counted by using the traffic counting application. The Results section discusses the comparison of the baseline, VDS, and ATR counts.

Table 2: Data Collection Location Summary

No	Sensor Type	Number of Lanes	Setup Style	Location
1	ATR	4		I-285 Northbound near Orchard Road
2	ATR	4		I-285 Southbound near Orchard Road
3	VDS	4	Pole-mounted, 24 ft. travel lane offset	I-285 Northbound near Orchard Road
4	VDS	4	Pole-mounted, 24 ft. travel lane offset	I-285 Southbound near Orchard Road
5	VDS	4	Gantry-mounted, Side	I-285 Northbound near Cumberland Parkway
6	VDS	4	Gantry-mounted, Median	I-285 Southbound near Cumberland Parkway
7	VDS	4	Pole-mounted, 36 ft. travel lane offset	I-285 Northbound near Cascade Road
8	VDS	4	Pole-mounted, 36 ft. travel lane offset	I-285 Southbound near Cascade Road
9	VDS	4	Gantry-mounted, Median	I-285 Northbound near US-78
10	VDS	4	Gantry-mounted, Median	I-285 Southbound near US-78
11	RTMS	3	Pole-mounted	US-78 Eastbound near Idlewood Road
12	RTMS	3	Pole-mounted	US-78 Westbound near Idlewood Road
13	VDS	7	Pole-mounted	I-75/I-85 Near 14th Street

Figure 4: Second Round Data Collection Sites

RESULTS

RESULTS – FIRST ROUND

More than 380 lane-hours of video from pan-tilt-zoom cameras were manually counted and compared with ATR and VDS counts for the first-round data analysis. Typically, GDOT numbers VDS installation lanes from the inside lane to the outside lane. During the analysis, a lane mapping issue was identified in the VDS data and it was determined that the lowest "Detector ID" corresponds to the innermost lane in the VDS data during the period of data collection. Table 3 shows the correct lane configuration for that period.

Table 3: GDOT VDS Lane Configuration and Correct Lane Configuration (November 2011)

Station ID	GDOT VDS Lane Configuration	GDOT Detector ID	Correct Lane Configuration
285-1052	Lane 4	9646	Lane 1 (innermost lane)
	Lane 2	9647	Lane 2
	Lane 3	9648	Lane 3
	Lane 1	9649	Lane 4 (rightmost lane)
285-1053	Lane 1	9650	Lane 1 (innermost lane)
	Lane 4	9651	Lane 2
	Lane 3	9652	Lane 3
	Lane 2	9653	Lane 4 (rightmost lane)
285-0210	Lane 1	7366	Lane 1 (innermost lane)
	Lane 4	7367	Lane 2
	Lane 2	7368	Lane 3
	Lane 3	7369	Lane 4 (rightmost lane)
285-0211	Lane 4	7370	Lane 1 (innermost lane)
	Lane 3	7371	Lane 2
	Lane 1	7372	Lane 3
	Lane 2	7373	Lane 4 (rightmost lane)

ATR Southbound near Orchard Road (067-2373)

ATR station 067-2373 collects northbound and southbound traffic on I-285. Figure 5 and Figure present y-y plots of the ATR counts versus the baseline manual counts and box plots of the percentage error between the hourly lane baseline counts and the ATR data, respectively. The y-y plots reveal that the ATR counts display a close agreement with the baseline manual counts. In the box plots, the tops and bottoms of each “box” are the 25th and 75th percentiles of the samples, respectively. The distances between the tops and bottoms are the interquartile ranges. The line at the center of each box is the sample median. If the median is not centered in the box, it shows skewness in the statistical distribution of the differences. The whiskers are lines extending above and below each box, and they are drawn from the ends of the interquartile ranges to the farthest observations not considered an outlier. Outliers are defined as being greater than 1.5 times the interquartile range away from the top and bottom of the box. Observations beyond the whisker length are marked as outliers and displayed with a red + sign. Notches display the variability of the median between samples [19]. From the box plots, the percentage differences were mostly within 5%. When considering the sum of all lane counts, the mean percent differences were within 1% and the mean absolute percent differences were within 2% for either direction.

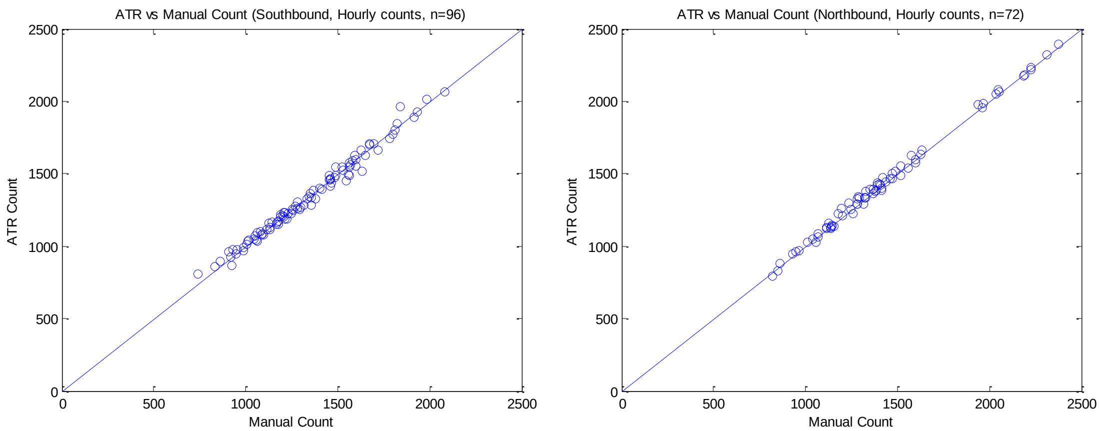
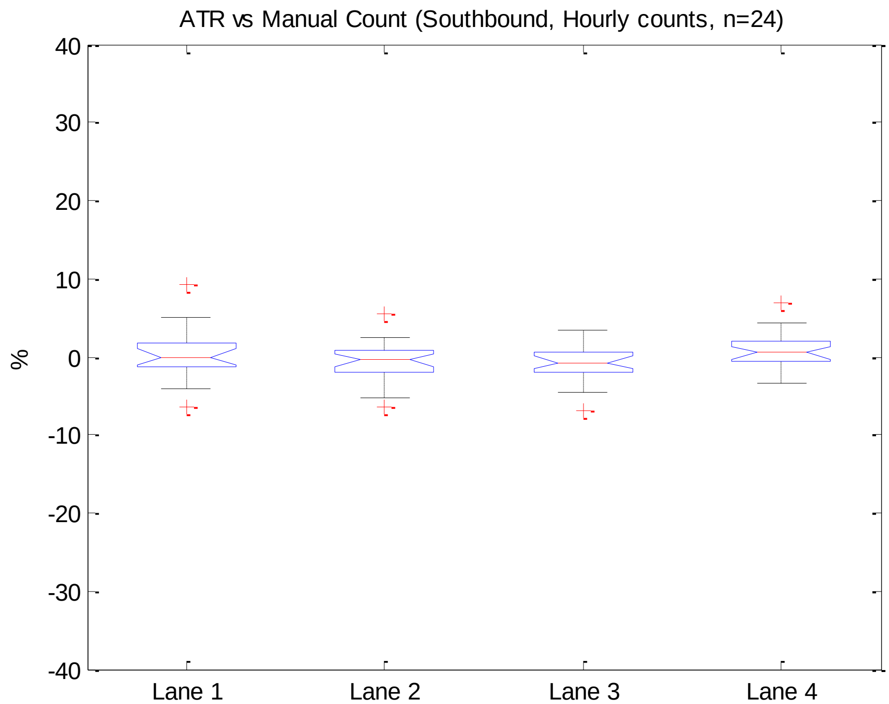
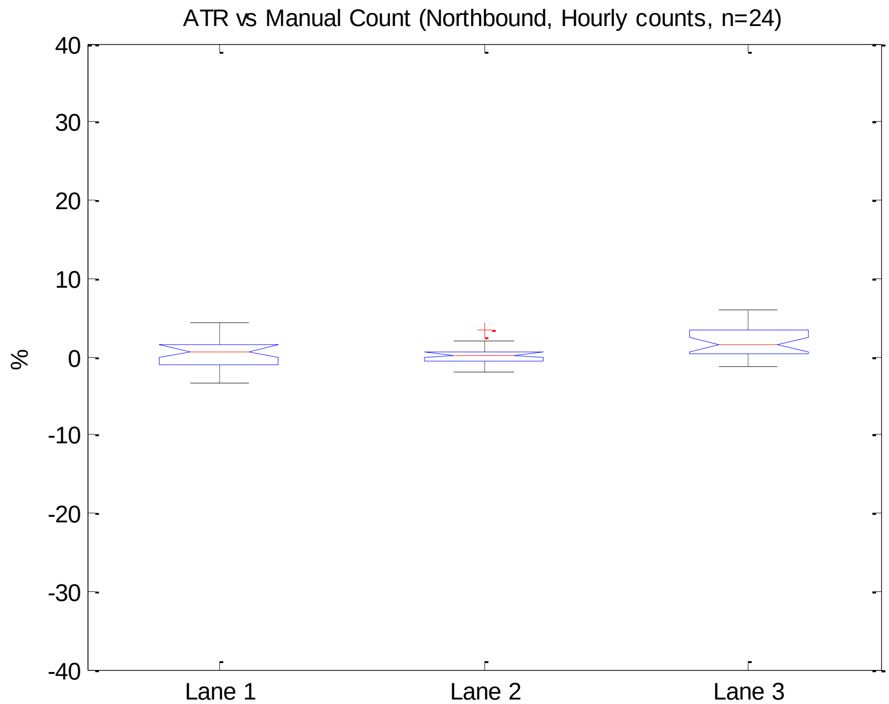


Figure 5: Y-Y Plots for ATR vs. Baseline, Lane-by-Lane (All Lanes) Manual Counts, ATR Station 067-2372 (Left: Southbound; Right: Northbound)



(a)

Figure 6: Lane-by-Lane ATR Comparison to Baseline Counts, ATR Station 067-2373: (a) Southbound, (b) Northbound



(b)

Figure 6: Lane-by-Lane ATR Comparison to Baseline Counts, ATR Station 067-2373: (a) Southbound, (b) Northbound (Continued)

Pole-mounted VDS, 24 ft. offset at Orchard Road (285-1052 and 285-0211)

VDS stations 285-1052 and 285-0211 are both pole-mounted (see Figure 7). VDS station 285-1052 is located approximately 300 ft. away from the northbound Orchard Road ATR station (067-2373) and collects southbound traffic, while VDS station 285-0211 is located at the northbound Orchard Road ATR station (067-2373) and collects northbound traffic. Figure 8 and Figure 9 give the VDS camera views and the y-y plots of the VDS counts versus the baseline manual counts, respectively. Lane 4 of the northbound traffic (VDS station 285-0211) was not included because accurate baseline manual counts were not available due to the view obstruction from the Orchard Road overpass. The y-y plots show a general correlation between the VDS and baseline counts. However, as shown from the northbound VDS camera, at higher traffic volumes the VDS camera slightly undercounted compared to the baseline manual counts. Figure 10 shows the box plots for the percent difference between the VDS counts and baseline manual counts by lane. The VDS median differences are generally within 5%, the box boundaries (25th to 75th percentile differences) are within 10%, and the box whiskers are generally within 15% (with one exception) of the baseline manual count. The researchers found that the lane-by-lane mean absolute percent differences were within 7%. When considering the sum of all lanes, the mean percent differences were within 1% and the average absolute percent differences were within 6%. The larger variability than that of the ATR counts is evident. Interestingly, the southbound VDS unit shows a wider distribution of the differences in the lanes farther away from the camera. This observation matches expectations that the lanes farther away from the camera would experience more occlusion and splash-over issues. However, similar evidence was not found in the northbound VDS data.

Figure 7: First Round, Pole-mounted VDS Camera Location (Top: Southbound Station 285-1052; Bottom: Northbound Station 285-0211)

Figure 8: First Round, Pole-mounted VDS Camera Views (Left: Southbound Station 285-1052; Right: Northbound Station 285-0211)

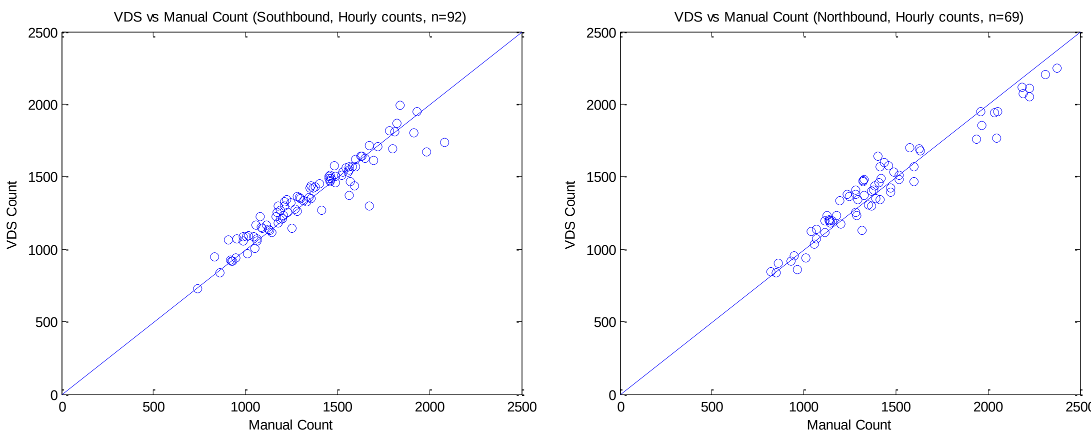
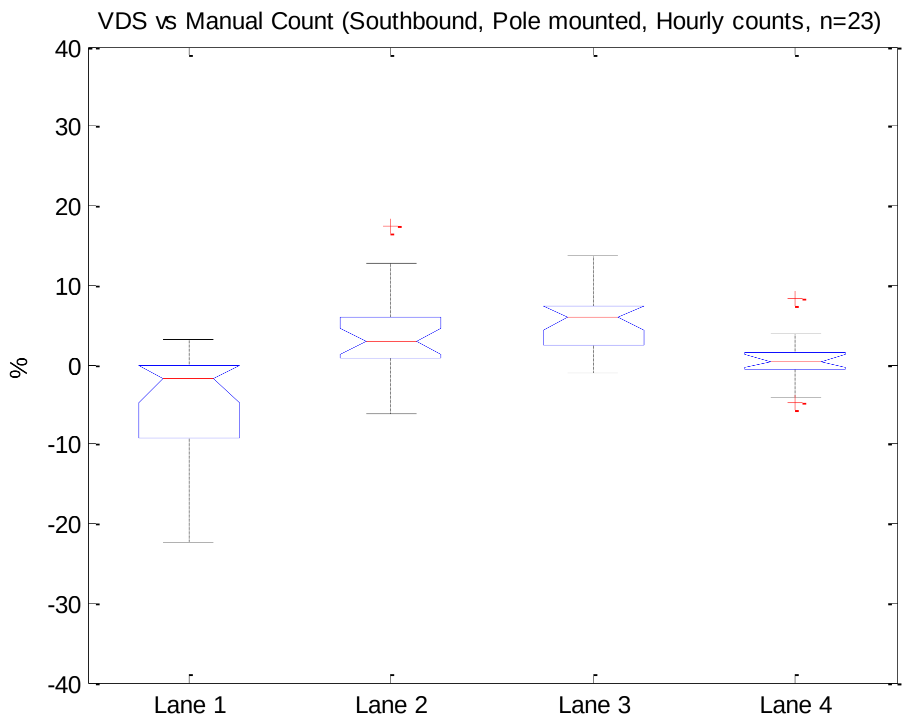
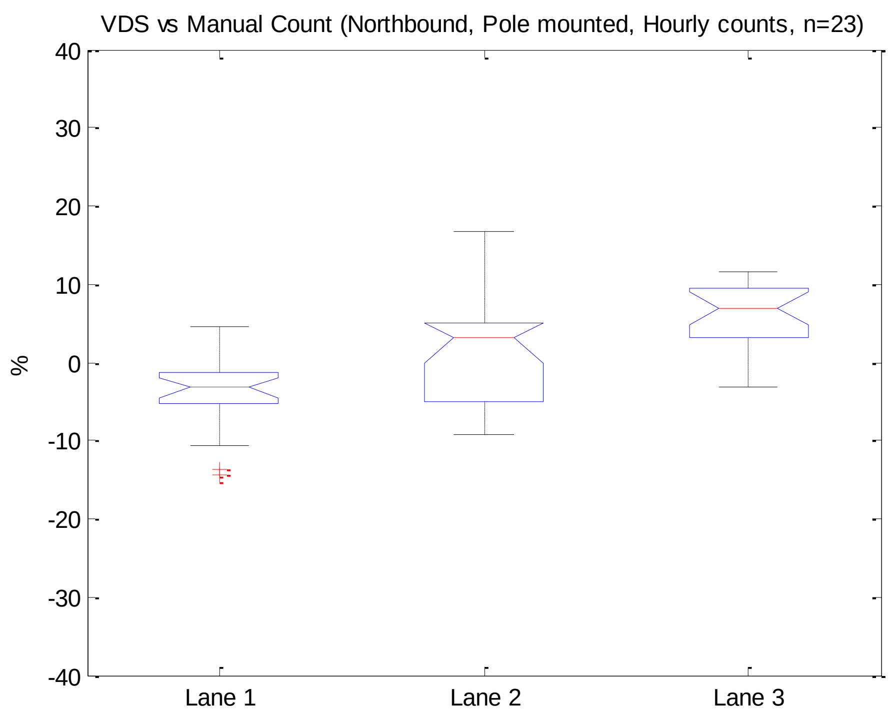


Figure 9: Y-Y Plots for VDS vs. Baseline, Lane-by-Lane (All Lanes) Manual Counts, Pole Mounted (Left: Southbound Station 285-1052; Right: Northbound Station 285-0211)



(a)



(b)

Figure 10: Lane-by-Lane VDS Traffic Count vs. Baseline Manual Counts, Pole Mounted: (a) Southbound Station 285-1052, (b) Northbound Station 285-0211

Gantry-mounted VDS at Cumberland Parkway (285-1053 and 285-0210)

VDS stations 285-1053 and 285-0210 are gantry-mounted (Figure 11). While the southbound VDS station 285-1053 is located in the median and collects southbound traffic, the northbound VDS station 285-0210 is located on the right side of the travel lanes and collects northbound traffic. Figure 12 and Figure 13 present the VDS camera views and y-y plots of VDS counts versus baseline counts, respectively, for stations 285-1053 and 285-0210. The y-y plots show a positive relation between the baseline counts and VDS counts. However, at lower traffic volumes some data points from the south-bound camera show the VDS camera undercounting. Four data points (Lane 1 through Lane 4 VDS 285-1053) showing significant undercounting (between 35% and 52%) were from the November 16th 6AM–7AM time period. The significant undercounting disappeared after 7:30AM, and the researchers believe that the undercounting was related to foggy conditions. Also, the northbound VDS camera shows a trend to slightly undercount at high volumes. Figure 14 shows the box plots for the VDS counts versus the baseline manual counts. This plot shows that the VDS counts are generally within 15% of the baseline counts.

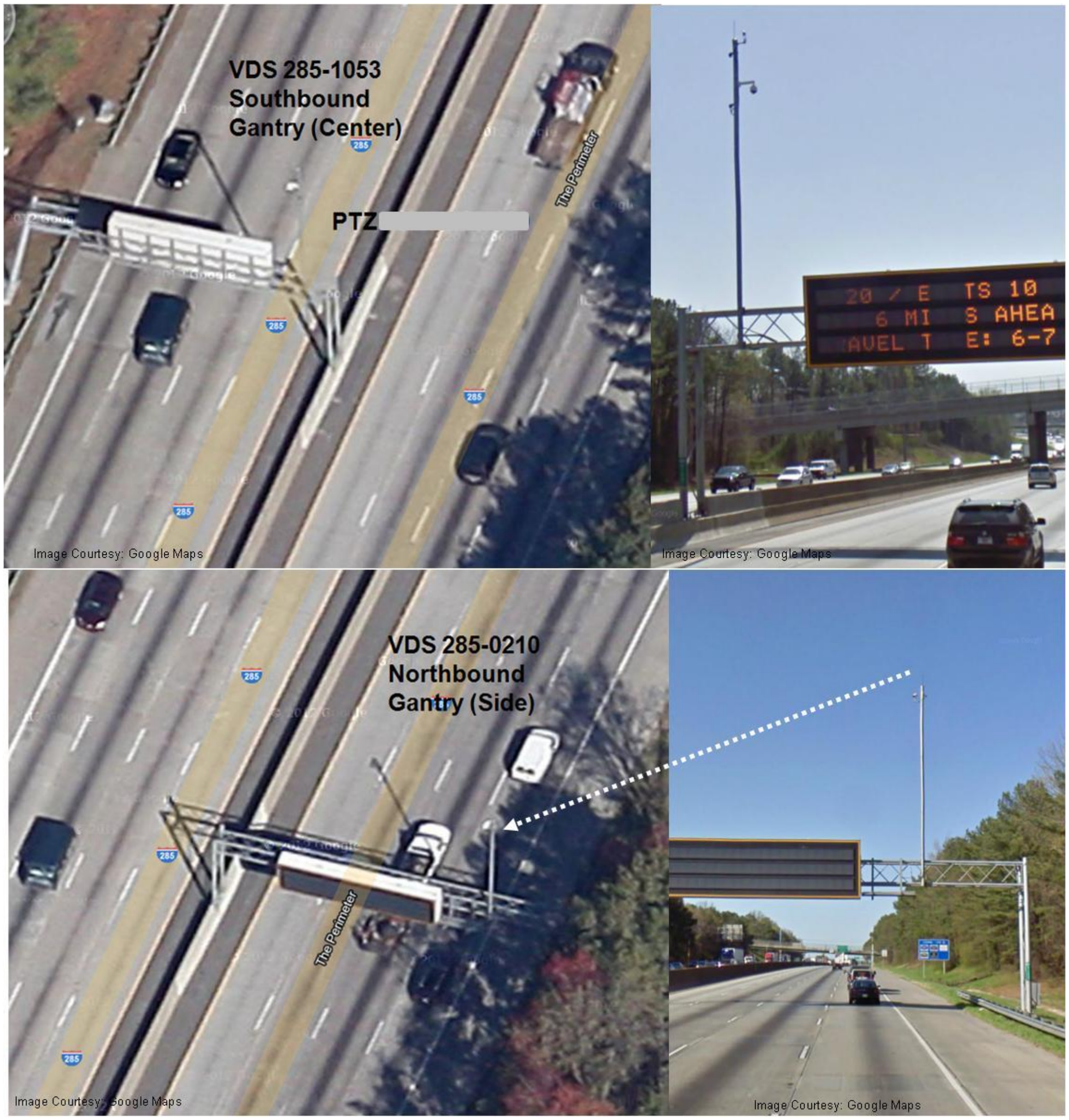


Figure 11: First Round, Gantry-mounted VDS Camera Location (Top: Southbound Station 285-1053; Bottom: Northbound Station 285-0210)

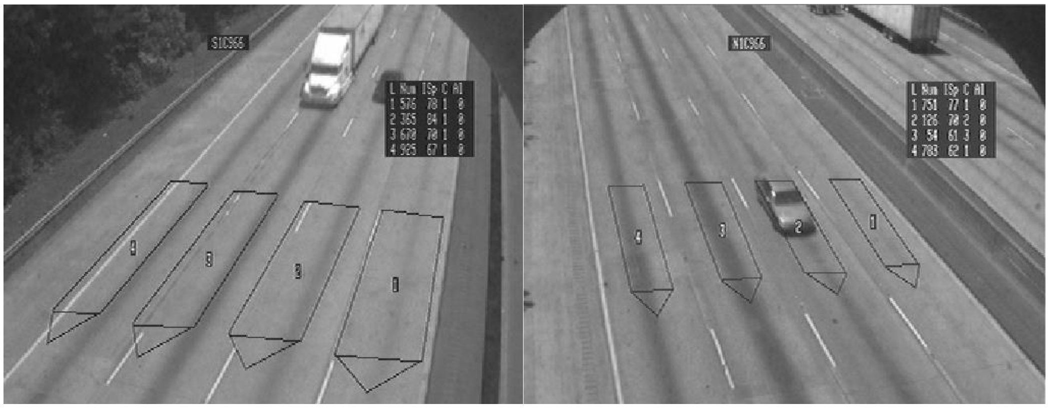


Figure 12: First Round, Gantry-mounted VDS Camera Views
(Left: Southbound Station 285-1053; Right: Northbound Station 285-0210)

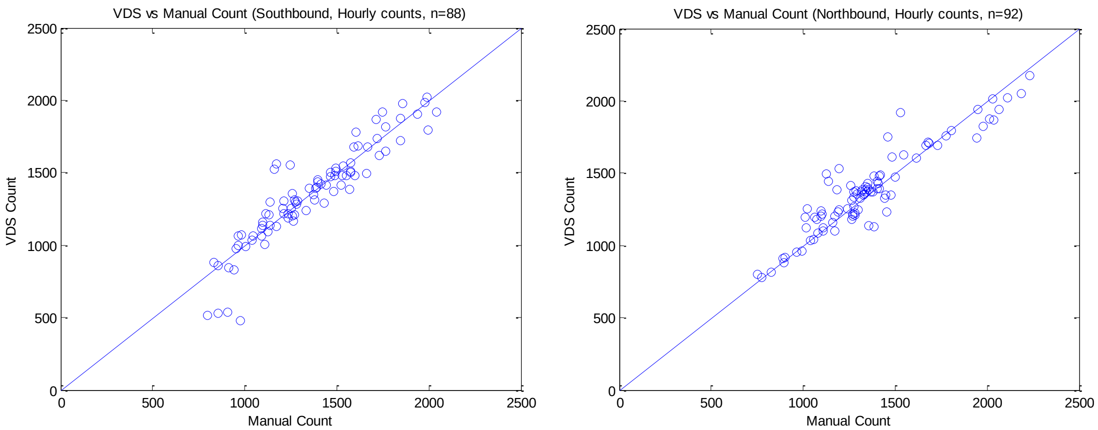
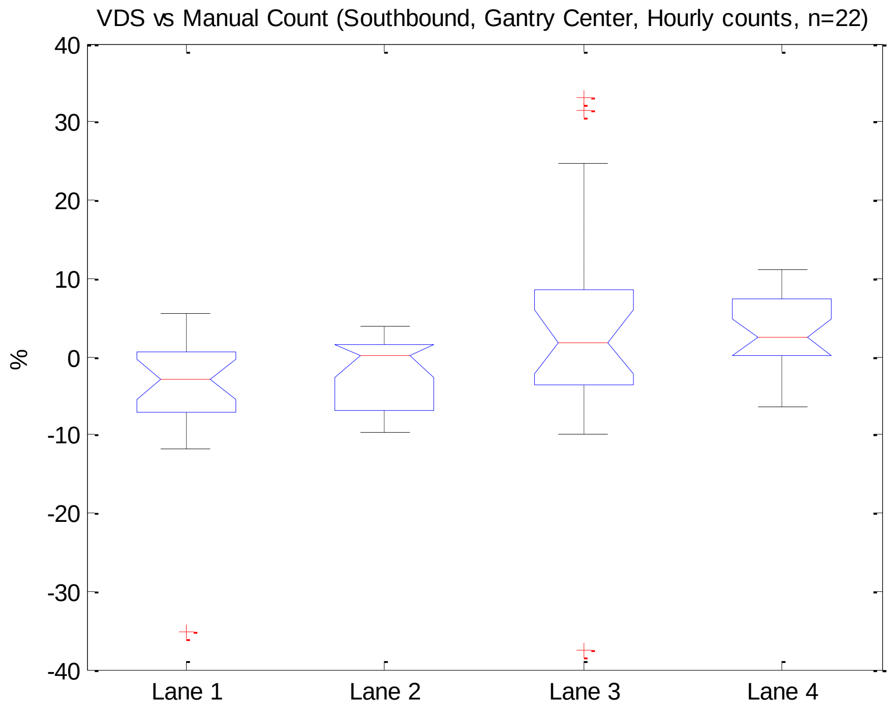
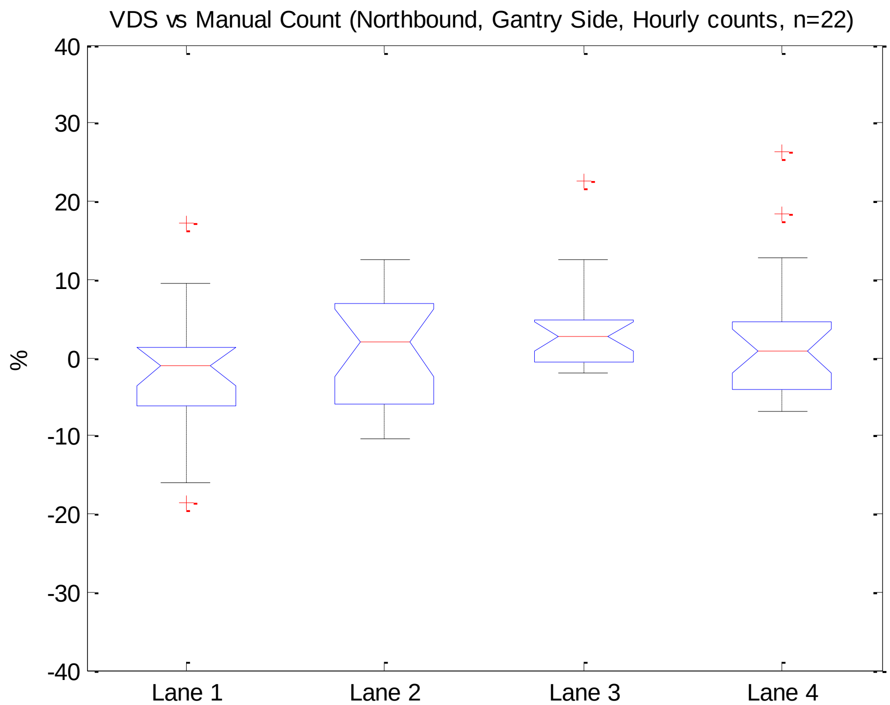


Figure 13: Y-Y Plots for VDS vs. Baseline, Lane-by-Lane (All Lanes) Counts
(Left: Southbound Station 285-1053; Right: Northbound Station 285-0210)



(a)



(b)

Figure 14: Lane-by-Lane VDS Traffic Count Comparison to Baseline Manual Counts, Gantry (Center): (a) Southbound Station 285-1053, (b) Northbound Station 285-0210

First Round Result Summary

Overall, the lane-by-lane absolute percentage errors between the lane-hour baseline counts and the ATR/VDS data were mostly within 5% (ATR, Figure) and 15% (VDS, Figure 10 and Figure 14) and the lane-by-lane mean absolute percentage errors were in the ranges of 1.0–2.0% (ATR), 1.8–6.4% (VDS pole-mounted), and 3.6–9.2% (VDS gantry-mounted). In the selected sites, the counts from pole-mounted VDS units were more accurate than those from gantry-mounted VDS units. Researchers suspect that the higher mounting height in the pole-mounted VDSs resulted in this greater accuracy. For confirmation, the research team tested a second set of gantry-mounted VDS sites in the second round of analysis.

The results in the first round of this study were in agreement with the results reported by FHWA [11, 12]. The ATR presented higher accuracy, although for this site the VDS provided traffic counts within the accuracy level (±10% at 90% confidence) required by FHWA [1]. Regarding the differences between the ATR/VDS counts and baseline manual counts, the ATR/VDS measuring locations are approximately 100 to 300 ft. from the viewing area of the PTZ camera. Therefore, a slight difference might exist in the number of vehicles counted due to lane changes occurring between the ATR/VDS detection zone and the baseline count detection zone. Also, there could be inherent inaccuracies in the ATR/VDS counts and/or baseline counts (for example, the accuracy of the loop detectors are unknown and time synchronization with the loops is not guaranteed). Therefore, interpreting the slight discrepancies between two counts is difficult. However, a relatively small difference between the ATR/VDS counts and baseline counts indicates that these data collection instruments are able to provide reasonably accurate traffic counts. To assure more unbiased and accurate data comparison, several quality assurance and quality control (QA/QC) baseline counts were taken by a different data collector and compared. Also, 20 second cumulative vehicle counts were compared to check if VDS camera times were synchronized.

QA/QC – Manual Counts

To facilitate a more unbiased and objective evaluation, 32 lane-hours of video were counted by a second data collector and the percentage difference was compared between the initial counts and the second counts. The average absolute percentage errors of the 5 minute counts were 1.7%. The counts match up well, as shown in the y-y plot (Figure 15). Even though a 5 minute sampling period can cancel some errors, this result shows that baseline counts obtained from manual counts using the traffic counting application are sufficiently accurate for the evaluation of other vehicle detection technologies, such as ATR, VDS, and RTMS.

QA/QC – VDS/PTZ Time Synchronization

Additionally, 20 second cumulative vehicle counts were compared to verify if VDS and PTZ camera times were properly synced (Figure 16). The VDS counts were found to lag the PTZ data by approximately 40–60 seconds. This 40–60 second lag is expected to potentially decrease the accuracy of the count comparisons. However, the researchers found the impact on the hourly traffic counts to be minimal since (1) the time period of the lagging is relatively small compared to the 1 hour aggregation period and (2) the traffic condition did not vary drastically in a typical 60–120 second period.

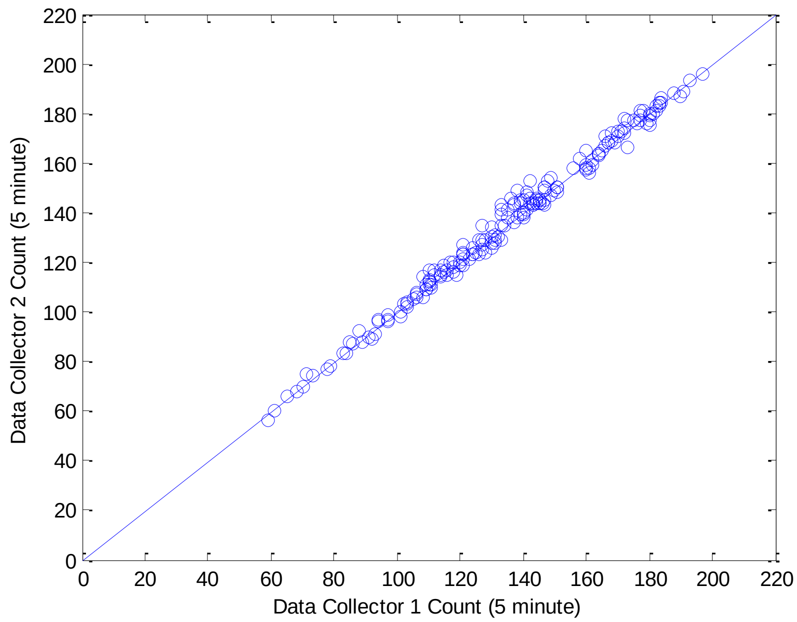


Figure 15: QA/QC Baseline Manual Count Comparisons between Two Data Collectors, Lane-by-Lane (All Lanes) Data (Gantry Center: Southbound Station 285-1053 and Northbound Station 285-0210)

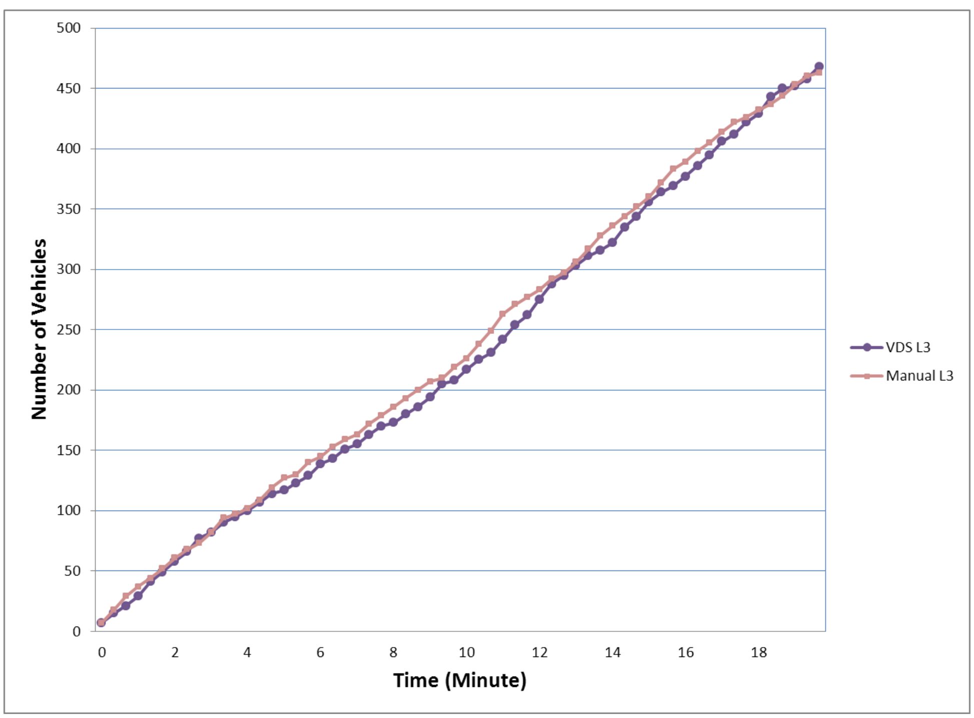


Figure 16: VDS/PTZ Time Synchronization Check (Gantry Center: Southbound Station 285-1053 and Northbound Station 285-0210)

RESULTS – SECOND ROUND

After the first-round evaluation, the research team selected the following four study sites to investigate the performance of the RTMS and VDS detectors under various conditions, including mounting styles and offsets:

1. Gantry-mounted VDS on I-285 near US-78
2. Pole-mounted VDS with 36 ft. offset on I-285 near Cascade Road
3. RTMS on US-78 near Idlewood Road
4. Pole-mounted VDS on the I-75/85 Connector near 14th Street

More than 700 lane-hours of video collected from PTZ cameras during the 6AM–10AM and 3PM–7PM time periods in 2012 were processed for baseline counts, and the researchers conducted quantitative analysis.

Gantry-mounted VDS, I-285 near US-78 (285-0065 and 285-1980)

In the first-round analysis, the counts from pole-mounted VDS units were more accurate than gantry-mounted VDS units. To test a gantry mounting at additional locations to verify the findings from the first round, two gantry-mounted VDS stations (285-0065 and 285-1980) were chosen (Figure 17). The location of these two stations on I-285 near US-78 has four lanes of traffic each in the northbound and southbound directions. The baseline manual counts from videos recorded from the closest PTZ camera were compared to the VDS counts at GDOT stations 285-0065 (southbound) and 285-1980 (northbound). A total of five weekday peak hours (6AM–10AM and 3PM–7PM) were used in this analysis.

Figure 17: Gantry-mounted VDS Camera Location on I-285 near US-78

Figure 18 shows the PTZ camera view of I-285 near US-78 used to collect base-line manual counts. This image shows that in the northbound (left) direction a freeway merging area was included in the camera view. Due to excessive lane changes at this merging area in the PTZ view, while the VDS view (Figure 19) does not cover an area with heavy lane changes, Lane 4 could not be included in the comparison.

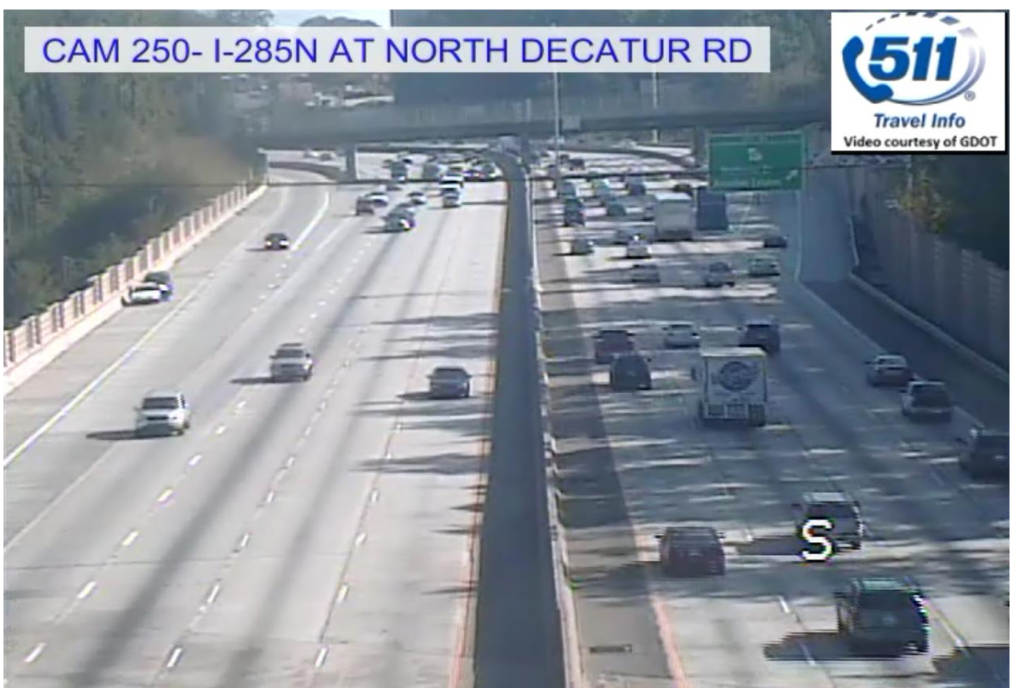


Figure 18: PTZ Camera View on I-285 near US-78

Figure 19: Camera Views for VDS Units on I-285 near US-78 (Left: Northbound Station 285-1980; Right: Southbound Station 285-0065)

For this location, when considering the sum of all lanes counts, the VDS mean percent errors (MPEs) were −3.8 % and −4.1%, and the VDS hourly mean absolute percent errors were 7% and 6.7% for the northbound and southbound directions, respectively. When considering the lane-by-lane counts, the mean percent error by hour ranged between −0.6% and −7.2%, and the mean absolute percent error by hour ranged between 4.25% and 7.6%. This percentage difference is similar to the hourly mean absolute percent error at the gantry location (6.1%) in the first-round analysis. Figure 19 shows the camera views for VDS cameras at GDOT stations 285-0065 (southbound) and 285-1980 (north-bound). Figure 20 presents the y-y plots for the VDS cameras versus baseline, for lane-by-lane data, in both directions. The y-y plot for the southbound camera shows that at high-volume traffic the VDS camera at this site tends to undercount compared to the baseline manual counts. Figure 21 shows the box plots for the percent error of the hourly VDS counts from the baseline manual counts by lane. This plot shows that the percent error is generally within 10% of the baseline manual counts.

While the VDS camera in the northbound direction near Cumberland Parkway (first round) is located over the right edge of the rightmost lane, the southbound camera near Cumberland Parkway and the two cameras at this site are located over the left edge of the leftmost lane. The y-y plots show a positive relation between the baseline and VDS counts. However, at lower traffic volumes there are some data points that show the VDS unit is undercounting. The researchers found that four data points (Lane 1 through Lane 4 southbound) are showing significant undercounting (between 35% and 52%) on November 16th at 6AM–7AM. The significant undercounting disappeared after 7:30AM. The researchers believe that the undercounting was related to foggy conditions. Also, these VDS units show a trend of slightly undercounting at high volumes. Figure 21 show the box plots for the differences by lane of the VDS from the baseline counts. The VDS median differences are generally within a few percent, the box boundaries are within 10%, and the box whiskers are within 15% of the baseline count. This is similar to that seen in the previously discussed pole-mounted camera data. When considering the sum of all lanes counts, the mean percent differences were within 5% and the average absolute percent differences were within 7%, while the lane-by-lane mean percent differences were within 7.2% and the lane-by-lane mean absolute percent differences were within 7.6%.

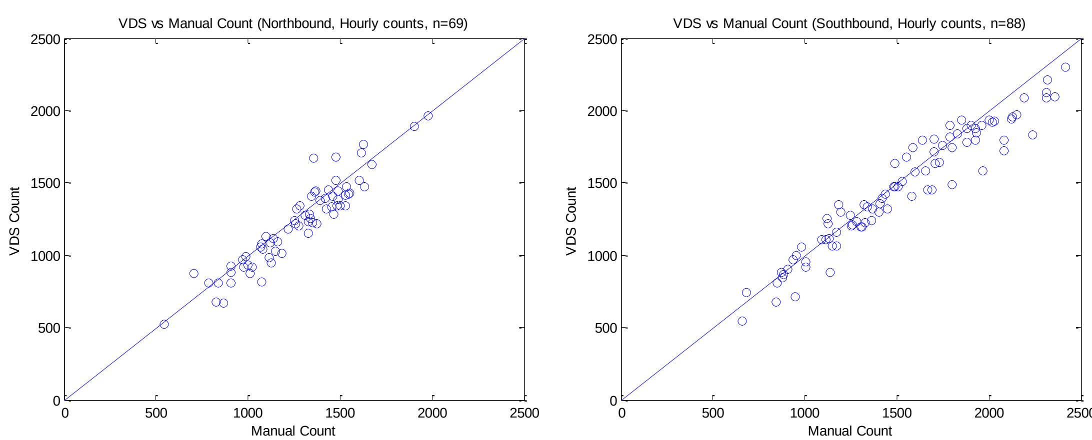


Figure 20: Y-Y Plots for VDS Traffic Counts vs. Baseline, Lane-by-Lane

(All Lanes) Manual Counts (Left: Station 285-1980; Right: Station 285-0065)

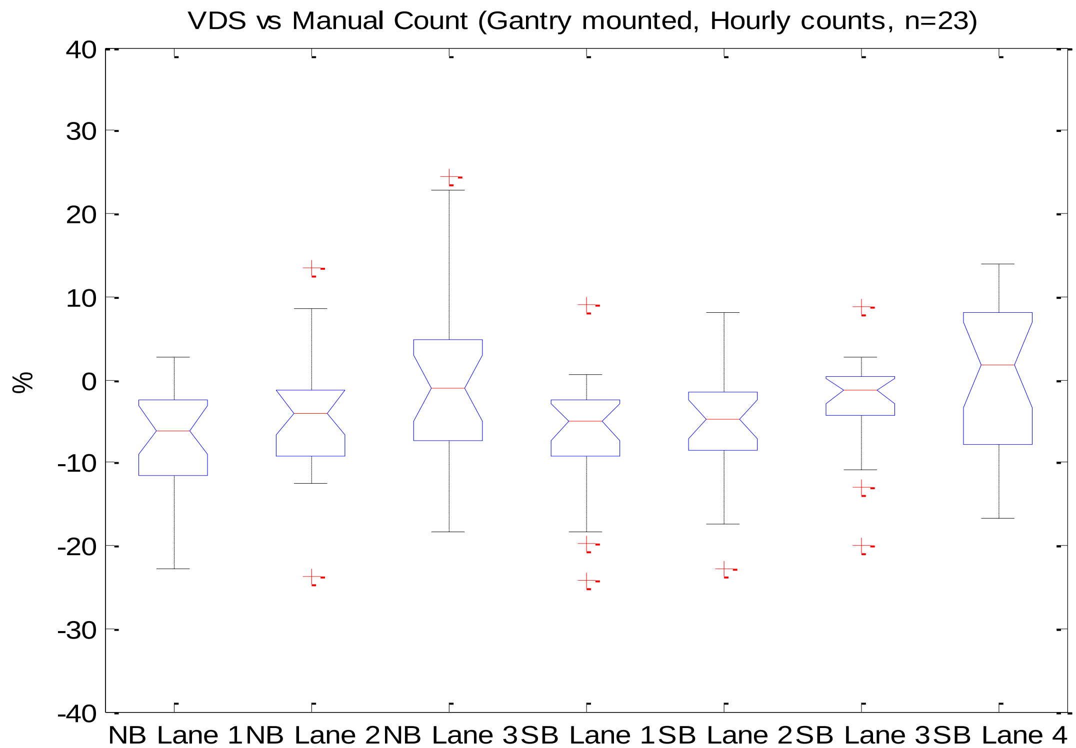


Figure 21: Lane-by-Lane VDS Traffic Counts Comparison to Baseline; Gantry-mounted: Stations 285-0065 (Southbound) and 285-1980 (Northbound)

Pole-mounted VDS, 36 ft. offset, I-285 near Cascade Road (285-0177 and 285-1084)

To explore the potential effects of an increase in offset distances on the accuracy of VDS counts, the researchers chose the Cascade Road study sites (Sites 5 and 6 in Figure 4) with VDS cameras each mounted on a pole that has a 36 ft. offset from the edge of the travel lanes (Figure 22). Similar to the previous sites, the Cascade Road location has four lanes of traffic in both the northbound and southbound directions. The baseline counts from the video recorded from the closest PTZ camera were compared with the VDS counts from GDOT stations 285-0177 (northbound) and 285-1084 (southbound). A total of four weekday peak hours (6AM–10AM and 3PM–7PM) were used from Cascade Road for this analysis.

For this location, when considering the counts over the sum of all lanes, the mean percent errors by hour were −1.11 and −1.34% and the mean absolute percent errors by hour were 5.86% and 7.24% for the northbound and southbound directions, respectively. Furthermore, when considering the lane-by-lane counts, the hourly mean percent error was within 5% and the hourly mean absolute percent error was within 10.2%. Figure 23 shows the camera views of the VDS cameras located at GDOT stations 285-0177 (northbound) and 285-1084 (southbound). Figure 24 shows the y-y plot for both VDS cameras at the Cascade Road location. The southbound location appears to be slightly undercounting during higher volume traffic conditions. Figure 25 shows the box plots for the percent error of the VDS counts from the baseline manual counts by lane. This plot shows that the average percent error is generally within 10% of the baseline manual counts, similar to other VDS locations.

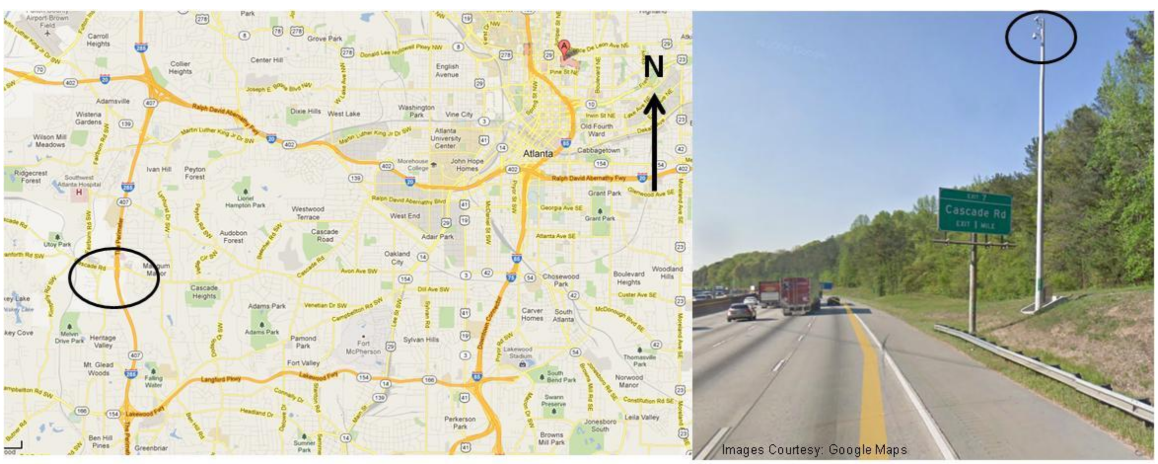


Figure 22: VDS Camera Location on I-285 near Cascade Road

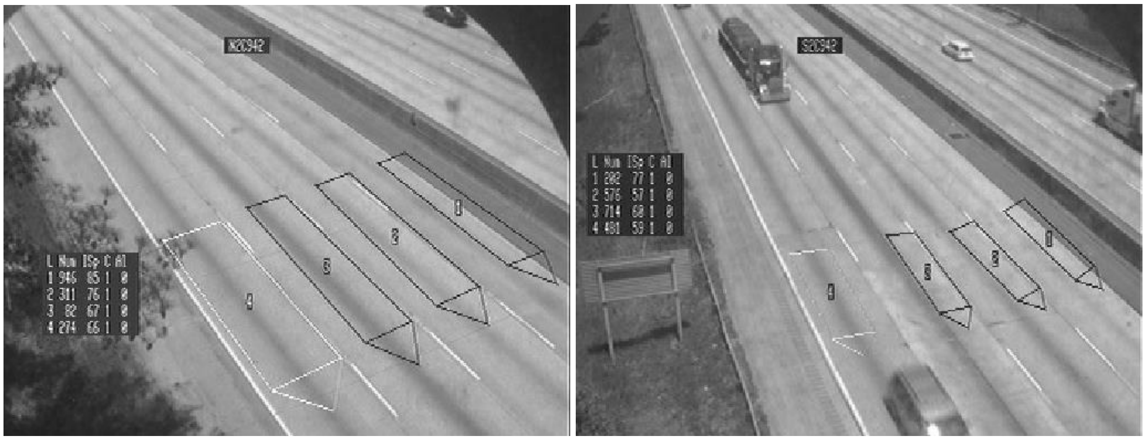


Figure 23: Camera Views for VDS Units on I-285 near Cascade Road (Left: Station 285-0177 NB; Right: Station 285-1084 SB)

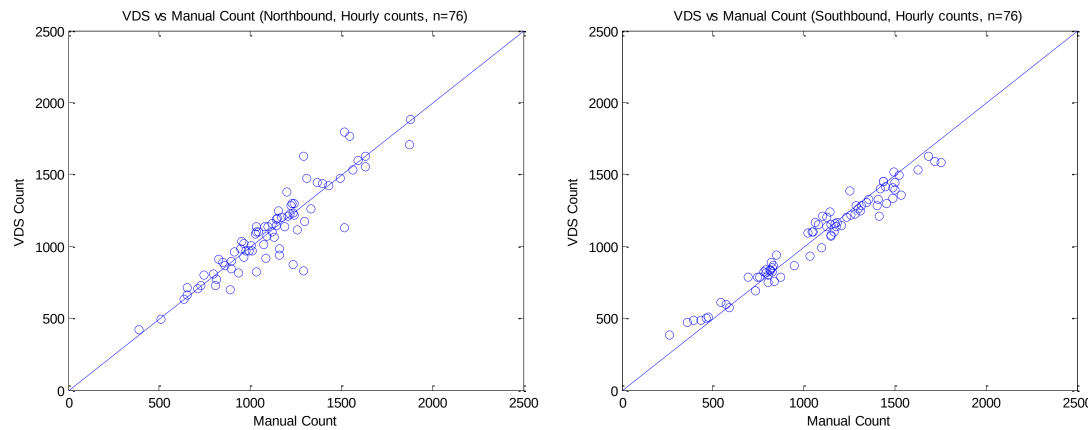
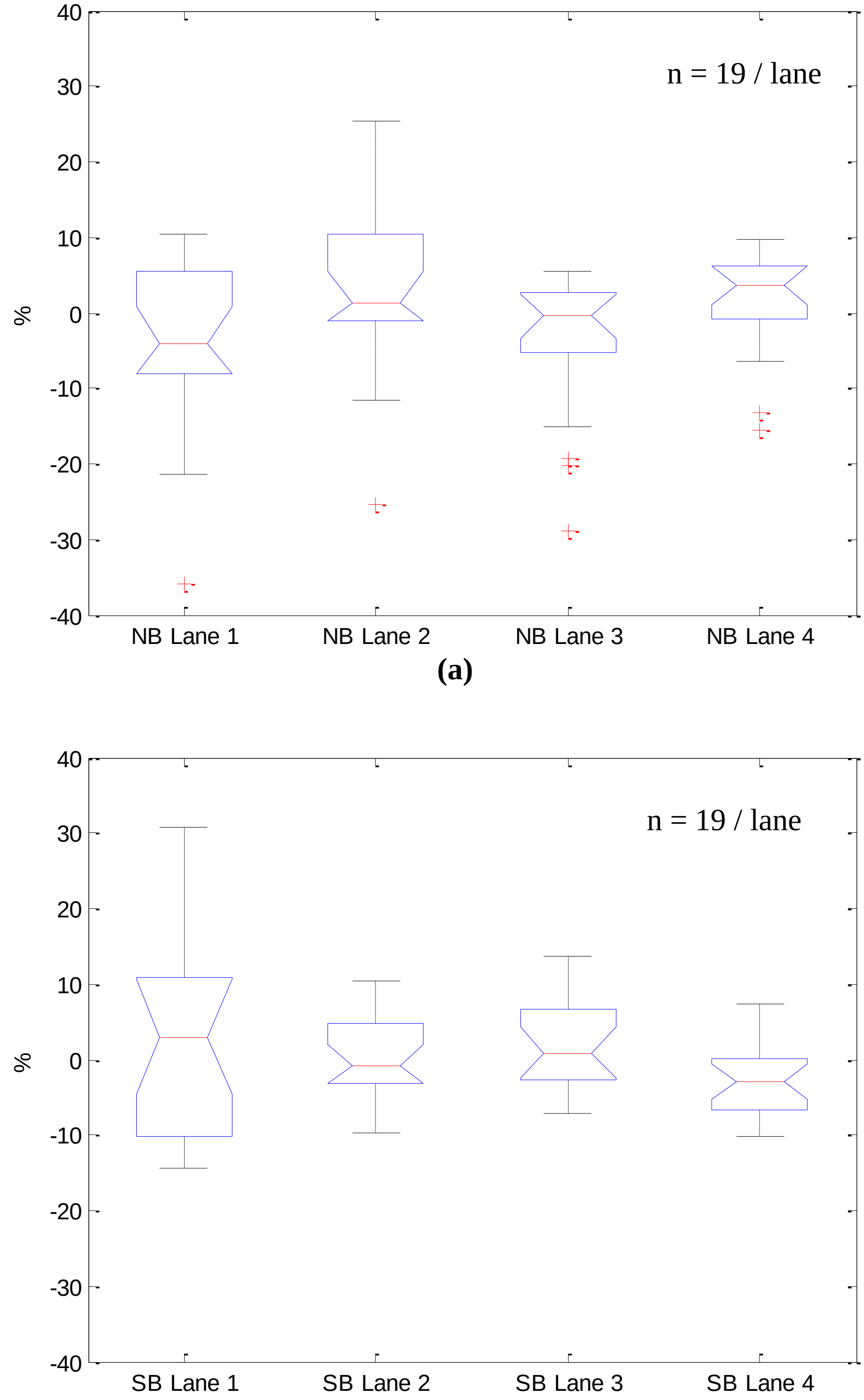


Figure 24: Y-Y Plots for VDS vs. Baseline, Lane-by-Lane (All Lanes) Manual Counts (Left: Station 285-0177; Right: Station 285-1084)



(b)

Figure 25: Lane-by-Lane VDS Traffic Counts Comparison to Baseline Manual Counts, Pole Mounted with 36 ft Offset: (a) Station 285-0177, (b) Station 285-1084

RTMS on US-78 near Idlewood Road (780007 and 780992)

Researchers chose the study site at US-78 (Figure 26) to compare the RTMS-generated counts to baseline counts generated from PTZ camera recordings near the RTMS sensors. RTMS at the US-78 location was chosen to compare the RTMS-derived counts to baseline counts based on PTZ cameras near the sensors. GDOT stations 780007 (eastbound) and 780992 (westbound) were chosen for their proximity to a PTZ camera that had a good view of the freeway. A total of six weekday peak hours (6AM–10AM and 3PM–7PM) were used at this location for the analysis.

For this location, when considering the sum of all lanes counts, the mean hourly percent errors were −2.2 and −3.2% and the mean hourly absolute percent errors were 4.4 and 5.2% for the eastbound and westbound directions, respectively. Furthermore, when considering the lane-by-lane counts, the mean hourly percent error was within −5.9% and the mean hourly absolute percent error was within 7.9%. Figure 27 shows the y-y plots (lane-by-lane data) for the RTMS location on US-78. The eastbound RTMS sensor correlates well with the baseline manual counts under 1250 vehicles per hour. However, at levels approximately over 1250 vehicles per hour, the sensor begins to slightly undercount. Furthermore, the westbound sensor has some data points at very low traffic volumes that appear to show that the RTMS sensor is slightly overcounting at these low-volume conditions. The westbound RTMS sensor also appears to begin to undercount when traffic volumes exceed approximately 1250 vehicles per hour. Overall, the RTMS sensor counts seem to correlate well with the baseline manual counts. Figure 28 shows the box plots for the percent error of the RTMS counts by lane. This plot shows the average percent error is mostly below 10%. The outlying data points were from earlymorning periods with light traffic volume, where a small difference in vehicle counts can yield a relatively high percentage difference.

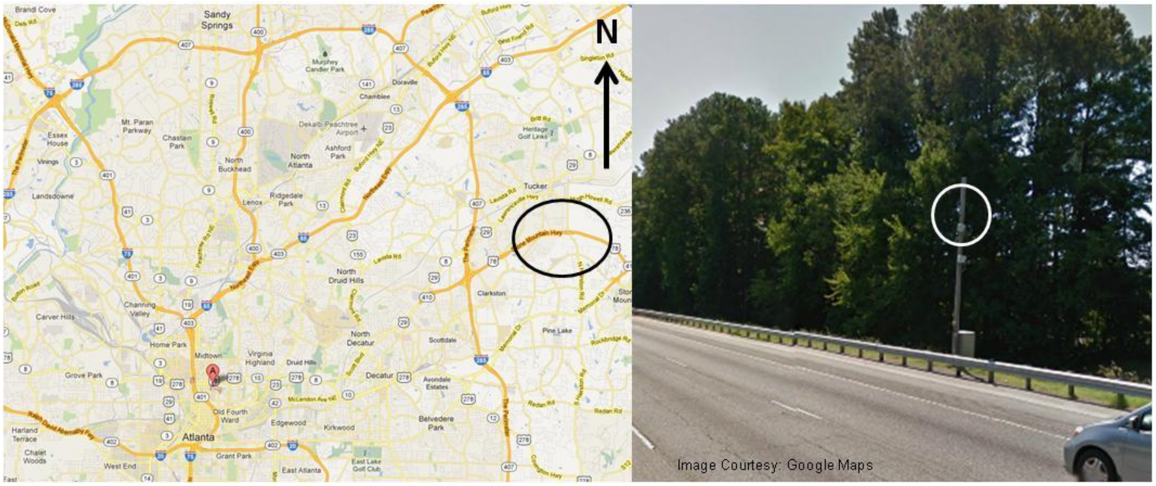


Figure 26: RTMS Station Location on US-78

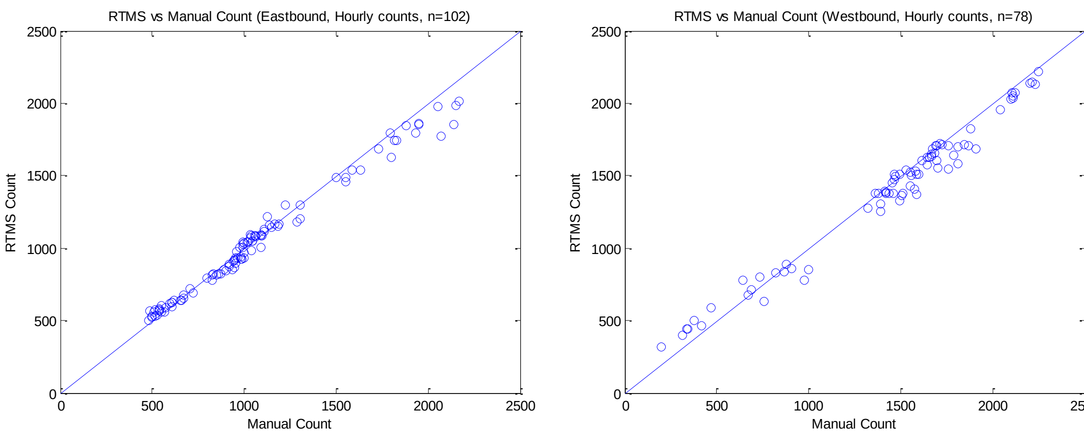
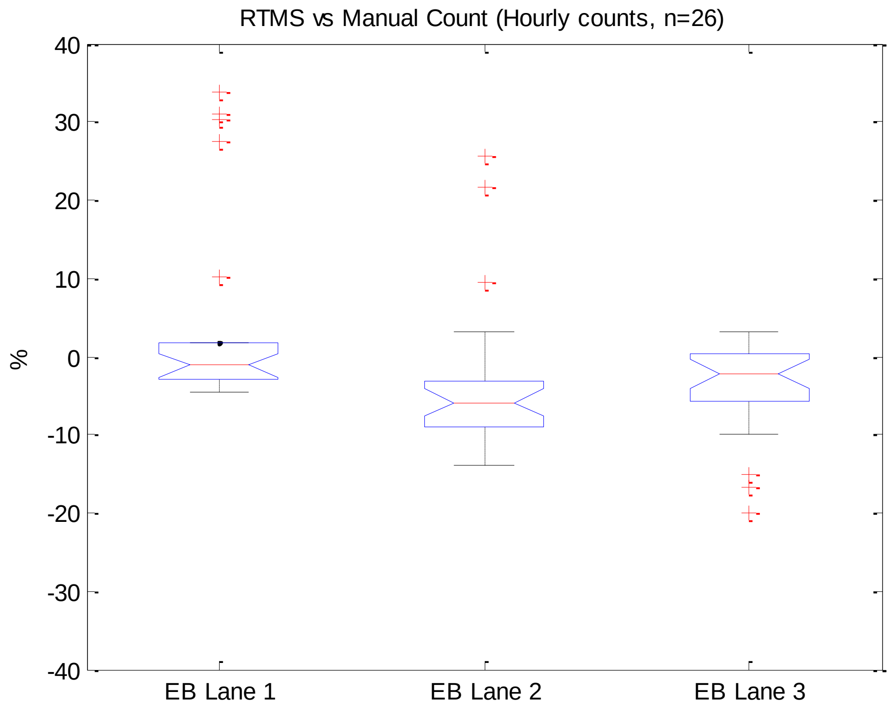
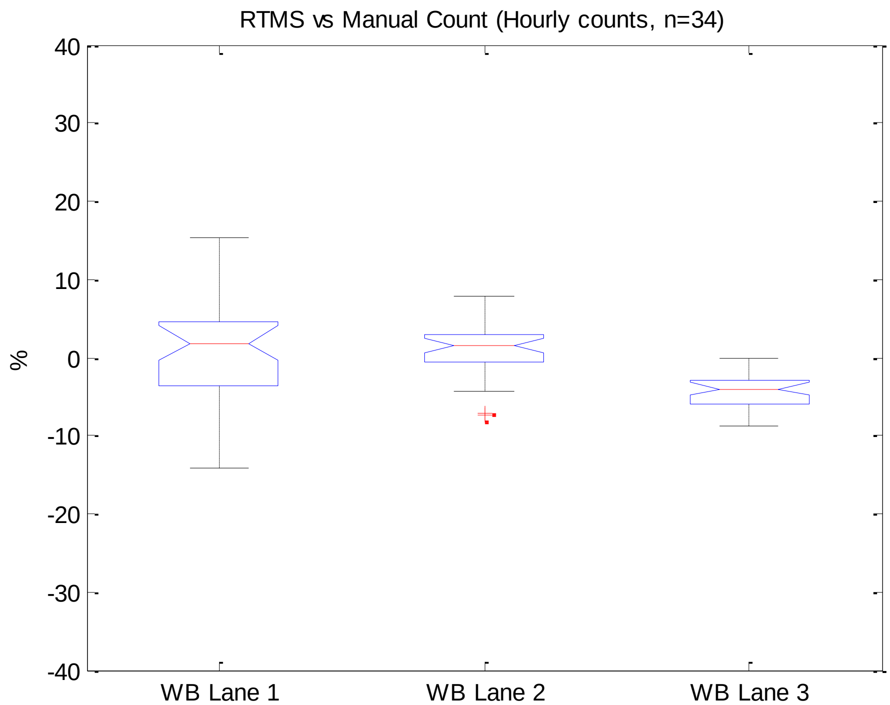


Figure 27: Y-Y Plots for RTMS vs. Baseline, Lane-by-Lane (All Lanes) Manual Counts (Left: Station 780007; Right: Station 780992)



(a)



(b)

Figure 28: Lane-by-Lane RTMS Traffic Count Comparison between Baseline Manual Counts and GDOT Stations: (a) 780007 (Eastbound) and (b) 780992 (Westbound)

Pole-mounted VDS on I-75/85 Connector near 14th Street (10131)

The site selected for the I-75/85 Connector comparison was the 14th Street VDS camera viewing the southbound traffic at GDOT station 10131 (Figure 29). This location has seven lanes of mainline traffic, and researchers chose it over the 10th Street and North Avenue locations because (1) PTZ cameras on those locations were moved frequently and (2) the view was partially occluded by nearby trees.

After initial comparison of the baseline counts from the recorded PTZ camera video and the VDS collected counts, researchers found that the VDS camera was significantly overcounting during the morning peak and undercounting during the afternoon peak. To verify the validity of the data, AM traffic count data and PM traffic count data were compared separately to the next downstream VDS camera's traffic counts (10th Street, GDOT station 10132) to explore if a potential systemic error occurred. The two manual count sets matched better with the downstream VDS counts, implying that the selected site had severe accuracy issues and was possibly malfunctioning. Figure 30 shows the camera views of VDS cameras at stations 10131 and 10132. Figure 30 illustrates that station 10131 is located on the outside of the highway with a large shoulder and station 10132 is located in the median with no shoulder. The offset at station 10131, combined with the large width of the highway, may be causing calibration issues with the camera. Also, as this VDS camera view crosses seven lanes, occlusion is more likely due to the low angle to the detection zone, compared to three or four lanes in other study locations.

Figure 31 shows the count comparison between the VDS cameras at station 10131, station 10132, and the baseline counts by lane from July 7, 2012, for 4PM–5PM.

This comparison shows a better agreement between station 10132 and the baseline counts than station 10131 and the counts. Also, Figure 31 shows that at station 10131 the lanes farther from the camera (inside lanes) are, in general, reporting a larger error than the closer lanes, evidence of the difficulty in calibration at this distance and angle combination.

Figure 32 shows y-y plots for station 10131’s VDS camera versus the baseline manual counts for the AM and PM peak periods. This figure shows strong evidence of inaccurate data reported from that station’s VDS camera. The AM peak plot shows the VDS camera’s tendency to overcount, while the PM peak plot shows that the VDS camera has a consistent undercounting over all lanes. This high difference in counts may be caused by a number of factors, including (1) low angle to the detection zone, (2) occlusion due to the increased offset resulting from the presence of seven lanes, and (3) inability of the VDS unit to process vehicle detections over seven lanes simultaneously.

Figure 29: VDS Camera on I-75/85 Connector

Figure 30: Camera Views for VDS Units on I-75/85 Connector (Left: 14th St. Camera, Station 10131; Right: 10th Street Camera, Station 10132)

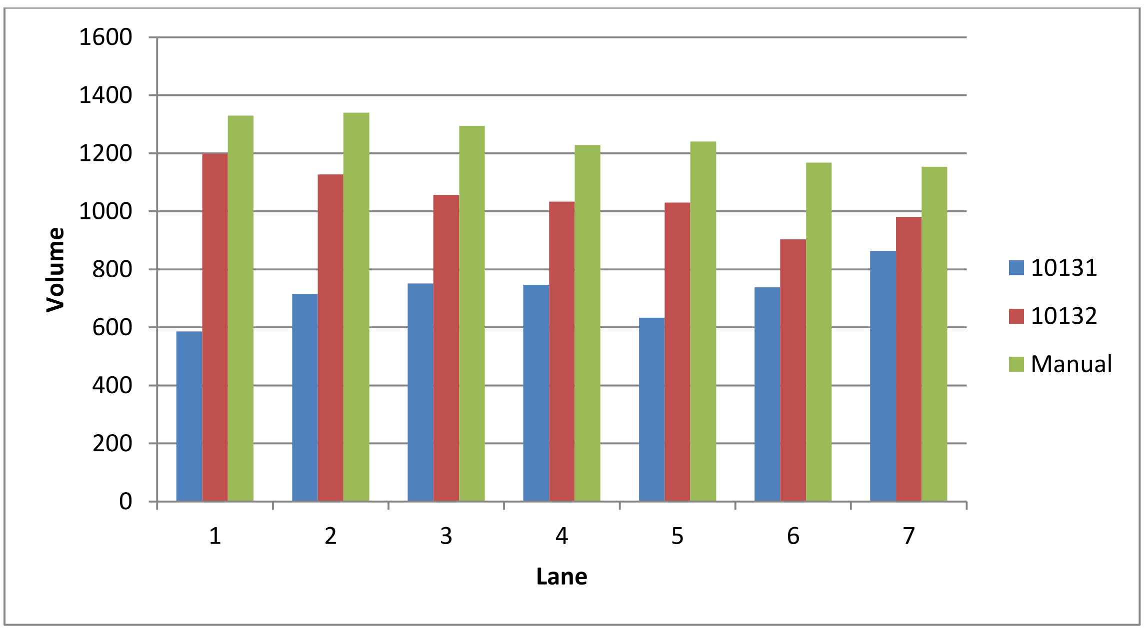


Figure 31: Lane-by-Lane Count Comparison between GDOT VDS Stations 10131, 10132, and Baseline Manual Counts

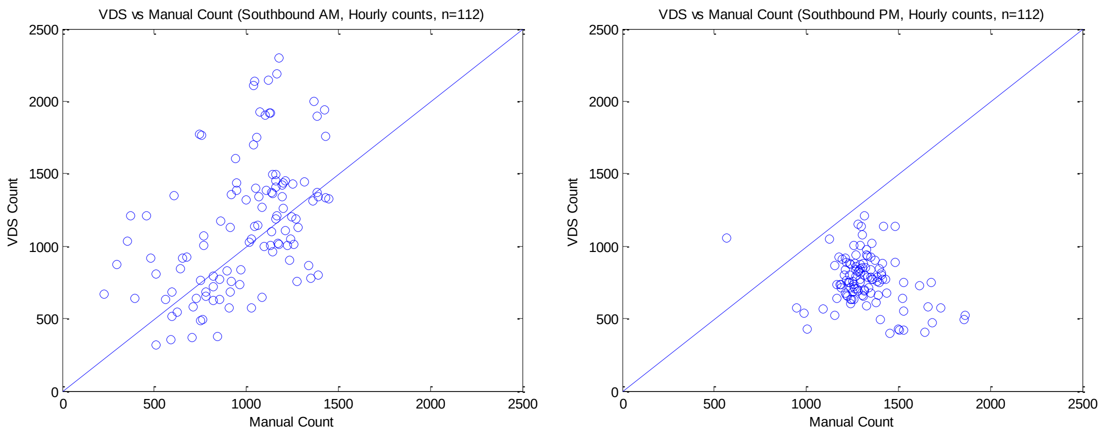


Figure 32: Y-Y Plots for VDS Station 10131 vs. Baseline Lane-by-Lane (All Lanes) Manual Counts (Left: AM; Right: PM)

Second Round Result Summary

After the first-round data analysis, four additional locations were analyzed in the second-round analysis to investigate the performance of the RTMS and VDS detectors under various conditions, including mounting styles and offsets. More than 700 lane-hours of video from PTZ cameras were collected at four different locations: (1) gantry-mounted VDS on I-285 near US-78, (2) pole-mounted VDS with 36 ft. offset on I-285 near Cascade Road, (3) RTMS on US-78 near Idlewood Road, and (4) pole-mounted VDS on the I-75/85 Connector near 14th Street. Absolute percentage errors between the hourly lane-by-lane baseline manual counts and the VDS/RTMS counts data were mostly within 10–15% (Figure 33) except at the I-75/85 Connector location. Pole-mounted VDS with 36 ft. offset performed with similar accuracy to VDS with 24 ft. offset. The VDS sites that were tested tended to undercount in high traffic volume conditions. The RTMS sensors' counts were found to correlate well with the baseline manual counts, although under-counting was observed at higher volumes. Overall, results from the gantry-mounted VDS on I-285 near US-78 and pole-mounted VDS with 36 ft. offset on I-285 near Cascade Road were similar to the VDS results in the first round.

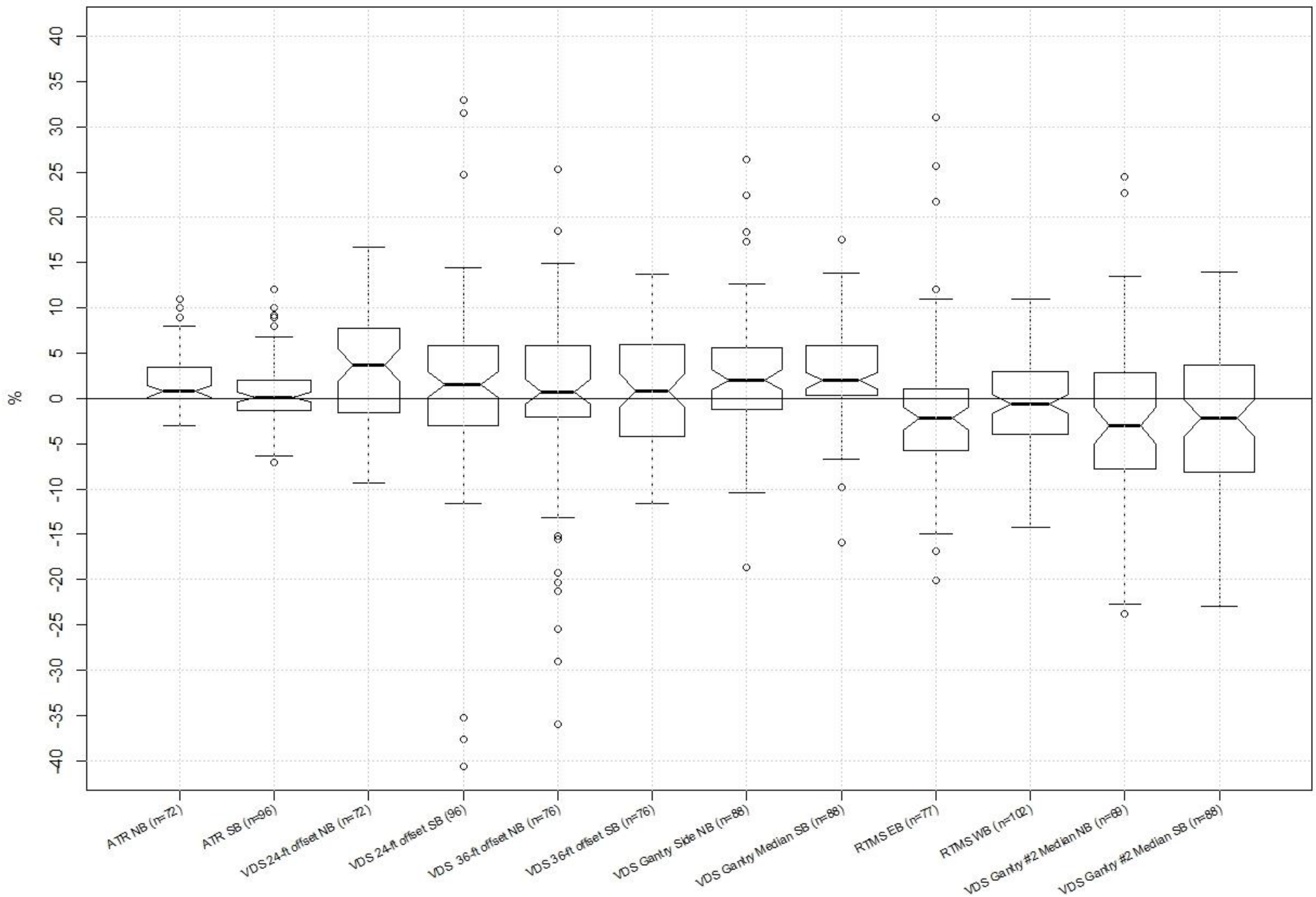


Figure 33: Hourly Traffic Counts Lane-By-Lane (All Lanes in one Direction) at Detection Stations vs. Baseline Manual Counts for the Study Sites

STATISTICAL SIGNIFICANCE OF DIFFERENCES BETWEEN COUNTS

After the two rounds of analysis, researchers conducted two-tailed paired two-sample t-tests of the baseline traffic counts and ATR/VDS/RTMS counts. To determine the statistical significance of the differences between the counts, the null hypothesis was set as “the differences between the baseline manual counts and the ATR/VDS/RTMS counts are not statistically significant.” P value from the test represents the probability of seeing the observed difference, just by chance if the null hypothesis is true. P value close to 0 indicates that the difference is statistically significant, whereas a P value close to 1 suggests there is no significant difference between the counts other than that due to random variation [20].

Table 4 presents the P values for the two-tailed paired two-sample t-tests. Those results indicate that only Lanes 3–7 of the I-75/85 Connector location reject the null hypothesis at the 0.05 level, indicating the VDS counts and baseline counts are statistically significantly different. However, other locations failed to reject the null hypothesis, indicating they are not statistically significantly different.

Table 4: Two-tailed Paired Two-sample t-test Results

Station ID	Site Description	Lane	P value
285-1052	I-285 at Orchard Road SB, Gantry Side	Lane 1	0.394
		Lane 2	0.442
		Lane 3	0.290
		Lane 4	0.927
285-1053	I-285 at Orchard Road SB, Gantry Center	Lane 1	0.673
		Lane 2	0.690
		Lane 3	0.407
		Lane 4	0.627
285-0210	I-285 at Orchard Road NB, Gantry Side	Lane 1	0.860
		Lane 2	0.884
		Lane 3	0.275
		Lane 4	0.510
285-0211	I-285 at Orchard Road NB, Gantry Side	Lane 1	0.670
		Lane 2	0.939
		Lane 3	0.102
		Lane 4	0.256
285-1980	I-285 near US-78 VDS NB	Lane 1	0.223
		Lane 2	0.220
		Lane 3	0.903
285-0065	I-285 near US-78 VDS SB	Lane 1	0.292
		Lane 2	0.171
		Lane 3	0.481
		Lane 4	0.738
285-0177	I-285 at Cascade Road VDS NB	Lane 1	0.651
		Lane 2	0.665
		Lane 3	0.466
		Lane 4	0.784
285-1084	I-285 at Cascade Road VDS SB	Lane 1	0.893
		Lane 2	0.968
		Lane 3	0.805
		Lane 4	0.647
780007	US-78 RTMS EB	Lane 1	0.388
		Lane 2	0.981
		Lane 3	0.746
780992	US-78 RTMS WB	Lane 1	0.505
		Lane 2	0.288
		Lane 3	0.972
10131	I75/85 Connector at 14th Street VDS SB	Lane 1	0.248
		Lane 2	0.082
		Lane 3	**0.009**
		Lane 4	**$2.19e^{-4}$**
		Lane 5	**$7.78e^{-6}$**
		Lane 6	**$2.54e^{-6}$**
		Lane 7	**$6.41\ e^{-4}$**

CONCLUSIONS

In excess of 1000 lane-hours of video from PTZ cameras were processed to evaluate the performance of the RTMS and VDS detectors under various conditions, with variations in mounting styles, heights, and offsets. The researchers note the following conclusions:

- For pole-mounted VDS with 24 ft. offset, the lane-by-lane median, box boundary, and whisker differences are generally within 5%, 10%, and 15% of the baseline count data, respectively.
- For pole-mounted VDS with 36 ft. offset, the lane-by-lane median, box boundary, and whisker differences are generally within 5%, 10%, and 25% of the baseline count data, respectively.
- For gantry-mounted VDS, the lane-by-lane median, box boundary, and whisker differences are generally within 3%, 10%, and 15% of the baseline count data, respectively.
- When data are aggregated over all lanes, the different configurations of VDS installations, including gantry-mounted, 24 ft. offset pole-mounted VDS, and 36 ft. offset pole-mounted VDS, have median differences under 5% (Figure 34 and Table 5) with the baseline counts, and 95% confidence bounds within ±6%.
- The VDS unit covering seven lanes showed severe deviation from the baseline counts, in excess of 40% differences from the baseline manual counts.
- The differences of lane-by-lane RTMS counts from baseline counts are generally within 8%; however, higher percentage differences were seen under low-volume conditions.

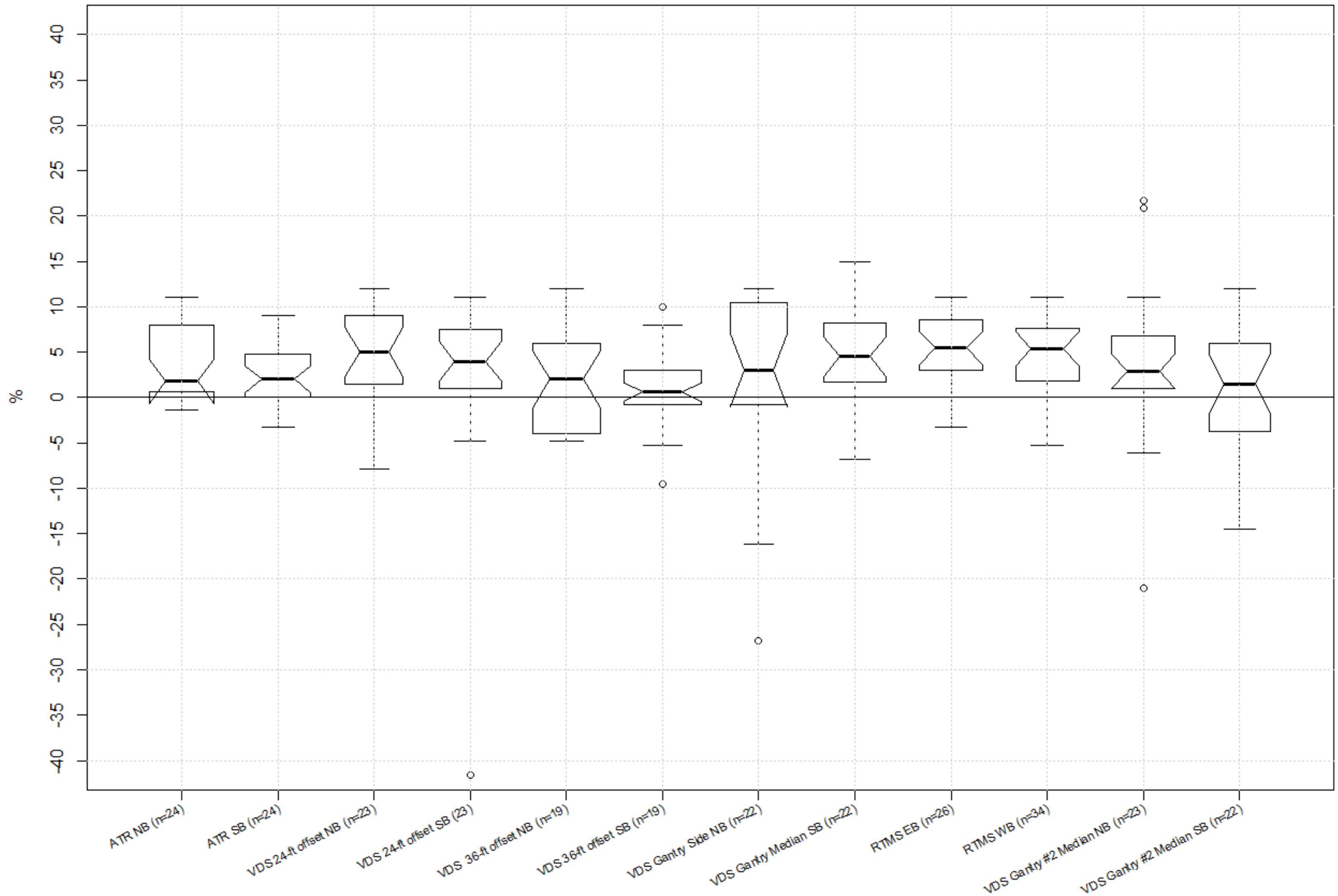


Figure 34: Hourly Traffic Counts Aggregated over All Lanes in each Direction, at Detection Stations vs. Baseline Manual Counts for the Study Sites

Table 5: MPE and MAPE Results Summary, All Lanes and Lane-by-lane

No	Type	No of Lanes	Setup Style/Location	All Lanes						Lane By Lane		
				MPE	Lower 95%	Upper 95%	MAPE	Lower 95%	Upper 95%	Lane Number	MPE	MAPE
1	ATR	4	I-285 Northbound near Orchard Road	0.77%	0.38%	1.16%	1.45%	1.18%	1.72%	1	0.44%	1.58%
										2	0.17%	0.94%
										3	1.84%	1.93%
2	ATR	4	I-285 Southbound near Orchard Road	-0.25%	-0.76%	0.26%	1.87%	1.52%	2.22%	1	0.09%	1.85%
										2	-0.84%	1.82%
										3	-1.10%	1.96%
										4	0.71%	1.87%
3	VDS	4	Pole Mounted/ I-285 Northbound near Orchard Road	0.46%	-1.22%	2.45%	5.49%	4.58%	6.41%	1	-4.34%	4.79%
										2	0.44%	5.56%
										3	5.61%	6.17%
4	VDS	4	Pole Mounted/ I-285 Southbound near Orchard Road	0.56%	-0.79%	1.90%	4.36%	3.35%	5.37%	1	-5.86%	6.38%
										2	3.14%	4.43%
										3	4.83%	4.98%
										4	0.61%	1.81%
5	VDS	4	Gantry Mounted Side/ I-285 Northbound near Cumberland Parkway	0.43%	-0.95%	1.80%	4.81%	3.85%	5.77%	1	-3.05%	5.68%
										2	0.05%	5.50%
										3	2.94%	3.60%
										4	1.65%	4.44%
6	VDS	4	Gantry Mounted Median/ I-285 Southbound near Cumberland Parkway	-0.68%	-2.60%	1.23%	6.09%	4.63%	7.54%	1	-4.36%	5.27%
										2	-3.28%	5.00%
										3	3.10%	9.19%
										4	2.26%	5.46%
7	VDS	4	36 feet offset Pole Mounted/ I-285 Northbound near Cascade Road	-1.11%	-3.63%	1.41%	7.24%	5.31%	9.17%	1	-4.98%	8.82%
										2	2.87%	7.69%
										3	-4.19%	6.64%
										4	1.16%	5.53%
8	VDS	4	36 feet offset Pole Mounted/ I-285 Southbound near Cascade Road	-1.34%	-2.93%	0.26%	5.86%	4.92%	6.79%	1	-2.96%	10.18%
										2	-0.59%	4.76%
										3	0.98%	4.67%
										4	-3.58%	4.62%
9	VDS	4	Gantry Mounted Median/ I-285 Northbound near US78	-3.84%	-5.69%	-1.99%	6.97%	5.74%	8.19%	1	-6.84%	7.26%
										2	-4.43%	7.14%
										3	-0.56%	6.52%
10	VDS	4	Gantry Mounted Median/ I-285 Southbound near US78	-4.13%	-5.78%	-2.48%	6.67%	5.43%	7.90%	1	-7.20%	7.59%
										2	-6.67%	7.41%
										3	-2.98%	4.25%
										4	1.08%	7.04%
11	RTMS	3	Pole Mounted/ US-78 Eastbound near Idlewood Road	-2.19%	-3.36%	-1.01%	4.40%	3.25%	5.07%	1	-4.19%	4.19%
										2	0.05%	3.08%
										3	-2.94%	6.57%
12	RTMS	3	Pole Mounted/ US-78 Westbound near Idlewood Road	-3.22%	-4.53%	-1.92%	5.23%	4.30%	6.16%	1	-3.50%	4.09%
										2	-5.92%	7.94%
										3	-0.42%	3.69%
13	VDS	7	Pole Mounted/ I-75/I-85 Near 14th Street	-17.32%	-22.96%	-11.67%	38.92%	35.62%	42.23%	1	13.16%	64.33%
										2	-13.99%	40.63%
										3	-17.92%	34.19%
										4	-23.12%	32.56%
										5	-26.58%	34.26%
										6	-24.95%	32.52%
										7	-24.76%	37.60%

A portion of these differences may be attributable to the spatial separation between the baseline count location (PTZ camera view) and the ATR/VDS/RTMS sensor locations. These separations range from 50 to 300 ft. Some of the difference between the detector and the baseline counts may be attributed to vehicle weaves occurring between the ATR/VDS/RTMS detection zone and the baseline manual count detection zone. However, observations at the sites indicate that this impact was likely low.

In addition to the above findings, Table 5 shows the mean percent error and mean absolute percentage error for each sensor type aggregated over all lanes with 95% confidence intervals, as well as the lane-by-lane MPE and MAPE. The accuracy of VDS counts varied from site to site, with mean differences as well as confidence intervals varying by location. A significant implication of this observation is that the decision to utilize VDS data cannot be made universally under these conditions and will require site-by-site review. Also, a uniform correction factor cannot be developed for application to all VDS data. Instead, correction factors must be developed on a site-by-site basis.

Based on observations in this study, the inaccuracies in VDS data appear to typically arise from (1) vertical occlusion (multiple vehicles counted as one) leading to undercounting; (2) horizontal occlusion (trucks in closer lane counted over two lanes) leading to overcounting under low-volume conditions and undercounting in high-volume conditions (where one truck occludes multiple cars); or 3) unfavorable lighting conditions (e.g., dew accumulation on lens/dome, fog, refraction of light on dust particles during dusk and dawn, etc.).

Additional observations include the following:

- *Gantry-mounted VDS*: Accuracy for video detection systems with gantry-mounted cameras was not significantly better than that of pole-mounted VDS sites. Gantry-mounted cameras are typically lower (about 45 ft. above pavement) than pole-mounted cameras (about 65 ft. above pavement) in the Metro Atlanta area. Therefore, it is likely that the advantage of a smaller horizontal offset is diluted by the loss in vertical height leading to similar impacts of vertical and horizontal occlusions.
- *VDS on 36 ft. Offset Poles*: Accuracy of VDS detection sites with cameras mounted on 36 ft. offset poles was marginally lower than units with cameras mounted on 24 ft. offset poles. Neither the 24 ft. offset nor the 36 ft. offset allows the camera to be pointed vertically downward at an angle sufficient to eliminate occlusions in the camera view. The count quality degrades slightly with the increased offset.
- *RTMS:* Based on the counts from two sites with three lanes at each site, RTMS counts showed similar or marginally better accuracy than VDS units. The hourly counts, aggregated over all lanes, had less than 5% differences from the ground truth, while the hourly lane-by-lane counts had less than 10% difference. High variations (by percentage) were seen under low-volume conditions. A confounding factor in the comparison of the RTMS and VDS performance may be the number of lanes at each site (four lanes at VDS sites and three lanes at RTMS sites), since the quality of data for these technologies usually degrades with the

increase in number of lanes covered by a single unit beyond certain thresholds when the installation conditions are less than ideal.

- *VDS Single Camera Covering Seven Lanes:* VDS covering seven lanes with one camera was found to suffer significant accuracy problems. While it was not possible to determine the exact cause of the accuracy degradation without additional study, possible causes include: (1) the view is too flat, leading to severe vertical occlusion; 2) the vehicles are occupying too few pixels for accurate detection by the video processing algorithm; and 3) the performance of the video processing unit in a VDS unit degrades as the number of lane detectors configured in a single unit exceeds a given threshold.

RECOMMENDATIONS

Although the selected sites may not be taken as representative of all possible sites, the results in this report on the accuracy of ATR/VDS/RTMS were similar to the results reported by FHWA [11, 12]. The ATR provided the best reflection of the baseline data. While the VDS and RTMS were found to provide less precise data, they were capable of providing reasonably accurate traffic counts. The acceptability of the data for a given application is dependent on the accuracy demands of that application. For example, as the data aggregated over all lanes had low differences from the baseline counts, it is likely these data are sufficient for obtaining AADT values as per the precision level requirements outlined in Table 6.2 of the HPMS Field Manual [1]. If the intent is to find evidence of a small change, say in the range of 0–5%, in a before-and-after study, the data must be used with caution. Additionally, if the samples are collected/aggregated over shorter time periods (e.g., 5 minute bins) the variability will be higher. The following are a summary of the lessons learned:

- *Accuracy of VDS counts varied from site to site and lane to lane.* Confidence intervals for traffic counts also varied by location. Therefore, the decision to utilize VDS data cannot be made universally and will require site-by-site review. Also, a uniform correction factor cannot be applied to all VDS counts. If there is a need to apply a correction factor to remove a consistent bias in the data, the correction factor needs to be determined for each detector (lane-by-lane).
- *Accuracy of counts from VDS and RTMS are sensitive to site-specific deployment characteristics.* Thus, it is recommended to perform field validation of the data at any site before choosing it as an alternative HPMS data source. It is recommended

that prior to incorporation of data, at least several peak and non-peak hours be checked for an individual VDS camera to confirm that the data satisfies the precision-level requirements outlined in Table 6.2 of the HPMS Field Manual (e.g., ±10% accuracy at 90% confidence for Interstates in urbanized locations with a population of at least 200,000).

- *To improve VDS count accuracy, camera angles and location may need to be adjusted*. In practice, it may be less resource intensive to choose an alternative site rather than attempt to refocus the camera and reevaluate the detectors for accuracy, particularly where multiple VDS cameras exist in close proximity along a corridor.
- *Counts aggregated over all lanes provide the highest accuracy*. Traffic counts aggregated over all lanes are expected to have less variation than lane-by-lane counts because the over/undercounting in one lane due to splash-over/occlusion is in many cases compensated by under/overcounting in the adjacent lane.
- *There is a likely limit to the number of lanes that may be accurately counted by a single VDS unit.* For VDS detection, it is recommended to use multiple units to detect vehicles over sections with a large number of lanes. Use of multiple cameras will allow for better viewing angles and less occlusion or pixilation issues.
- *Assessing and monitoring a reliability or reliable/confidence performance tracking coefficient for each detection site might be useful.* This step can help in selecting sites with good data for future studies or to serve as potential HPMS sites, and it could facilitate better and more frequent use of the traffic monitoring data instead of expending resources on short-term counts.

REFERENCES

1. Federal Highway Administration. *Highway Performance Monitoring System Field Manual*. 2013.

2. Mergel, J. *An Overview of Traffic Monitoring Programs in Large Urban Areas*. Center for Transportation Information of Volpe National Transportation Systems Center, 1997.

3. "UNECE—Handbook on Statistics on Road Traffic, Methodology and Experience." United Nations Economic Commission for Europe (UNECE) – Transport Division, 2007.

4. Leduc, G. *Road Traffic Data: Collection Methods and Applications.* European Commission Joint Research Centre. Institute for Prospective Technological Studies, 2008.

5. Ahn, K., H. Rakha, and D. Hill. Data Quality White Paper. Federal Highway Administration, 2008.

6. Federal Highway Administration. *Traffic Detector Handbook: Third Edition*. Federal Highway Administration, 2006.

7. Federal Highway Administration. *Traffic Monitoring Guide*. Federal Highway Administration, 2001.

8. Transportation Research Board. *Traffic Monitoring Data: Successful Strategies in Collection and Analysis*. Transportation Research Circular E-C120, 2007.

9. Fekpe, E., D. Gopalakrishna, and D. Middleton. *Highway Performance Monitoring System Traffic Data for High-Volume Routes: Best Practices and Guidelines.* Federal Highway Administration, 2004.

10. Minge, E., J. Kotzenmacher, and S. Peterson. *Evaluation of Non-Intrusive Technologies for Traffic Detection.* Minnesota Department of Transportation, 2010.

11. Turner, S., J. Carson, L. Wilkinson, K. Travis, and C. Zimmerman. *Traffic Monitoring: A Guidebook.* Federal Highway Administration, 2010.

12. Federal Highway Administration. *Traffic Data Quality Measurement*. 2004.

13. Rhodes, A., E. J Smaglik, and D. Bullock. *Vendor Comparison of Video Detection Systems.* Purdue University, West Lafayette, IN, 2006.

14. Medina, J., R. Benekohal, and M. Chitturi. *Evaluation of Video Detection Systems*. Illinois Department of Transportation, 2009.

15. Middleton, D., and R. Parker. *Evaluation of Promising Vehicle Detection Systems*. Texas Transportation Institute, 2002.

16. Birchfield, S., W. Sarasua, and N. Kanhere. *Computer Vision Traffic Sensor for Fixed and Pan-Tilt-Zoom Cameras.* Transportation Research Board IDEA Award NCHRP-140, 2010.

17. Hidas, P., and F. Milthorpe. *Traffic Counts for Strategic Transport Model Validation: What Counts?* Proceedings of the 32rd Australasian Transport Research Forum (ATRF), 2009.

18. Toth, C., W. Suh, V. Elango, R. Sadana, A. Guin, M. Hunter, and R. Guensler. *Tablet-Based Traffic Counting Application Designed to Minimize Human Error.* Proceedings of 92nd Annual Meeting and Conference of the Transportation Research Board (TRB), 2013.

19. Mathworks website. "Box Plots." http://www.mathworks.com/help/stats/box-plots.html.

20. Hamilton, M. J. "Paired 2 Sample t-Test." Retrived June 1 2013. http://www.unm.edu/~marcusj/Paired2Sample.pdf