

Integrating Intersection Traffic Signal Data into a Traffic Monitoring Program

Final Report

*GDOT Research Project TO 02-128; RSCH PROJ 13-10
Georgia Tech Project No. 2006U45*

October, 2014

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1. Report No.: FHWA-GA-14-1310	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Integrating Intersection Traffic Signal Data into a Traffic Monitoring Program	5. Report Date: September 2014	
	6. Performing Organization Code:	
7. Author(s): Angshuman Guin, Ph.D.	8. Performing Organ. Report No.:	
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.: R.P. 13-10, T.O. 02-128	
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 2013-September 2014	
	14. Sponsoring Agency Code:	
15. Supplementary Notes:		
<p>16. Abstract:</p> <p>The objective of this study was to provide the Georgia Department of Transportation with an evaluation of the feasibility of integrating intersection traffic signal data into a traffic monitoring program. Some of the pertinent conclusions from this study are:</p> <ul style="list-style-type: none"> • Accuracy of 15-minute aggregates of vehicle counts is above 90% at a 95% level of confidence at majority of the study sites • Data quality at some intersections are affected by insufficient offset of the detection zone from the stop bar, leading to queuing of vehicles over the detector and resulting in over-counting of vehicles • Data from intersections using video based detection are of comparable quality as other intersections using inductive loop detectors <p>For using the intersection signal detector data for traffic monitoring the following cautions need to be exercised:</p> <ul style="list-style-type: none"> • Discard locations with data spikes i.e. detectors reporting more than 500 vehicles per lane per 15 minutes (threshold can be fine-tuned) at any single data-point • Ensure stability of data connection for completeness of data at remote locations which use wireless data transfers 		

- Data availability does not guarantee data quality. Check plot of historical data for expected traffic patterns before considering use of data in traffic monitoring
- Use data from signal detector downstream of midblock location (i.e. use data from two intersections instead of one)
- Use data from locations where the inductive loop detectors are physically located upstream of the beginning of turn lanes (if any)
- Avoid locations where there is evidence (can be confirmed with site visit during peak period) of vehicles queuing over the detection zone

To improve the usability of intersection signal detector data for traffic monitoring it is recommend that for future installations and maintenance on existing detectors, detection zones are moved further upstream beyond the maximum queue length of a typical peak hour queue and beyond the beginning of the turn lanes. If it is not possible to move detections zones upstream of turn lanes, detectors should be installed on turn lanes as well.

Based on the findings of the study, it is apparent that in majority of the cases, the intersection signal detector data is similar in quality to pneumatic tube count data in terms of both the mean and variability of the errors. However, there are two major concerns. Firstly, the intersection signal detector data does not provide classification data. If this is a major impediment in using the intersection signal detector data in traffic monitoring, this problem should be further investigated to identify possible solutions or workarounds. Secondly, as with any detection technology, the accuracy of the induction loop data feeding into the signal cabinets is dependent on the field deployment characteristics. While there is some variability in the level of error from site to site, in general following the intersection eligibility criteria guidelines should help ensure high quality of data for use in the traffic monitoring program. If the data from a particular site is expected to be used extensively on a long term basis, validation of the data via short term counts is recommended.

17. Key Words: Intersection Signal Data, Highway Performance Monitoring System, Automatic Traffic Recorders, Traffic Monitoring, Induction Loops, Pneumatic Tube, Data Accuracy		18. Distribution Statement:	
19.Security Classification (of this report): Unclassified	20.Security Classification (of this page): Unclassified	21. Number of Pages: 41	22. Price:

Form DOT 1700.7 (8-69)

Table of Contents

List of Figures	vi
List of Tables	ix
Executive Summary	1
Acknowledgments	3
1.0 Introduction	4
1.1 Objective.....	4
2.0 Literature Review	6
2.1 Accuracy of Vehicle Counting Technology	6
2.2 Use of Intersection Signal Data for Vehicle Counts	6
3.0 Methodology.....	8
3.1 Site Selection.....	8
3.2 Data Connection	10
3.3 Data Collection.....	10
3.3.1 Pneumatic Tubes	10
3.3.2 Video Processing.....	10
3.4 Analysis steps	12
3.4.1 Validation of Baseline data (Pneumatic Tube data)	12
3.4.2 Comparison of Signal Detector Data to Baseline Data	12
3.5 Pilot Data Collection Study	13
4.0 Results and Discussion.....	14
4.1 Quality Checks on Baseline Data	14
4.2 Effect of Presence of Turn Lanes	18
4.3 Effect of Lane Changes	21
4.4 Effect of Presence of Other Intersections	24
4.5 Effect of Distance between Intersections	24
4.6 Effect of Volume	26
4.6.1 Intersections without Queuing.....	26
4.6.2 Intersections with Queuing.....	30
4.6.3 Low Volume Road	32
4.7 Effect of Detection Technology	34
4.8 Summary of Results	38
5.0 Conclusions and Recommendations.....	43

5.1	Findings	43
5.2	Intersection Eligibility Criteria.....	43
5.3	Ideal Intersection for Data Use.....	45
5.4	Recommendations	46
5.4.1	Installation Considerations	46
5.4.2	Communication	46
5.4.3	Future Research.....	47
6.0	References	49
7.0	Appendix	7-0

List of Figures

Figure 1: Typical Placement of Offset Loops (Induction Loop Detectors) on Pavement (SR 92 @ Woodstock Road). <i>Image Courtesy: Google Street View</i>	9
Figure 2: Typical Placement of Detectors on Pavement. <i>Image Courtesy: Google Maps</i>	9
Figure 3: Traffic counting application screen shots: (a) lane setup, (b) buttons with the current count numbers showing. (c) Data collector collecting vehicle count data using application.....	11
Figure 4: Recorded View of Traffic on SR 92 and Woodstock Road from Video that was Post Processed using the Tablet Application	12
Figure 5: Time Series Plots for Manual Counts and Pneumatic Tube Counts at Intersection of SR 92 WB and King Road for Lane 1 (Top) and Lane 2 (Bottom)	15
Figure 6: Time Series Plots for Manual Counts and Pneumatic Tube Counts at Intersection of SR 92 WB and King Road for Lane 2 (Top) and Aggregates over All Lanes (Bottom)	16
Figure 7: Time Series Plot for Pneumatic Tube Counts Upstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Aggregates over All Lanes	17
Figure 8: Y-Y Plots for Manual Counts Vs Tube Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 1 (Top-Left), Lane 2 (Top-Right), Lane 3 (Bottom-Left) and Aggregates over All Lanes (Bottom Right).....	18
Figure 9: Layout of Test Site Location at Intersection of SR 140 and Steeple Chase Dr; Top: Site Overview; Bottom: Close-up View of Pneumatic Tube Count Site (<i>Image Courtesy: Google Maps</i>)	19
Figure 10: Layout of Test Site Location at Intersection of SR 141 and Old Alabama Road. Left: Site Overview; Right: Detailed View of Turn Lanes (<i>Image Courtesy: Google Maps</i>)	20
Figure 11: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple Chase Drive for Lane 1	20
Figure 12: Time Series Plots for Pneumatic Tube Counts and Signal Detectors Counts Aggregated over All Lanes at Intersection of SR 140 NB and Old Alabama Road	21
Figure 13: Layout of Test Site Location at Intersection of SR 92 and Dials Drive (<i>Image Courtesy: Google Maps</i>)	22
Figure 14: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 1	22
Figure 15: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 2.....	23
Figure 16: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Aggregates over All Lanes.....	23
Figure 17: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple Chase Dr for Lane 2.....	24

Figure 18: Layout of Test Site Location at Intersection of SR 92 and Roswell Crossing (<i>Image Courtesy: Google Maps</i>)	25
Figure 19: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 3.....	25
Figure 20: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Aggregates over All Lanes.....	26
Figure 21: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 2.....	27
Figure 22: Time Series Plot for Pneumatic Tube Counts <i>Downstream of Intersection</i> and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Aggregates over All Lanes.....	27
Figure 23: Layout of Test Site Location at Intersection of SR 92 and Roswell Crossing (<i>Image Courtesy: Google Maps</i>)	28
Figure 24: Time Series Plot for Pneumatic Tube Counts <i>Downstream of Intersection</i> and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Aggregates over All Lanes	29
Figure 25: Time Series Plot for Pneumatic Tube Counts <i>Downstream of Intersection</i> and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes	29
Figure 26: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 1	30
Figure 27: Time Series Plot for Manual Counts, Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Aggregates over All Lanes	31
Figure 28: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes.....	31
Figure 29: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes with Count Ceiling per lane at 350 vehicles	32
Figure 30: Layout of Test Site Location at Intersection of SR 314 and Banks Road (<i>Image Courtesy: Google Maps</i>)	33
Figure 31: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 1	33
Figure 32: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 2	34
Figure 33: Layout of Test Site Location at Intersection of SR 237 and SR 141 (<i>Image Courtesy: Google Maps</i>)	35
Figure 34: Layout of Detection Zones for Tablet based Manual Counts on video at Intersection of SR 237 and SR 141 (<i>Image Courtesy: Google Maps</i>)	35
Figure 35: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for Lane 1.....	36

Figure 36: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for Lane 2..... 36

Figure 37: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for Lane 3..... 37

Figure 38: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for 3 Through-Lanes and All 5 Lanes Including Left Turn Lanes 37

Figure 39: Detection Layout Schematic 43

Figure 40: Example of Traffic Counts with and without Data Spikes 44

Figure 41: Example of Time Series Plot with well Defined Traffic Volume Pattern 45

Figure 42: Proposed Detection Zone Placement Upstream of Beginning of Turn Lanes (*Image Courtesy: Google Maps*) 46

List of Tables

Table 1: Final Site List	8
Table 2: Summary of Percentage Errors	39

Executive Summary

Many signalized intersections operate under some form of actuated control, in that the intersection approaches have some type of sensor. The most common sensor is an inductive loop which can be configured to provide traffic counts. The Office of Traffic Operations is currently installing traffic signal detectors (inductive loops) in the pavement of various high volume corridors in the Atlanta vicinity. The traffic signal detectors are part of the Regional Traffic Operations Program (RTOP), a multi-jurisdictional, signal timing program with the goal of improving traffic flow and reducing vehicle emissions through improved signal timing. This research project determines if and how the traffic volume data from the inductive loops can be appropriately utilized in the Office of Transportation Data's (OTD) traffic monitoring program.

The objective of this study is to provide the Georgia Department of Transportation with an evaluation of the feasibility of integrating intersection traffic signal data into a traffic monitoring program. Specifically, this project evaluates whether the traffic signal detector data is of comparable quality when compared to portable traffic count data under different traffic flow conditions and different intersection geometries. This study also develops a set of eligibility criteria for identifying intersections that can be used for long term performance monitoring data collection.

The first step in the data quality analysis was to ensure that the pneumatic tube data is of acceptable quality and can be used as control data. A comparison of pneumatic tube count data to manual count data from videos provided evidence that the accuracy of the lane-by-lane 15-minute pneumatic counts was between 91% - 98% at a 95% level of confidence, depending on the sites. Occurrences of abnormally high values in some of the data from the signal controllers at some sites investigated in the pilot study, affected the choice of locations to be studied in the second phase. In the second phase of data collection, pneumatic tubes were deployed at multiple locations that varied by intersection geometries, spacing of intersections, traffic volumes, presence of queues etc. Locations with potential of heavy queue formation were oversampled in the study to further investigate the data spiking issues. The pneumatic tube data was supplemented with video based manual data collection for several intersections, including one that used video detection systems for vehicle detection instead of inductive loops. Visual comparisons of the time series plots of the data was followed by computation of the mean percentage errors, mean absolute percentage errors, root mean square error and the 95% bounds of the mean percentage errors.

Some of the pertinent conclusions from this study are:

- Accuracy of 15-minute vehicle counts aggregated over all lanes is above 90% at a 95% level of confidence at majority of the study sites
- Data quality at some intersections are affected by insufficient offset of the detection zone from the stop bar, leading to queuing of vehicles over the detector and resulting in over-counting of vehicles
- Data from intersections using video based detection are of comparable quality as other intersections using inductive loop detectors

For using the intersection signal detector data for traffic monitoring the following cautions need to be exercised:

- Discard locations with data spikes i.e. detectors reporting more than 500 vehicles per lane per 15 minutes (threshold can be fine-tuned) at any single data-point

- Ensure stability of data connection for completeness of data at remote locations which use wireless data transfers
- Data availability does not guarantee data quality. Check plot of historical data for expected traffic patterns before considering use of data in traffic monitoring
- Use data from signal detector downstream of midblock location (i.e. use data from two intersections instead of one)
- Use data from locations where the inductive loop detectors are physically located upstream of the beginning of turn lanes (if any)
- Avoid locations where there is evidence (can be confirmed with site visit during peak period) of vehicles queuing over the detection zone

To improve the usability of intersection signal detector data for traffic monitoring it is recommend that for future installations and maintenance on existing detectors, detection zones are moved further upstream beyond the maximum queue length of a typical peak hour queue and beyond the beginning of the turn lanes. If it is not possible to move detections zones upstream of turn lanes, detectors should be installed on turn lanes as well.

Based on the findings of the study, it is apparent that in majority of the cases, the intersection signal detector data is similar in quality to pneumatic tube count data in terms of both the mean and variability of the errors. However, there are two major concerns. Firstly, the intersection signal detector data does not provide classification data. If this is a major impediment in using the intersection signal detector data in traffic monitoring, this problem should be further investigated to identify possible solutions or workarounds. Secondly, as with any detection technology, the accuracy of the induction loop data feeding into the signal cabinets is dependent on the field deployment characteristics. While there is some variability in the level of error from site to site, in general following the intersection eligibility criteria guidelines should help ensure high quality of data for use in the traffic monitoring program. If the data from a particular site is expected to be used extensively on a long term basis, validation of the data via short term counts is recommended.

Acknowledgments

The authors of this report wish to thank the Georgia Department of Transportation for its support and assistance throughout this effort, in particular the efforts of Kiisa Wiegand, Scott Susten, Ray McEachern, Grant Waldrop, Robert Baker, Paul Tanner and Jane Smith.

1.0 Introduction

Many signalized intersections operate under some form of actuated control, in that the intersection approaches have some type of sensor. The most common is an inductive loop which can be configured to provide traffic counts. The Office of Traffic Operations is currently installing traffic signal detectors (inductive loops) in the pavement of various high volume corridors in the Atlanta vicinity. The traffic signal detectors are part of the Regional Traffic Operations Program (RTOP), a multi-jurisdictional, signal timing program with the goal of improving traffic flow and reducing vehicle emissions through improved signal timing. This research project will determine if and how the traffic volume data from the inductive loops can be appropriately utilized in the Office of Transportation Data's (OTD) traffic monitoring program.

The existing literature on the subject of intersection traffic signal data pertains to a wide range of topics including: placement and calibration of the embedded loops; how the signal system data should be archived; the appropriate schemas; and the development of scripts to transfer data, process and upload the data. One of the studies (1) focused on equipment design and installation practices, reviewing various loop configurations in terms of ability to provide traffic counts, and selecting instances around the country that are using the existing loops at traffic signals for counts. However, it appears that the traffic counts used by the different agencies were used only for real-time traffic monitoring; not for federal reporting purposes or as part of a highway performance monitoring program.

Another pilot study (2) demonstrated the feasibility of real-time monitoring of traffic operations at a signalized intersection. Using traffic volumes from existing loops and signal timing information, the control delay (uniform delay plus incremental delay) was estimated on a cycle-by-cycle basis using equations provided in the Highway Capacity Manual.

There are several other studies (3, 4) that investigate the use of data from signalized intersections for real-time traffic monitoring. However there is limited amount of research on the accuracy and robustness of the data. The current study aspires to bridge this gap and provide an objective evaluation of the accuracy of the data and feasibility of use as it pertains to federal reporting standards.

1.1 Objective

The overarching objective of this research is to provide the Georgia Department of Transportation with an evaluation of the feasibility of integrating intersection traffic signal data into a traffic monitoring program. Specifically, this project is intended to evaluate whether the traffic signal detector data is of comparable quality when compared to portable traffic count data under different traffic flow conditions and different intersection geometries. The key sub-objectives may be summarized as follows:

- Conduct a review of the literature on previous efforts at using traffic signal detector data

- Compare traffic signal detector data and data from portable traffic data collection devices from test sites chosen such that they include a variety of traffic volume levels and geometric and operational characteristics
- Develop a methodology for estimating mainline traffic counts (bi-directional) from traffic signal detectors
- Make recommendations regarding data quality standards
- Determine eligibility criteria for intersections to be used for performance monitoring data collection

2.0 Literature Review

There has been an ongoing effort of leveraging the large amount of data continuously generated for real time traffic operations for non-real time uses. Both the traffic operations program and traffic monitoring program typically use the same technology, the most commonly used one being inductive loop based sensors. However, the challenge is typically in the difference in the use of the technology for different purposes. While the exact counts might not be critical in traffic operations, where data is refreshed every few seconds, the error levels become much more critical for traffic monitoring where data is typically aggregated over longer periods of time. Errors in measurement tend to get accumulated over time if there is a bias in a particular direction.

2.1 Accuracy of Vehicle Counting Technology

Inductive loop based vehicle sensors have been in use for a long time in the transportation field and is one of the most well established intrusive detection technologies (Sherry, 2001). Texas Transportation Institute has reported the count accuracy to be 98 percent for properly designed and installed, preformed and standard saw-cut loops (Middlenton, 1999). The Minnesota Department of Transportation, based on field tests, have reported accuracies of 0.1 % - 3% for hourly counts on freeways and 2.8% to 8.6% at intersections (MDOT, 1997; MDOT, 2002). The accuracy of inductive loop varies with environmental conditions and is also dependent on the installation and calibration.

The survey conducted by Sherry (Sherry, 2001) indicated that inductive loops are used in traffic monitoring programs in 50 states and pneumatic tubes are used in 48 states. Pneumatic tubes have been used for vehicle counts since the early 1900s and their accuracy is widely accepted for temporary counts. There is not much recent literature regarding any accuracy studies for pneumatic tube counters. A South Dakota study reported a wide -0.92% to 30% error range for pneumatic tubes (Weber, 1999). McGowen and Sanderson (McGowen, 2011) also reported a wide error range, 6.9% to 27.6%, for 15 minute intervals. However over a two day period the error was in the range of 0.0% to 0.5%.

2.2 Use of Intersection Signal Data for Vehicle Counts

Using traffic operations data for traffic monitoring programs is an attractive idea and naturally, there have been previous efforts towards achieving this. An extensive study was performed by the Institute of Traffic Engineers (ITE) Traffic Engineering Council to study the use of existing loops at signalized intersections for traffic counts. The study examined the use of data from different types of loop configurations including exit loops, queue loops, advance loops and stop line loops for single loops; stop line loops and extension loops for multiple loop configurations; three and four loop configurations; as well as continuous long loops. The study also provided guidance on intersection geometry considerations such as presence of center median or island, loops beyond stop line, road transitions, adjacent lane detection in same and opposite direction of travel, pavement surface, loop crosstalk, use of multiple loops etc. Based on the information provided on the case studies in this report it appeared that as of 2007, the following cities and state DOT have attempted to use signal loop data for vehicle counts:

- City of Nashua, NH
- City of Fremont, CA
- City of Bellevue, WA

- Minnesota Department of Transportation
- North Carolina Department of Transportation

The survey in the report indicated that these entities used offline polling and retrieval of data at the time the survey was conducted. City of Fremont was the most advanced in this area and they had decided to exclusively use far side system loops for the counts (where far side system loops refer to induction loop detectors configured for vehicle counts and are installed immediately outside the bounds of the intersection, downstream of the intersection). The ITE study provides an appropriate pre-cursor to the current study in that the ITE study provides guidance on best practices for the design and placement of the loops. The current study builds on this effort and investigates the use of data from pre-installed offset (or advance) loops or other technologies used for vehicle detection at intersections (such as video detection systems) in a traffic monitoring program.

3.0 Methodology

3.1 Site Selection

An inventory of existing signalized intersection sites in Georgia to which the Office of Traffic Operations has data access was obtained. A list of potential sites to study was based on criteria such as geometric features, area characteristics (urban, suburban, rural), current traffic demands (vehicle volumes, percent trucks, etc.), and location. In addition, an initial snapshot of the signal detector data was obtained for the potential sites and reviewed to ensure that the data does not exhibit any abnormal artifacts.

As the study progressed, the initial list of study sites had to be modified to eliminate the initially identified rural site because of unavailability of data at the site. In addition the case study of intersection with data on all four approaches was eliminated because none of the intersections with loop detectors had detection on all four approaches. Some of the initial site selections had to be modified because of unavailability of appropriate anchor points for the pneumatic tubes near the proposed data collection location. The study sites were selected to cover different geometric feature scenarios and traffic demands. Figure 1 shows the typical location of an offset loop at an intersection. Figure 2 shows the typical setup of the different kinds of detection zones at an intersection on the RTOP corridors. Table 1 lists the final set of intersections along with the corresponding selection criteria, where data were collected for this study.

Table 1: Final Site List

	Intersection/Location	Criteria	Characteristics
1	SR 141 at East Jones Bridge Rd	High Volume Intersections	
2	SR 141 at Old Alabama Rd		
3	SR 92 at Woodstock/King Rd		
4	SR 140 at River Exchange Parkway		
5	Between SR 140 at Fouts Road and SR 140 at Steeplechase Drive	Distance between intersections (multiple cross streets vs. low cross streets)	Multiple cross streets between intersections
6	Between SR 92 at Woodstock/King Rd and SR 92 at Roswell Crossing		No significant cross streets. Distance between intersections is 900 ft.
7	Between SR 92 at Woodlands Dr and SR 92 at Dials Dr		No significant cross streets. Distance between intersections is 1450 ft.
8	SR 314 between Creek Wood Trl and Banks Rd	Medium/Low Volume	
9	SR 237 at SR 141 (Piedmont	VDS Based	



Figure 1: Typical Placement of Offset Loops (Induction Loop Detectors) on Pavement (SR 92 @ Woodstock Road). Image Courtesy: Google Street View

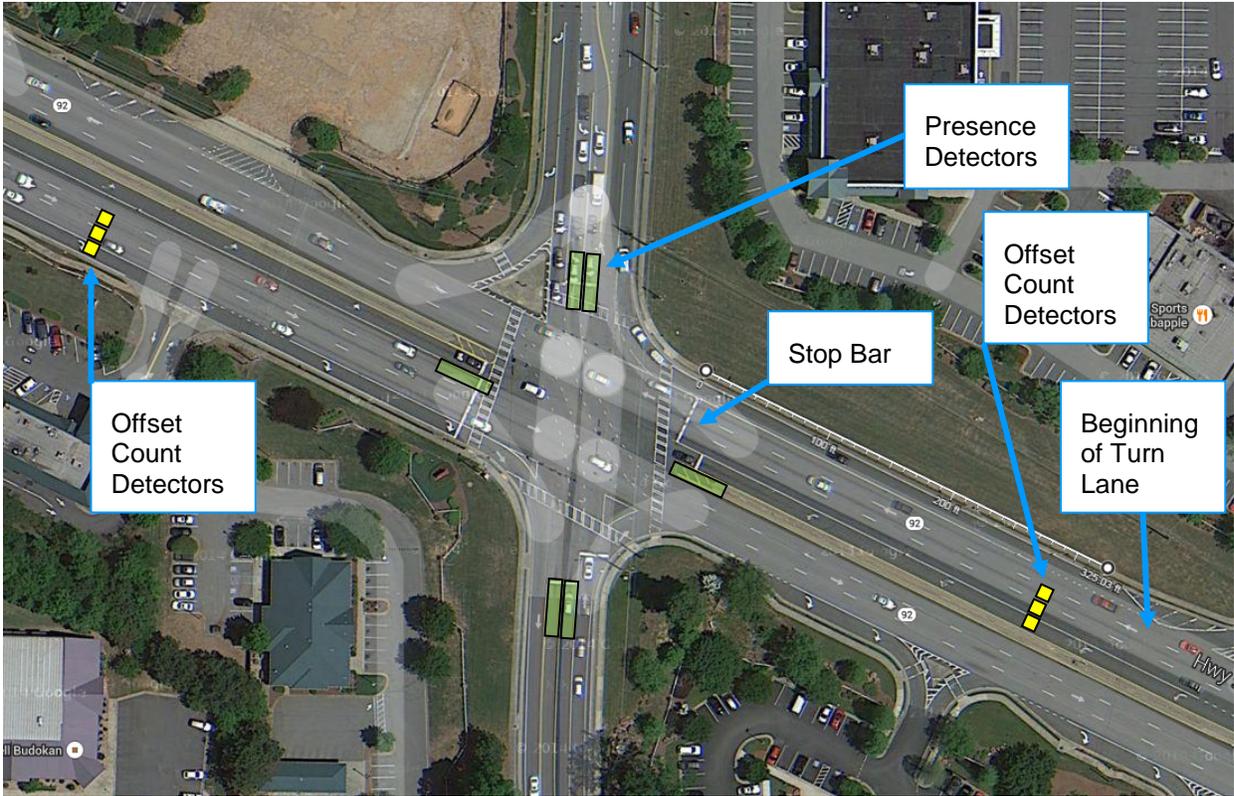


Figure 2: Typical Placement of Detectors on Pavement. Image Courtesy: Google Maps

3.2 Data Connection

To test the feasibility of using the signal detector data for counts, it is essential to ensure the availability of the data. The 15-minute aggregated data from the signal detectors are polled on a regular basis (usually once or twice daily) by a central server and the data is archived in a database. In addition, the central server receives real time data from the signal detectors for real-time operations purposes. This data is available to external applications as an XML data packet upon request from the server. To leverage the higher resolution of the real-time data stream, a script was setup on a remote server (at Georgia Tech) to obtain the real time data and archive it. However, data quality analysis indicated that the completeness of the data in the real-time stream could not be guaranteed. Therefore, the final solution involved a script for obtaining a daily snapshot of the 15-minute aggregated data from the database for analysis/processing and archiving.

3.3 Data Collection

Due to the resource intensive nature of video based data collection, the baseline data was collected using pneumatic tubes similar to a standard portable data collection effort conducted by GDOT for the traffic monitoring program. To ensure that the pneumatic tube data is reliable for use as baseline data for comparing with traffic signal detector data (also referred to as signal detector data or simply signal count data in this document), the research team conducted quality checks on this data using video based manually collected data.

3.3.1 Pneumatic Tubes

Portable count data was collected using pneumatic tube counters. The tubes were laid across the roadway as close as possible to the location of the in-pavement inductive loops detectors of the signal detectors. In several cases it was not possible to match the exact location because of constraints regarding the availability of anchor points for the pneumatic tube equipment. In such cases, the analysis has to take into account that differences in counts between the pneumatic tubes and the inductive loops could arise due to lane changes of the vehicles and the time offset between the arrivals of vehicles at the two detectors. The time-offset is typically minor during medium to light volume conditions but could become a significant factor under high volume conditions that lead to vehicle queuing over the detectors.

A total of six hundred and seventy two hours of directional data over nine study sites around Metro Atlanta was collected for analysis this study.

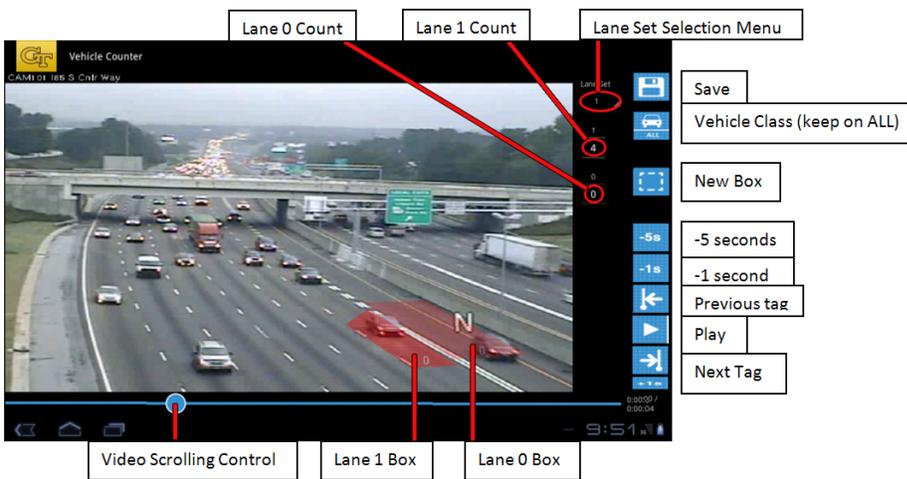
3.3.2 Video Processing

For validating the pneumatic tube counts, manual vehicle count data was collected. To ensure repeatability and high quality of the data, counts were performed using pre-recorded video at the count locations. The video was processed by data collectors using a tablet application that was developed at Georgia Tech (as part of TO 02-69; RSCH PROJ 10-03). Screenshots of the application interface can be seen in Figure 3. The data was obtained at a per-vehicle record level and was aggregated up to 15 minute bins to match the data from the pneumatic tubes. The video data was also used for validation of the data at intersections that used Video Detection Systems for counts, because the extremely high volume of traffic at these sites and the lack of anchor points made it impossible to collect data using pneumatic tube counters.

About 21 hours of per-lane manual vehicle count data was collected and analyzed for this study.



(a)



(b)



(c)

Figure 3: Traffic counting application screen shots: (a) lane setup, (b) buttons with the current count numbers showing. (c) Data collector collecting vehicle count data using application



Figure 4: Recorded View of Traffic on SR 92 and Woodstock Road from Video that was Post Processed using the Tablet Application

3.4 Analysis steps

3.4.1 Validation of Baseline data (Pneumatic Tube data)

To ensure that the pneumatic tube counter data was of a quality sufficient to serve as a baseline, the pneumatic tube data was validated against manually collected data. To ensure repeatability and high quality of the data, counts were performed using pre-recorded video at the count locations.

3.4.2 Comparison of Signal Detector Data to Baseline Data

Essential to the evaluation of the feasibility of integrating intersection traffic signal data into a traffic monitoring program is an evaluation of whether the traffic signal detector data is of a quality comparable to portable traffic count data under different traffic flow conditions and different intersection geometries. This is to ensure that the quality of data from the new system (signal detector) that is supplementing the old system (portable counts) is not inferior to the old system data. In addition, it is necessary to evaluate the accuracy of both the systems to ensure that apart from the comparative differences, the actual errors in the new system are not extremely high. Multiple paired comparisons were performed across the different datasets to check for both these scenarios.

3.4.2.1 Visual Analysis

The first step in the comparison was a visual analysis of the data to check for large differences or issues in the underlying dataset.

3.4.2.1.1 Time Series Plots

The 15-minute aggregates of counts were plotted as time-series charts with counts on the y-axis and time of day on the x-axis for the entire period of data collection. Both the test data and the baseline data were plotted on the same chart to enable easy comparison of the datasets. The time-series charts helped identify any systematic divergence between the values or characteristic attributes of the divergence, e.g. whether the differences are higher during certain flow conditions, time-of-day etc.

3.4.2.1.2 Y-Y Plots

The Y-Y plots between the test data and the baseline data shows the relationship of the magnitude of the error values to the magnitude of the actual values. This provided a time-independent view of the errors. A green line was drawn in these plots to serve as the guide line for the 45 degree line on which the data-points would lie in case of zero error. In addition two red lines were drawn to identify the 10% error bounds.

3.4.2.2 *Percentage Error*

The following statistics were used to compare the differences between the observed counts and the designated baseline counts.

- Mean Percentage Error (MPE)
- Mean Absolute Percentage Error (MAPE)
- Root Mean Squared Percentage Error (RMSPE)

For the inductive loop detector based signal detector counts, the pneumatic tube counts served as the baseline. For the pneumatic tube counts as well as the video detection system based signal detector counts, the manual counts served as the baseline.

Apart from the above measures of central tendency, the variability in the differences was studied by using the 95th percent confidence intervals on the mean percentage error values.

3.5 *Pilot Data Collection Study*

A pilot study with three adjacent intersections and three intermediate pneumatic tube data collection sites was performed to test the experimental setup. In this case study, the pilot study results matched up very well with expectations and no modifications were necessary to the experimental setup. However, the pilot data revealed some artifacts in the data under high volume conditions which affected the site selection plan. Additional high-volume sites with possible vehicle queuing over the detection station were chosen to further study any possible issues under high-volume traffic flow conditions. The results of the pilot data collection study as well as the full study are presented in Section 4.0.

4.0 Results and Discussion

This section describes the results of the comparative analysis. The different scenarios are analyzed on a case by case basis to observe the biases in the datasets or other issues in the data under the influence of different conditions such as geometric characteristics of intersections or flow conditions of the traffic. The subsections use the visuals, i.e. the time series plots, Y-Y plots etc. for discussion. Only the most relevant figures are presented during the discussions. For comprehensive reference, the entire set of charts for each site is provided in the Appendix, where the charts are grouped by site for ease of access. The MPE, MAPE and RMSPE values are provided as a summary table, along with the summary of the results at the end of this section.

4.1 Quality Checks on Baseline Data

Based on the results of initial comparisons between the signal detector data and the pneumatic tube data obtained in the pilot study, the quality of the portable traffic data collection devices was deemed to be acceptable for purposes of this study. In view of concerns about pneumatic tubes undercounting traffic under slow speed and high volume conditions, a detailed comparison of video based counts collected by the research team and the pneumatic tube counts was performed.

The pneumatic tube counter data and the manual count data are plotted as time series in Figure 5 and Figure 6 for the SR 92 at the Woodstock / King Road intersection. Y-Y plots are provided in Figure 8. The time series plots show that the tube count data is slightly higher than the manual counts in lanes 1 and 3, the fastest and slowest lanes respectively, but lower than the manual counts in lane 2 (the middle lane). The Y-Y plots show that while most of the data are within the 10% bounds, there are some points in the lane 3 data that fall outside the bounds. Overall, when aggregated across the lanes the data show a slight positive bias. The mean percentage errors vary within a range of -6% to 8.7% for the individual lane aggregates while the aggregate over all lanes has a mean error of 3%. For the SR 140 at River Exchange Parkway site, the results were better at the individual lane level (Figure 7), but similar at the aggregate over lanes level. The mean percentage error varied in the range of 2.3 to 3.1 for the individual lanes and was 2.7% for the aggregate over lanes in the eastbound direction.

A part of these errors can be explained away by the possibility of lane changes between the location of the tube count and the location of the screen-line for the manual count. However, the magnitude of the errors is too high to attribute completely to lane changes and differences in the arrival times at the two detection points. Due to the high degree of confidence in the manual data, it can be concluded that there is a certain amount of error in the pneumatic tube counts. While the error in the aggregates across lanes is 3%, the errors in counts in the individual lanes is likely to be higher (slightly less than the -6% to 8.7% range, if lane changing is taken into account).

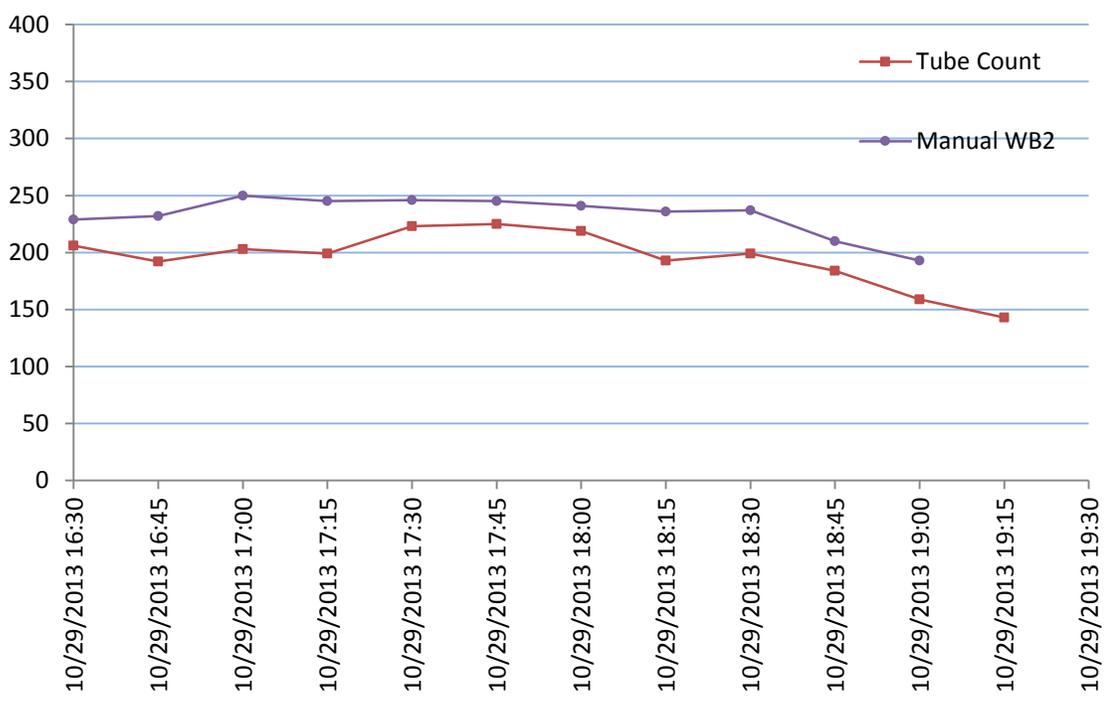
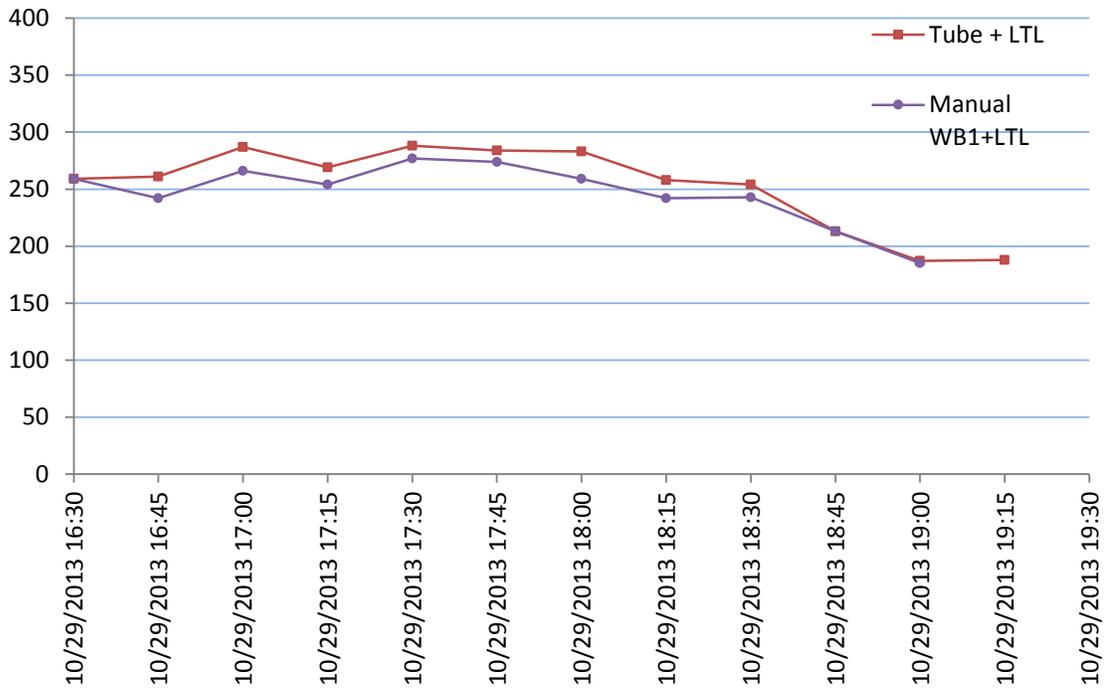


Figure 5: Time Series Plots for Manual Counts and Pneumatic Tube Counts at Intersection of SR 92 WB and King Road for Lane 1 (Top) and Lane 2 (Bottom)

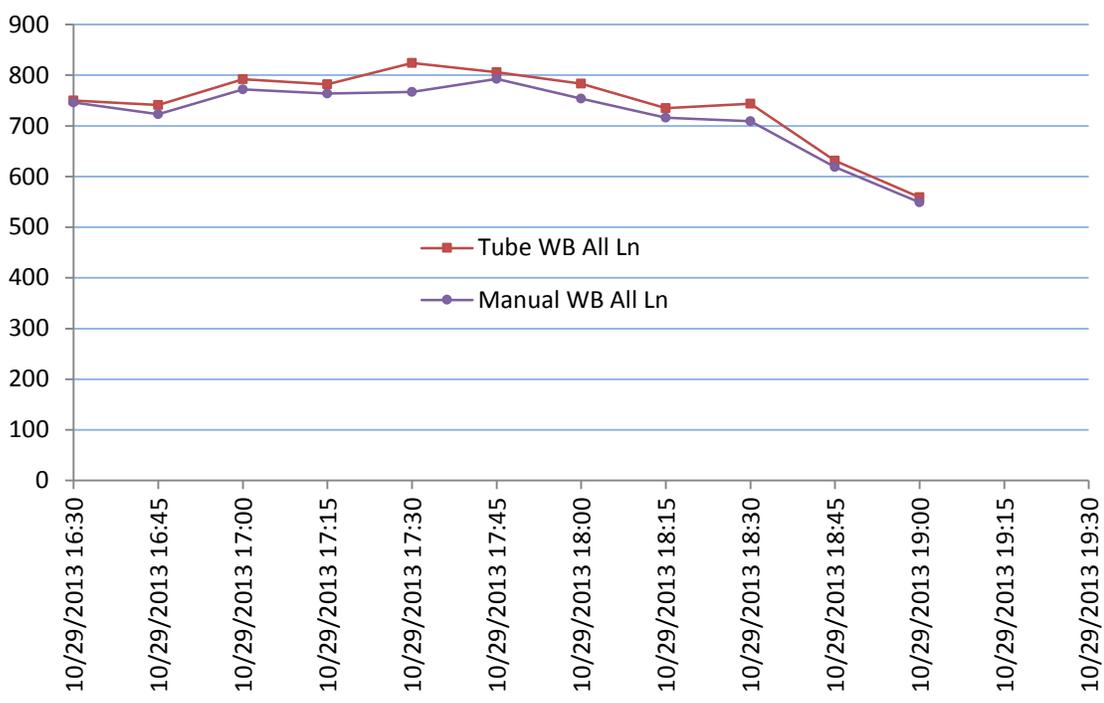
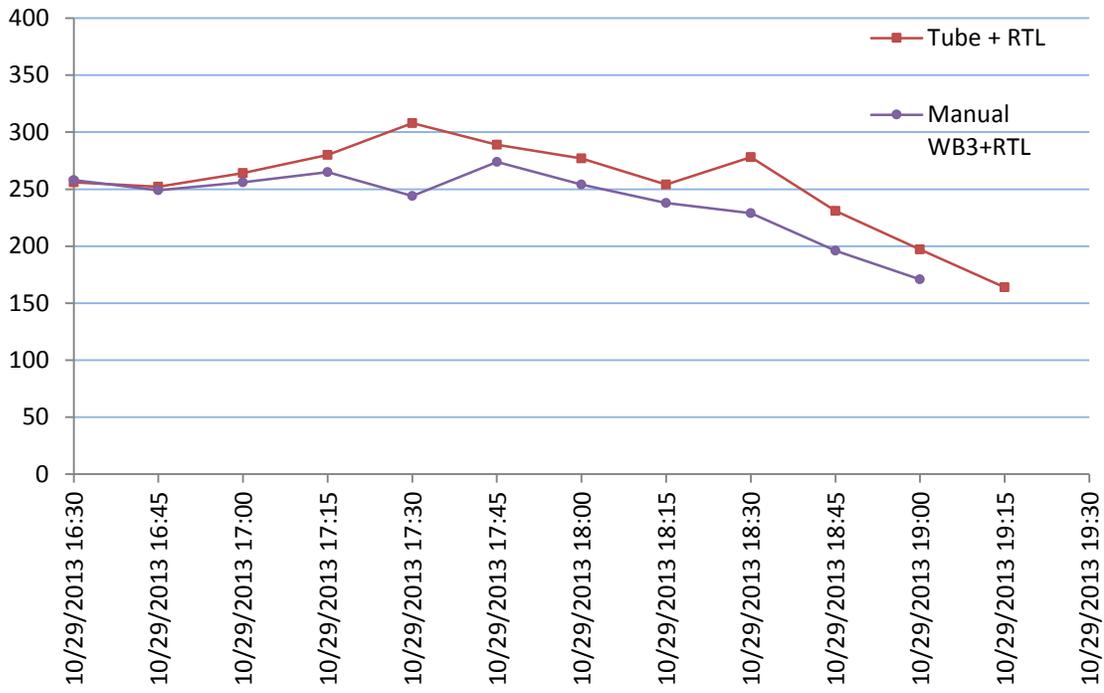


Figure 6: Time Series Plots for Manual Counts and Pneumatic Tube Counts at Intersection of SR 92 WB and King Road for Lane 2 (Top) and Aggregates over All Lanes (Bottom)

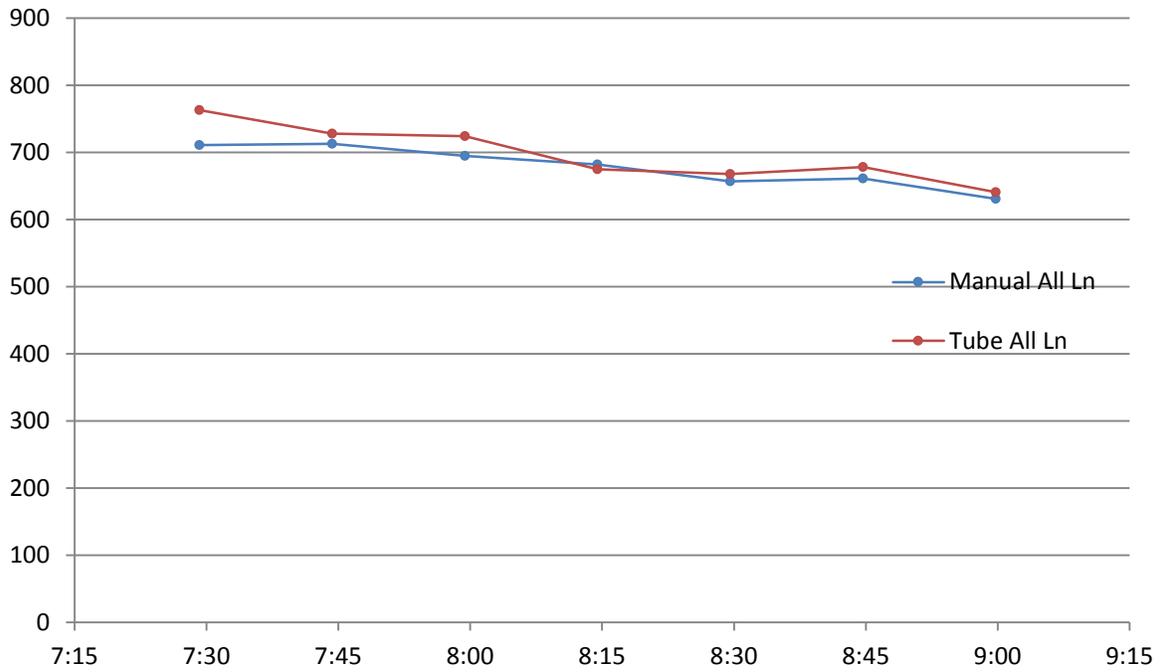


Figure 7: Time Series Plot for Pneumatic Tube Counts Upstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Aggregates over All Lanes

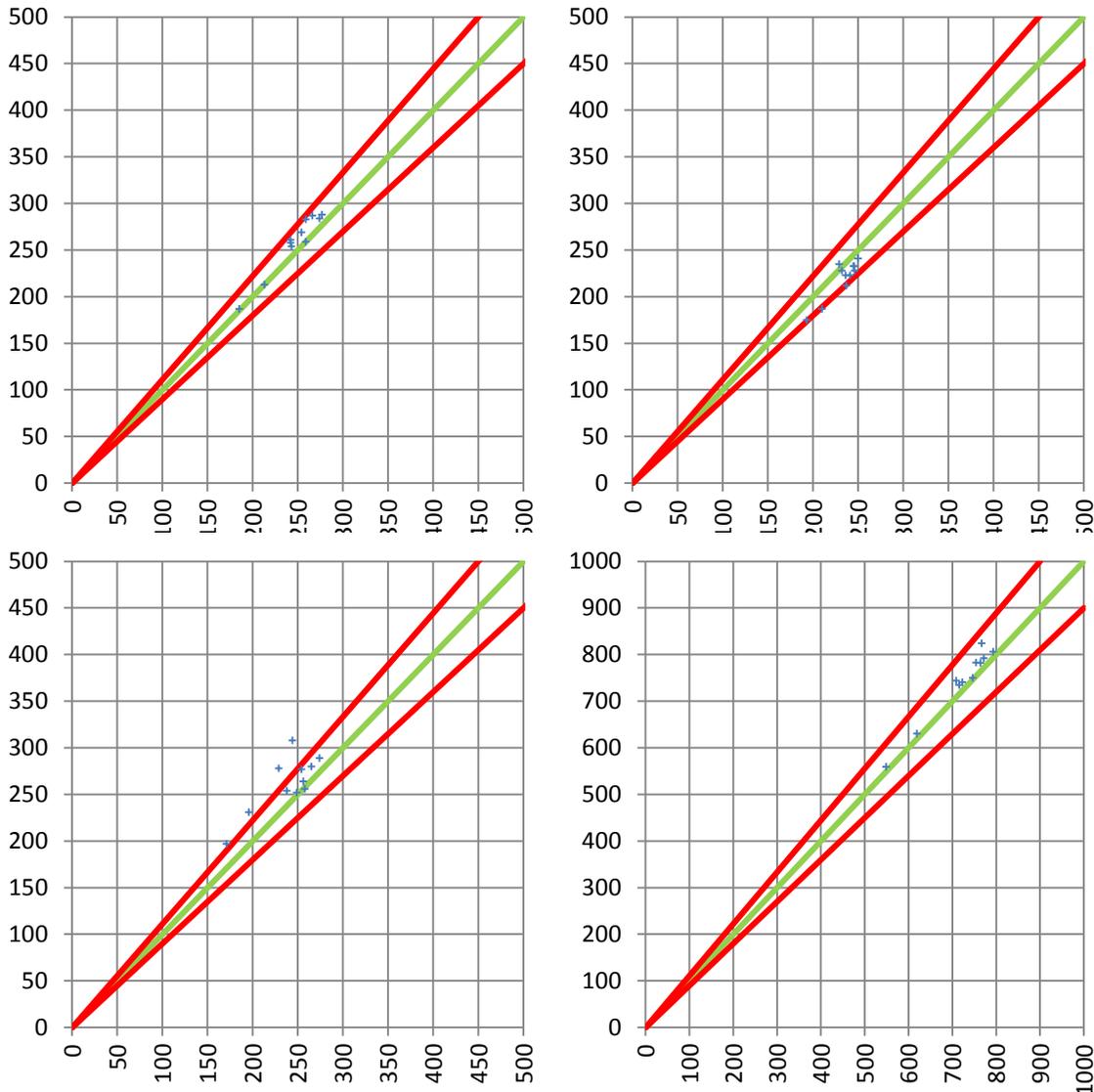


Figure 8: Y-Y Plots for Manual Counts Vs Tube Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 1 (Top-Left), Lane 2 (Top-Right), Lane 3 (Bottom-Left) and Aggregates over All Lanes (Bottom Right)

4.2 Effect of Presence of Turn Lanes

The challenge with obtaining traffic counts close to an intersection instead of at the midblock is with capturing the turning vehicles. If the detection zones are sufficiently upstream of the beginning of the turn lanes, all the vehicles should be accounted for. However, if the detection zones are downstream of the beginning of the turn lanes, a certain percentage (up to 100%) of the turning vehicles will be missed from the counts if the detection zones are solely on the through lanes. The percentage of loss depends on the traffic behavior near the intersection, i.e. whether the vehicles change lanes into the turn lanes before the detection zone or after.

The other potential impact of the presence of high turning volumes (usually evidenced by the presence of turn lanes or bays) is the associated high amount of lane changing. If a significant

portion of the lane changes occur in the detection zone, it could lead to faulty counts (over- or under-counts depending on the wheel path).

The absence of turn lanes did not show a direct relationship with the degree of match between the signal count data with the baseline data. SR 140 at Steeple Chase Drive (Figure 9) was the site with no turn lanes. While the data on the eastbound lanes showed a -5.7% error, the westbound lanes had an error of 0.7%. At the SR141 site at Old Alabama Road (Figure 10), there is a significant amount of traffic on the turn lane, but when the volumes on the through lanes are considered, the error levels are low (-2.6% NB and 0.7% SB). The natural errors in the data stream, for example the under-counts around 1 pm in Figure 11, probably contributed significantly towards the higher error level on the eastbound lanes. At the study sites there is not sufficient evidence of lane changing producing a significant effect on the error levels.

However it was observed that a significant amount (close to 100%) of the turning traffic was missed by the intersection signal detectors. In Figure 12, the signal detectors counts aggregated over the through lanes match up very well with the counts on those two lanes from the pneumatic tube counts. However, if the counts from the signal detectors on the two through lanes was used to represent the entire volume on that section of the road, the counts will be short by more than 15%.

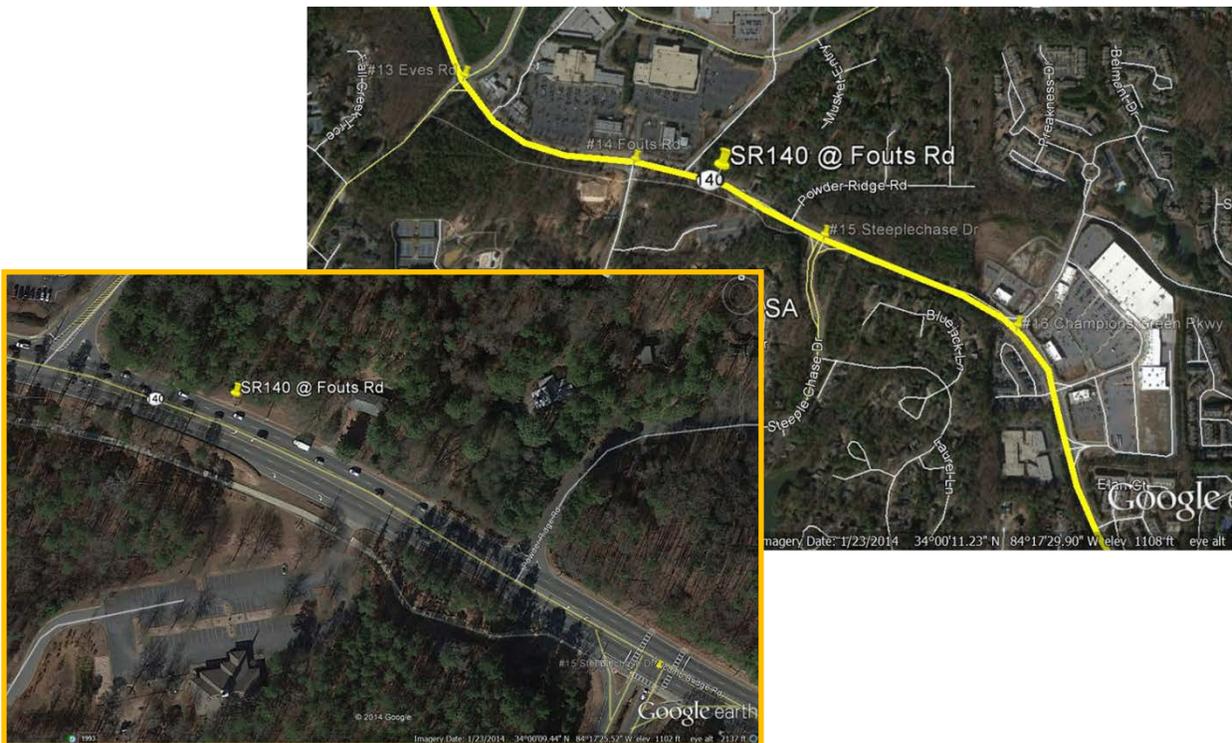


Figure 9: Layout of Test Site Location at Intersection of SR 140 and Steeple Chase Dr; Top: Site Overview; Bottom: Close-up View of Pneumatic Tube Count Site (Image Courtesy: Google Maps)

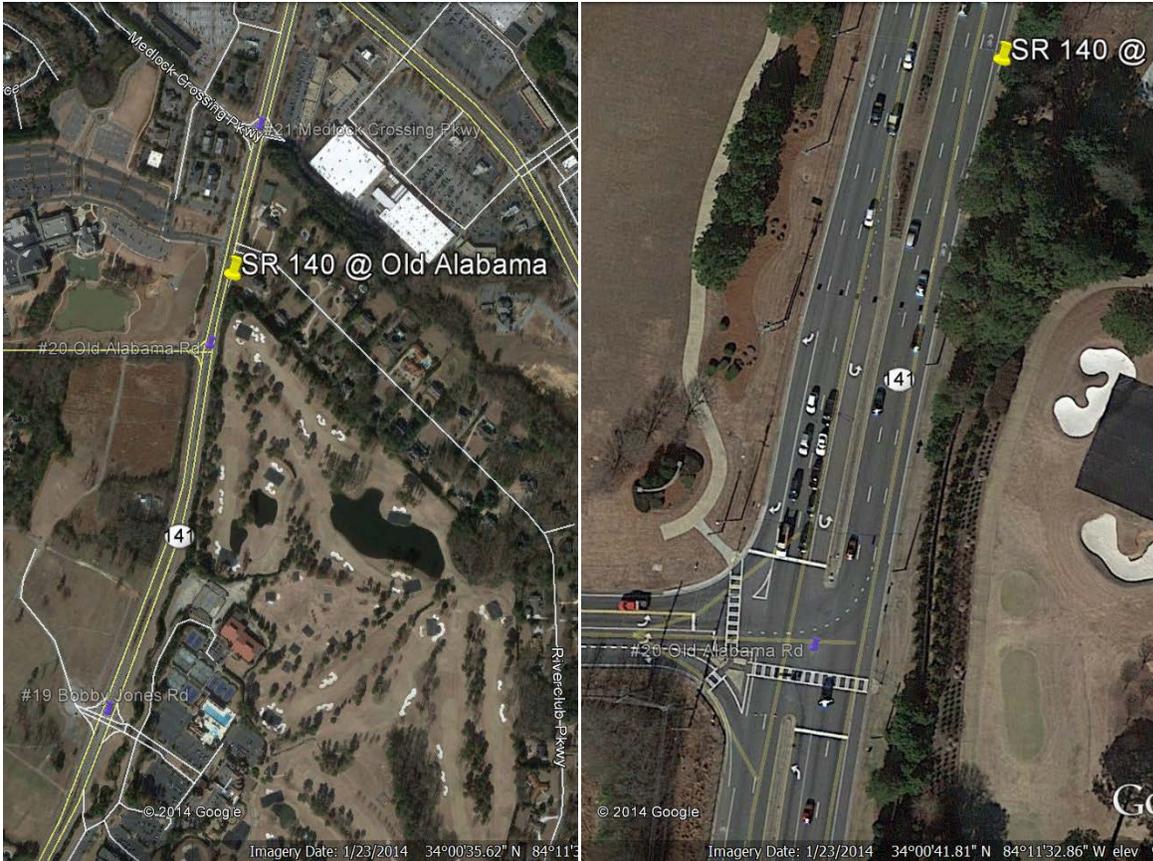


Figure 10: Layout of Test Site Location at Intersection of SR 141 and Old Alabama Road. Left: Site Overview; Right: Detailed View of Turn Lanes (Image Courtesy: Google Maps)

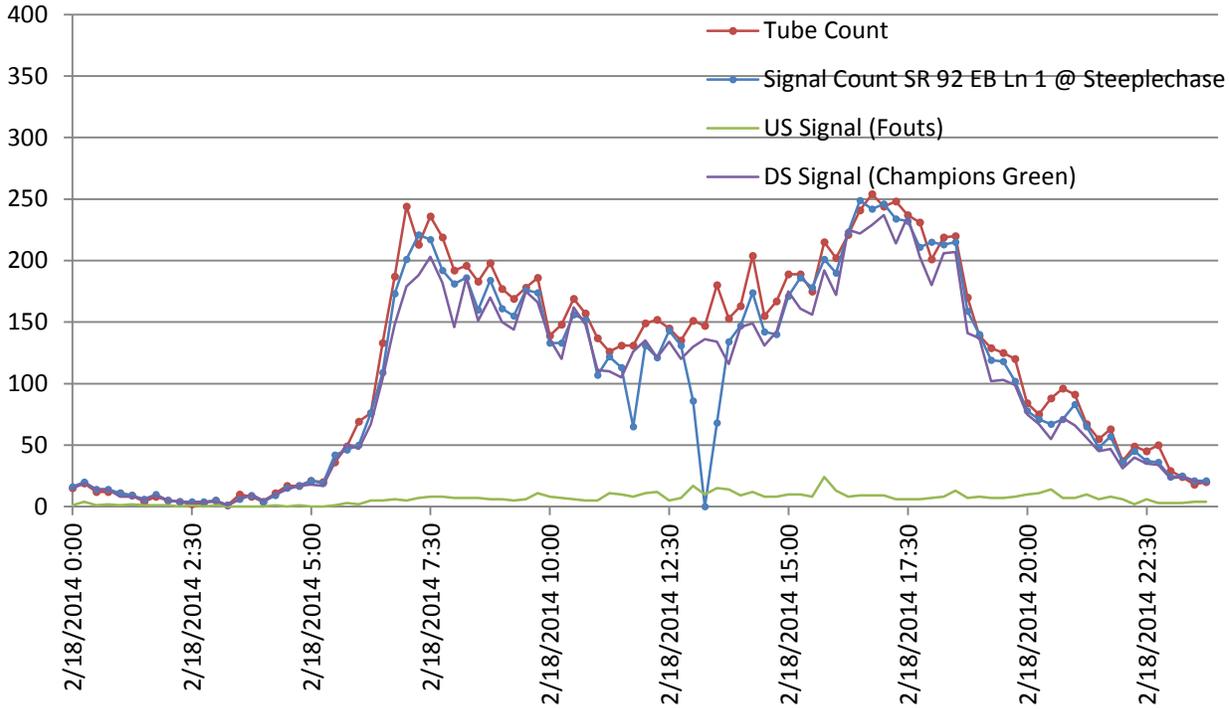


Figure 11: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple Chase Drive for Lane 1

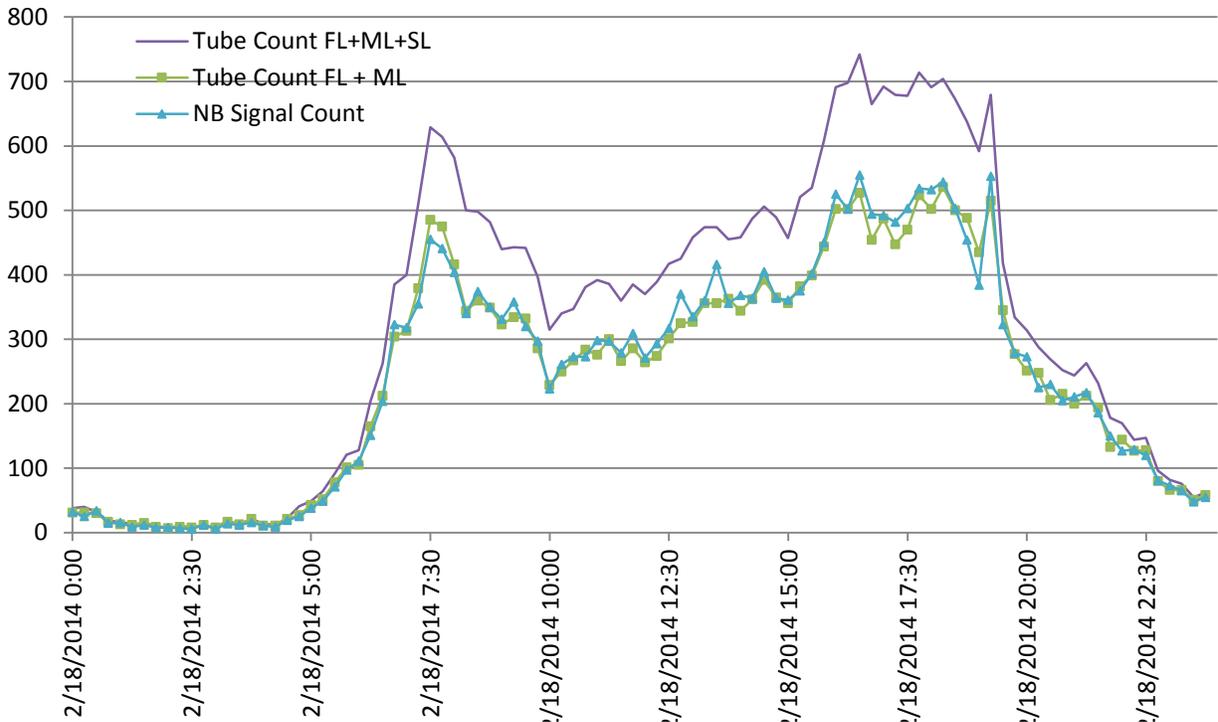


Figure 12: Time Series Plots for Pneumatic Tube Counts and Signal Detectors Counts Aggregated over All Lanes at Intersection of SR 140 NB and Old Alabama Road

4.3 Effect of Lane Changes

While no adverse effect of lane changing was observed at the Old Alabama Road site, some amount of lane changing was observed between the Pneumatic Tube data collection site and the intersection signal detector's detection zone for the study site on SR 92 between Woodlands Parkway and Dials Drive (Figure 13). There is a slight positive bias observed in the Lane 1 counts (Figure 14) while there is a slight negative bias observed in the Lane 2 counts (Figure 15). However, the total counts match quite well (Figure 16). The overall impact of lane changes at this site, where there are no other ingress or egress points between the detection zones is, as expected, minimal.



Figure 13: Layout of Test Site Location at Intersection of SR 92 and Dials Drive (Image Courtesy: Google Maps)

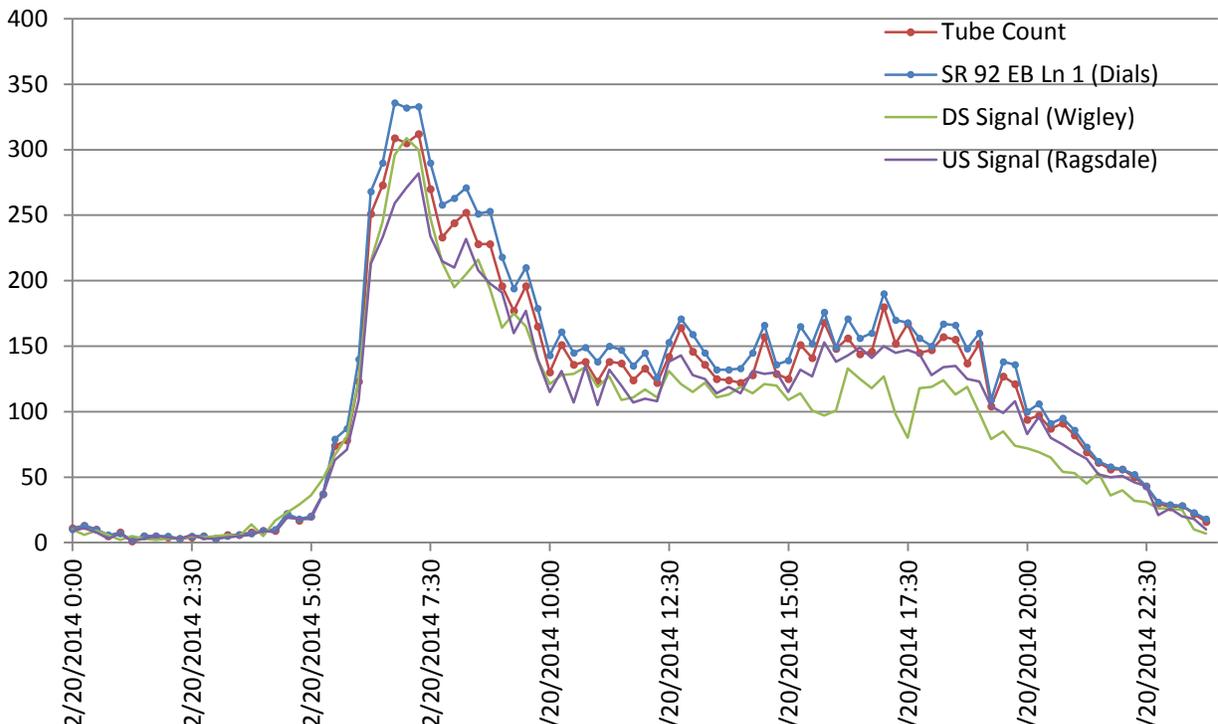


Figure 14: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 1

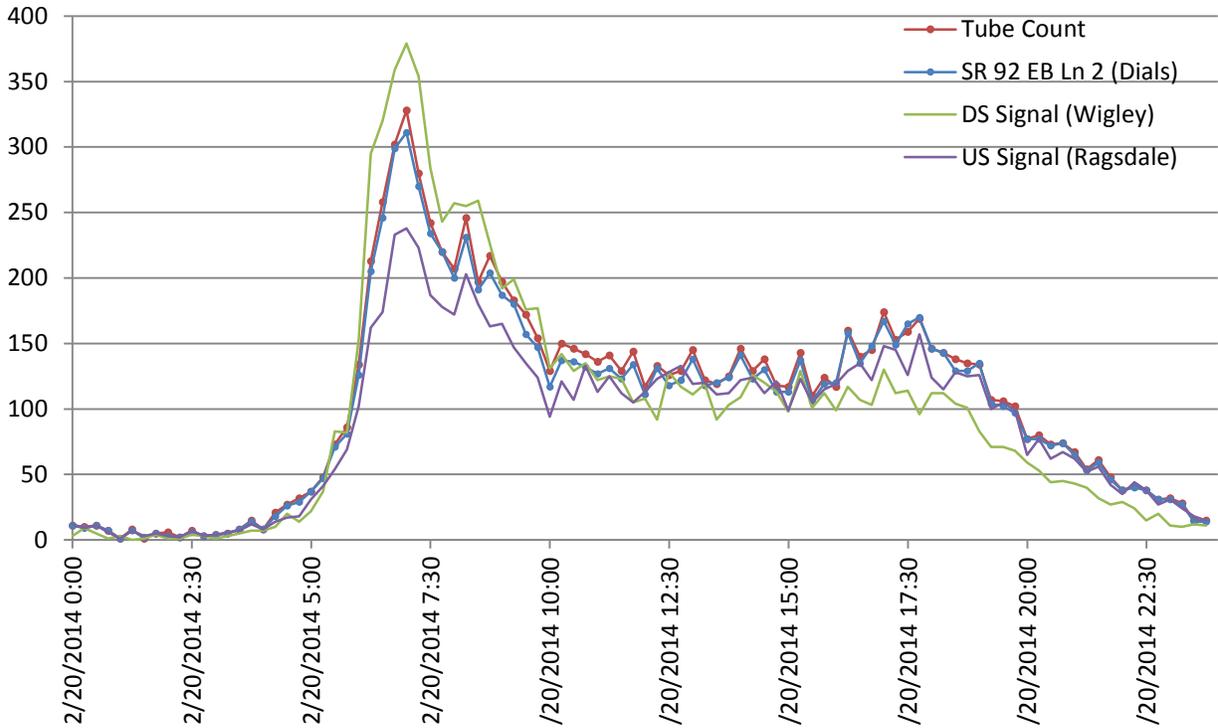


Figure 15: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 2

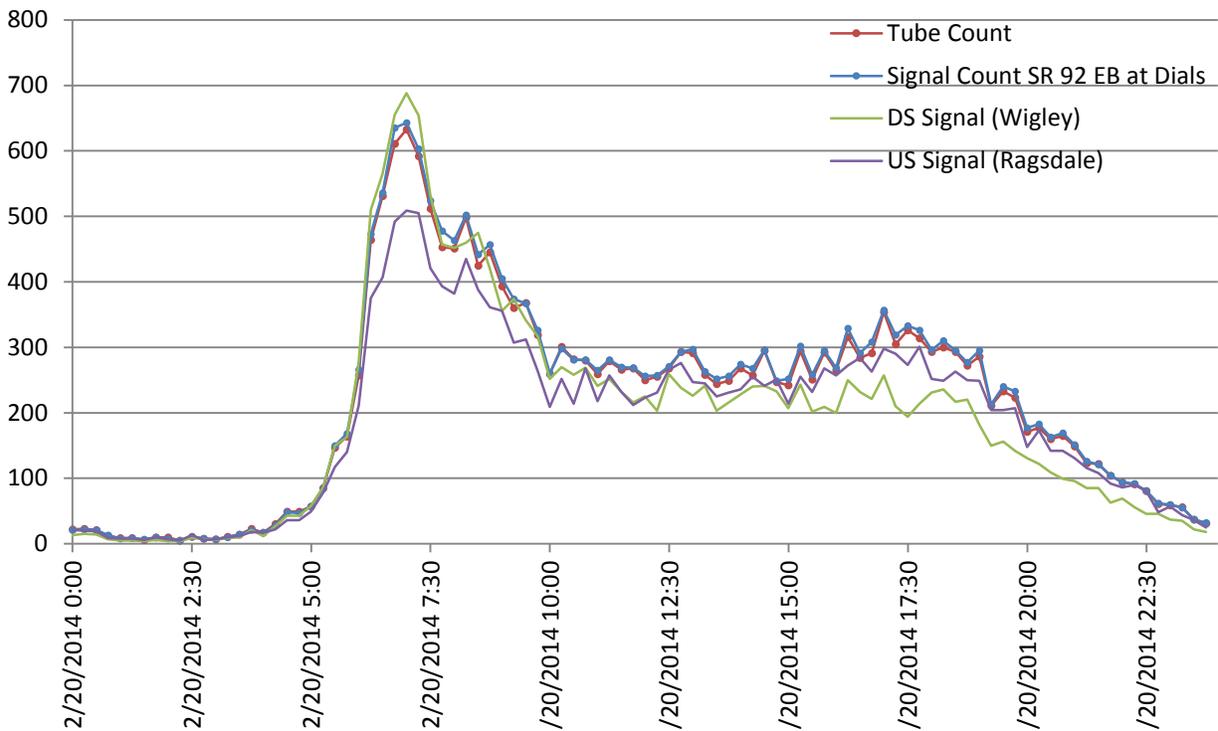


Figure 16: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Aggregates over All Lanes

4.4 Effect of Presence of Other Intersections

There are several ingress and egress points between the Fouts Road and Steeple Chase Drive intersections on SR 92 (Figure 9). The site without any major ingress and egress point between the intersections is SR 92 between Woodlands Parkway and Dials Drive (Figure 13). While the match between the signal detector counts and pneumatic tube counts are very well time-synchronized at the Dials Drive site (Figure 14, Figure 15, and Figure 16), there is some amount of volatility of the differences between the counts at the Steeple Chase Drive site (Figure 11 and Figure 17). The differences in the level of error are clear in the fast lane (7.5% versus 11.1% MAPE at Dial Road and Steeple Chase Drive sites respectively), but not that apparent on the slow lane (3.9% versus 4.1% MAPE).

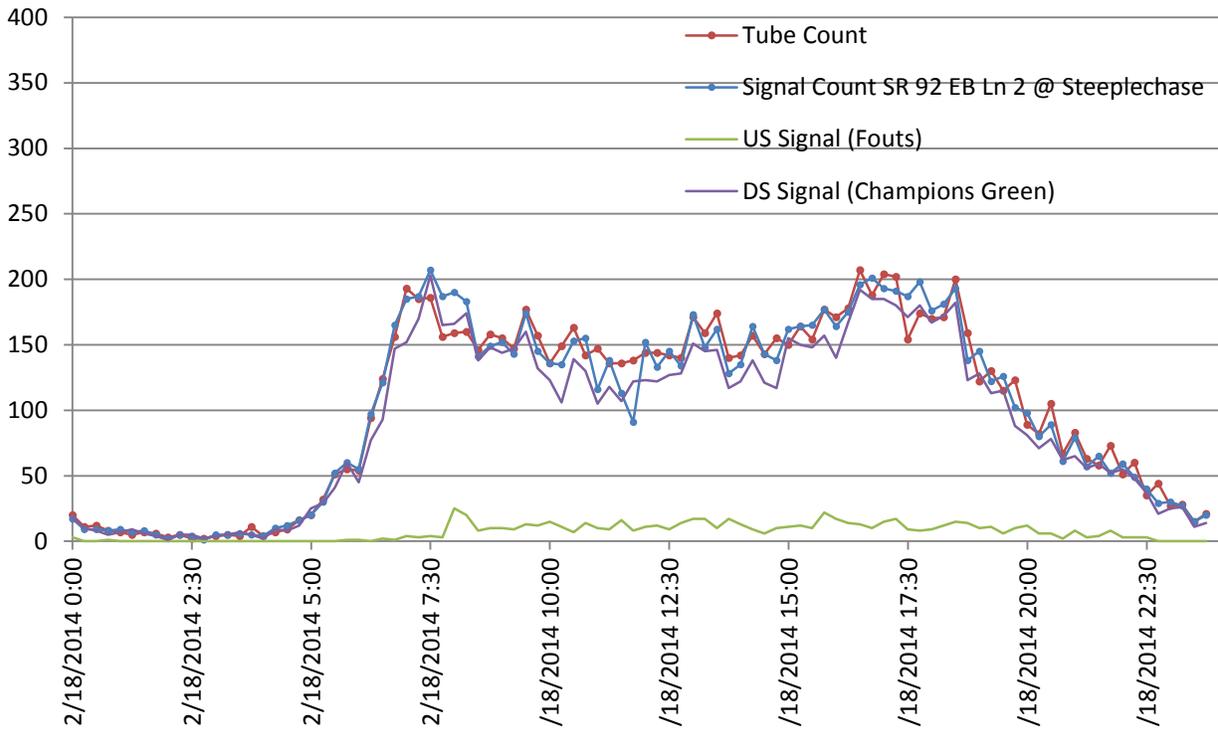


Figure 17: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple Chase Dr for Lane 2

4.5 Effect of Distance between Intersections

The distance between the intersections at the SR 92 site between Woodstock Road and Roswell Crossing is about 900ft (Figure 18) while the distance between the intersections at the SR 92 site between Woodlands Parkway and Dials Drive is about 1450 ft. Both sites are characterized by the absence of any crossroads between the intersections. The site with higher separation (Figure 14, Figure 15, and Figure 16) was expected to have higher variability of the errors, than the site with smaller separation (Figure 19 and Figure 20). But the observed results did not support this hypothesis. This can be explained to some extent by the presence of a right turning lane at the Roswell Crossing intersection as well as the present of a congested intersection (Woodstock Road) in close proximity, which could have negatively affected the data quality at the Roswell Crossing intersection.

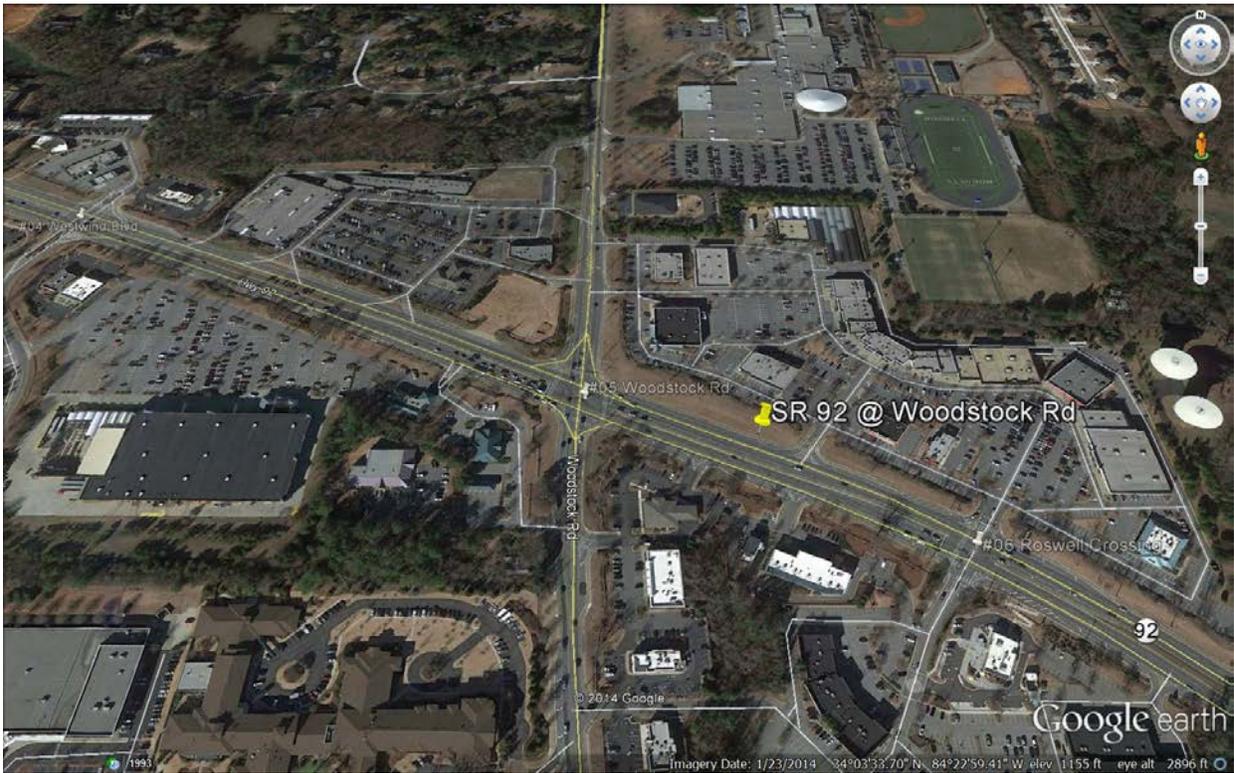


Figure 18: Layout of Test Site Location at Intersection of SR 92 and Roswell Crossing (Image Courtesy: Google Maps)

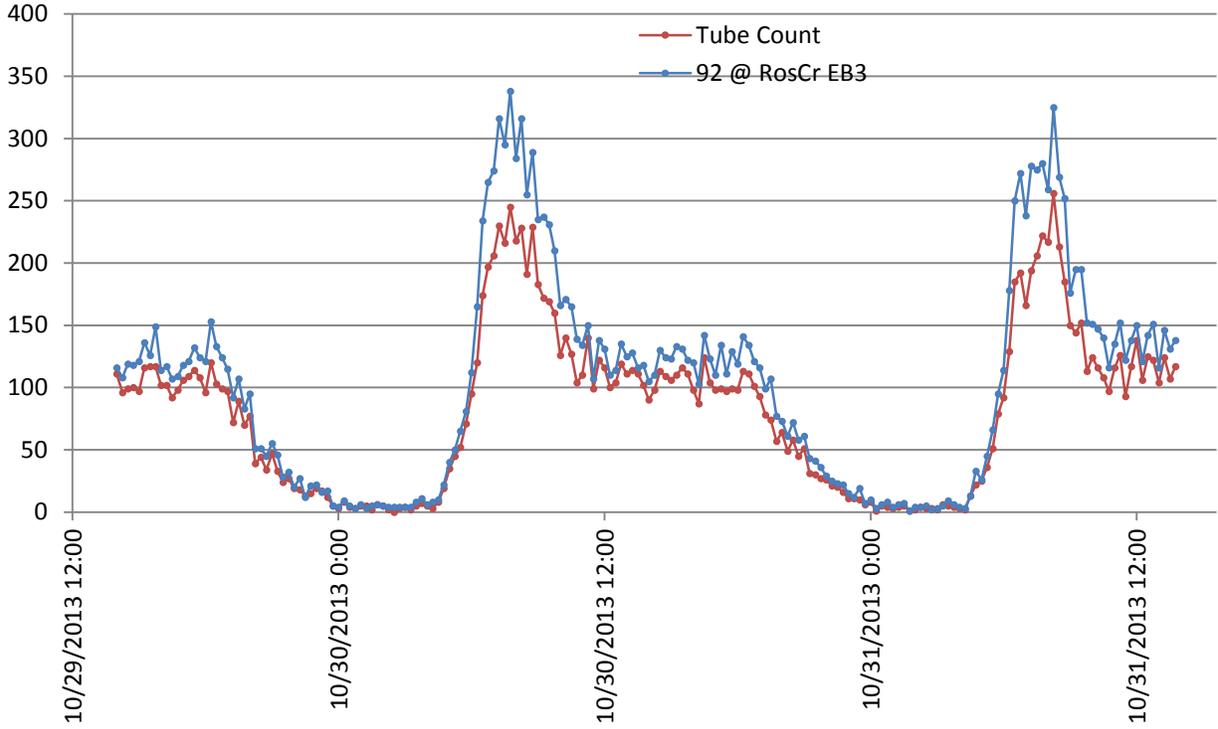


Figure 19: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 3

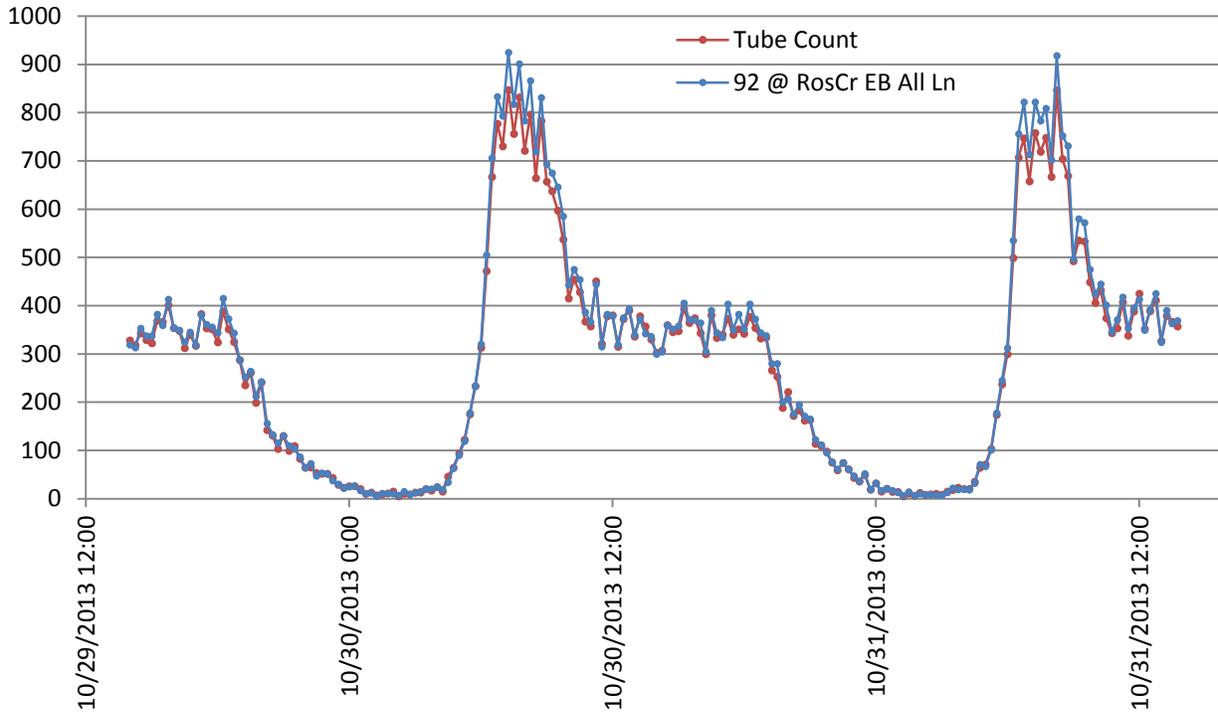


Figure 20: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Aggregates over All Lanes

4.6 Effect of Volume

4.6.1 Intersections without Queuing

4.6.1.1 SR 92 at Roswell Crossing

As explained in section 3.1, there were some anomalies observed at a high volume site during the pilot study. This prompted an oversampling of the high volume sites. The SR 92 intersection at Roswell Crossing was adjacent to the congested Woodstock Road intersection. But this signal had a higher amount of green time on SR 92 and therefore experienced very little queuing in the eastbound direction where it is downstream of the Woodstock Road intersection. On the eastbound approach the intersection signal counts matched up very well with lanes 1 and 2 of the pneumatic tube counts (Figure 21). However, the counts on lane 3 (Figure 19) did not match up too well. It is possible that the right turning traffic from Woodstock Road might have caused the queue on the slow extend up to the detection zone under heavy traffic conditions. While the mean percentage error over all lanes was 4.3% (Figure 20), the mean percentage error on the slow lane was 24.3%. Comparison with the pneumatic tube counts downstream of the intersection (Figure 22) yielded a mean percentage error in the same range (21.7%).

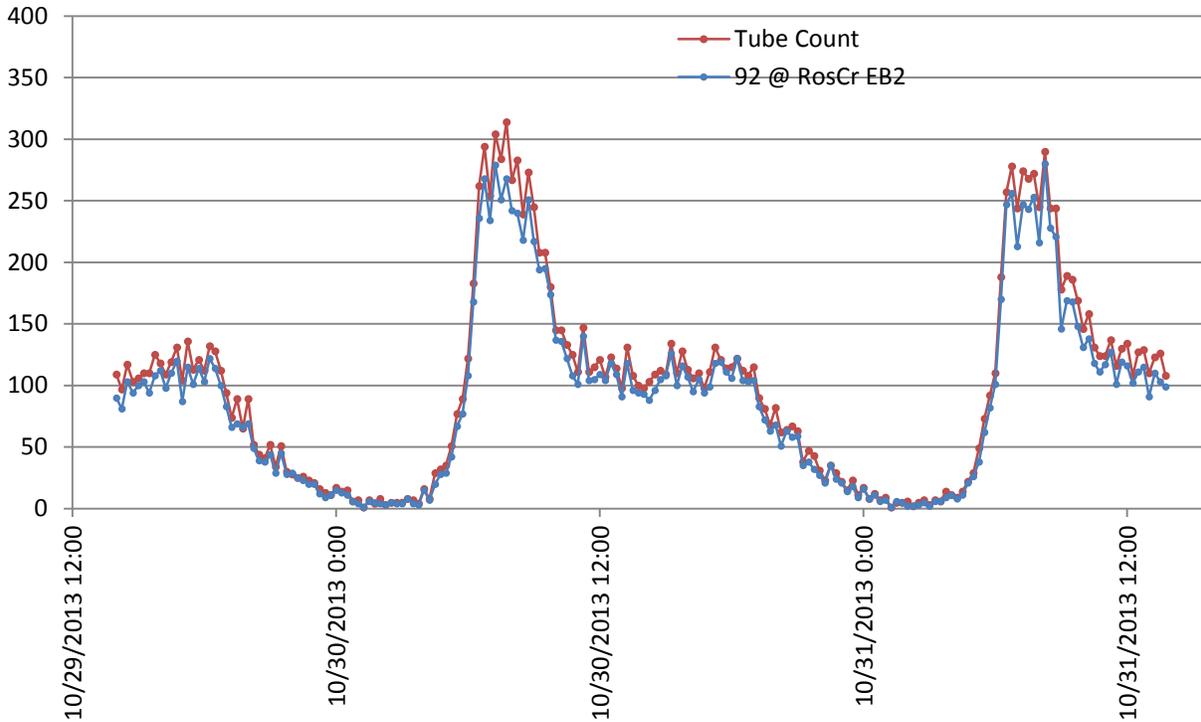


Figure 21: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 2

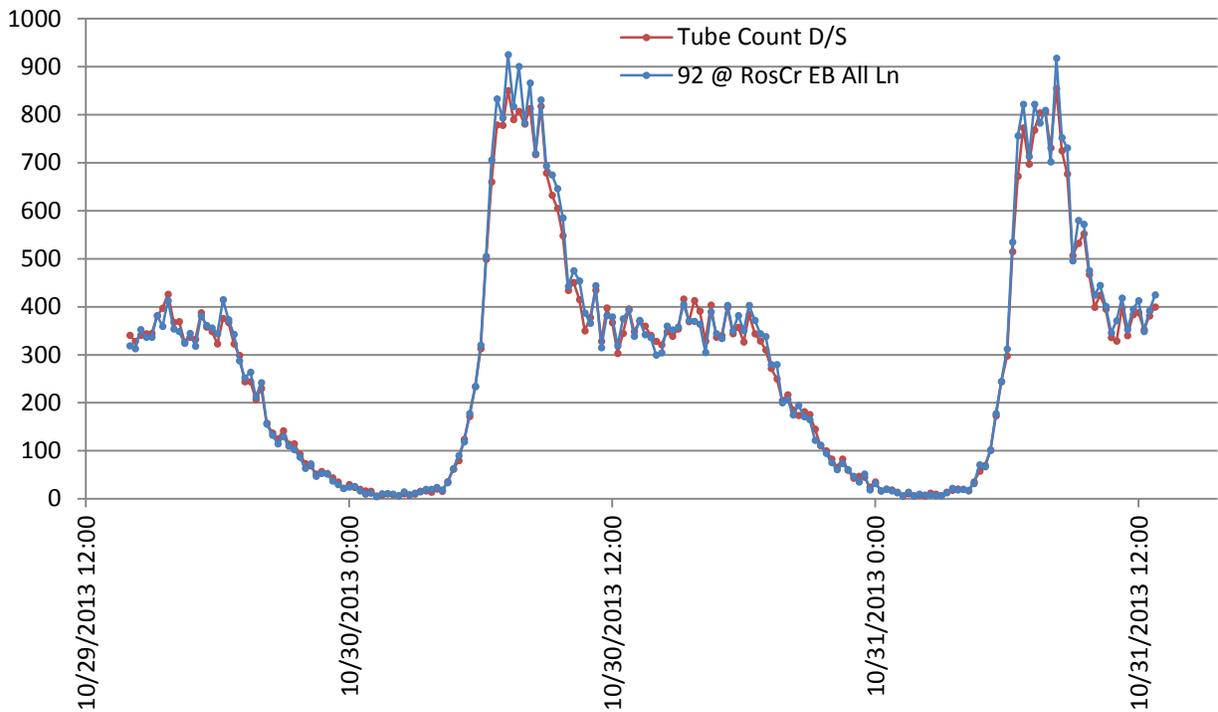


Figure 22: Time Series Plot for Pneumatic Tube Counts *Downstream of Intersection* and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Aggregates over All Lanes

4.6.1.2 SR140 @ River Exchange Parkway

The results at another high volume site, SR 140 at River Exchange Parkway (Figure 23), showed some undercounting under high volume conditions in a few instances (Figure 24 and Figure 25). But the overall aggregate mean percentage error was in a range of -9.7% to 4.4%.

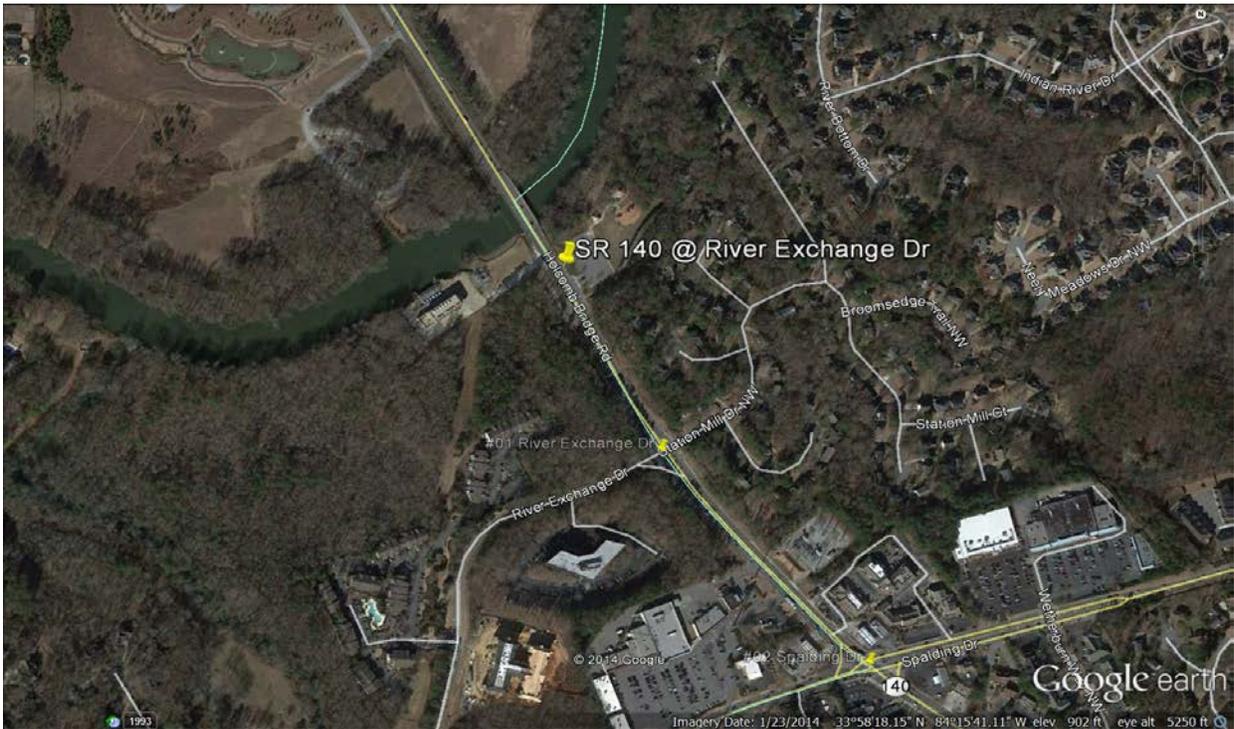


Figure 23: Layout of Test Site Location at Intersection of SR 92 and Roswell Crossing (Image Courtesy: Google Maps)

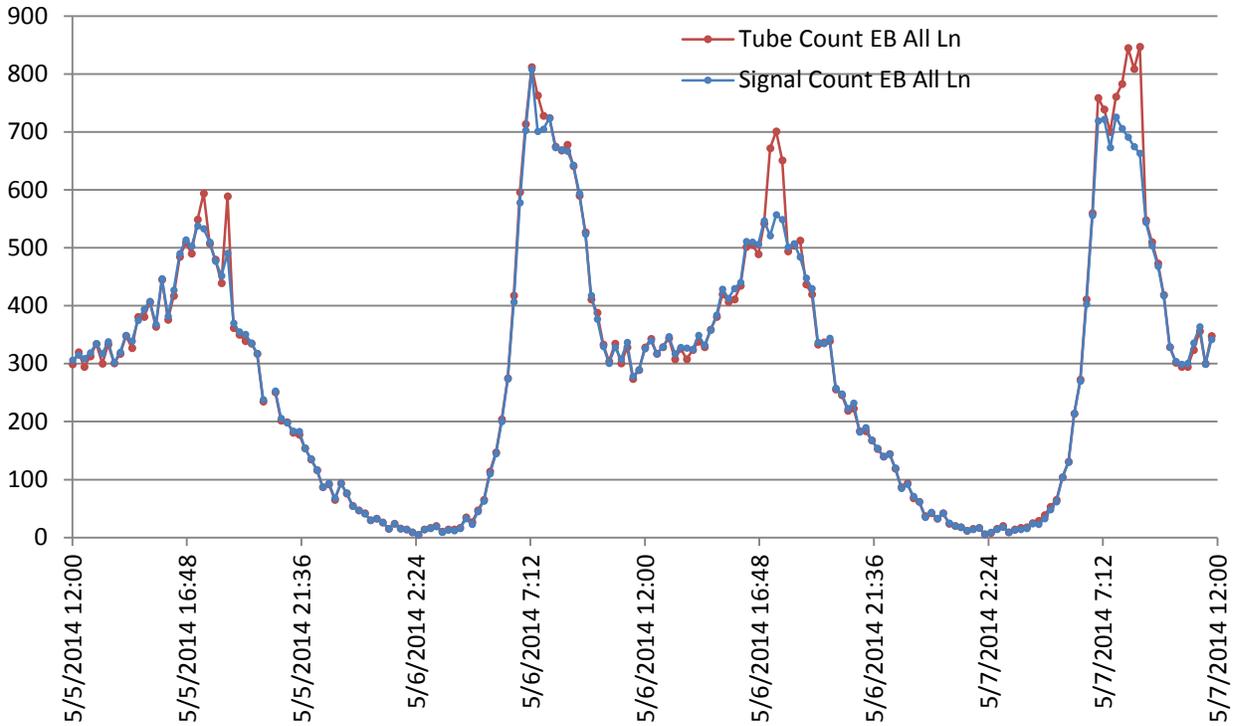


Figure 24: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Aggregates over All Lanes

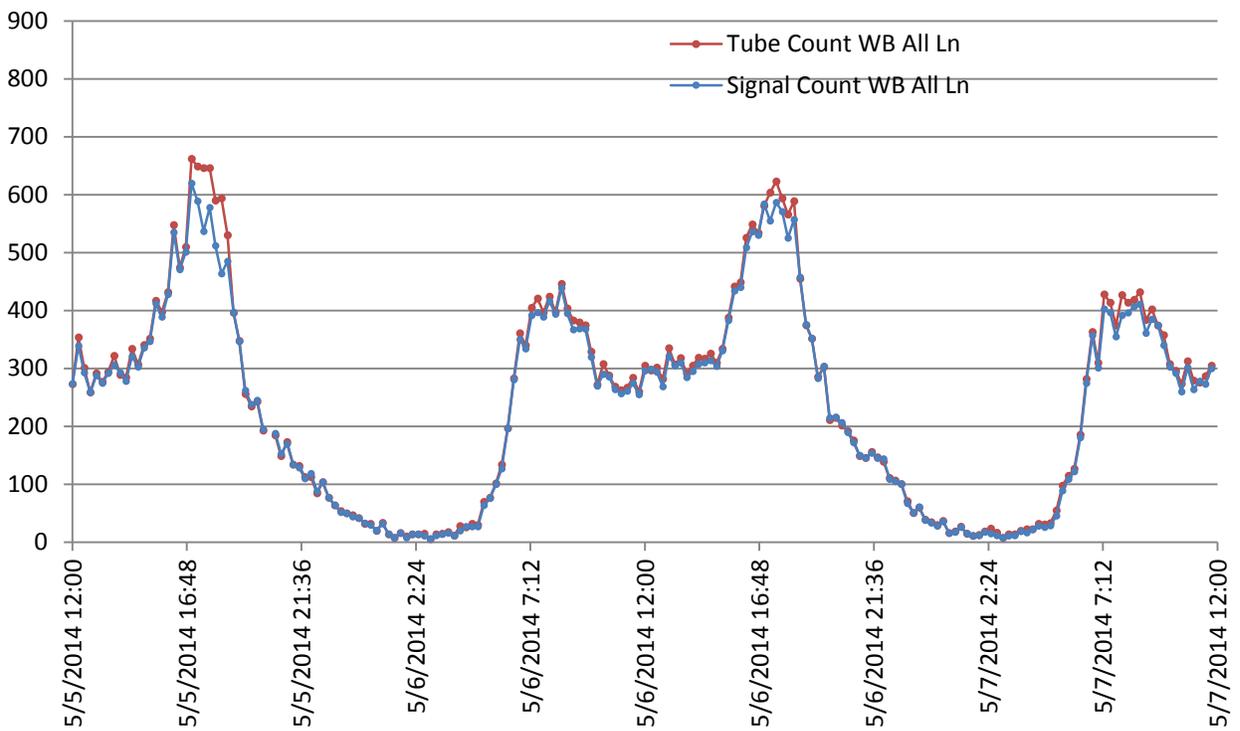


Figure 25: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes

4.6.2 Intersections with Queuing

The spikes in the data under congested conditions that can be observed in Figure 26 are observed in all three lanes at this site. Figure 27 shows a three way comparison of manual counts, pneumatic tube counts and signal detector counts and shows that the errors in the signal detector counts here are much larger than the error bounds of the pneumatic tube count data. Figure 28 shows that the errors are compounded when the data is aggregated across lanes.

If a basic filter using a threshold of 350 vehicles per 15-minutes per lane (translating to 1400 vehicles per hour per lane) is used to smooth out the spikes in the data, the data appears to get rid of the high volume spikes as shown in Figure 29. However, the entire afternoon peak periods record volumes significantly higher than the baseline counts. While the extremely high spikes are easy to identify, the dataset also includes over-counts that are too high and are difficult to identify and eliminate. If a per-vehicle-record based data stream is available, it might be possible to design a filter to completely eliminate the erroneous volumes, but it is difficult to eliminate such faulty data from the 15-minute aggregates.

Several other high volumes sites such as SR 92 at River Exchange Parkway were also studied (section 4.3.1) and volumes above 250 vehicles per 15-minute period per lane were observed, but evidence of these spikes in volumes were not seen. It is hypothesized that the erroneous volumes are a result of queuing over the induction loop detectors and compounded by some calibration issues.

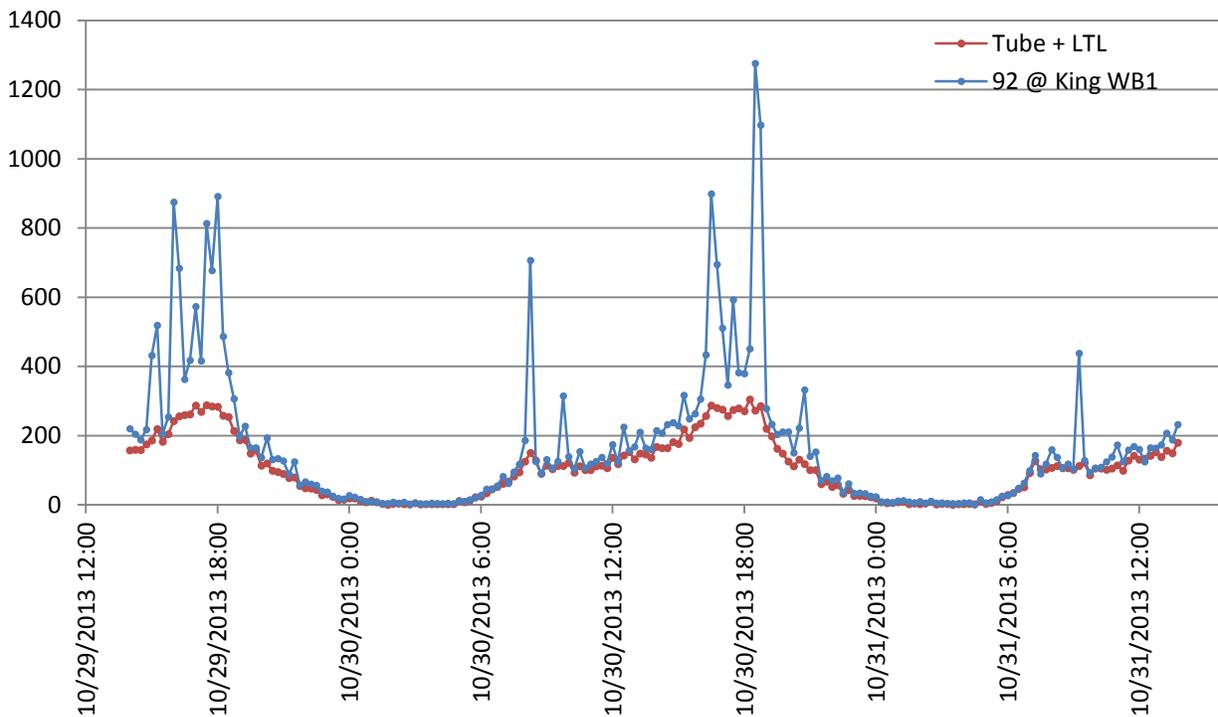


Figure 26: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 1

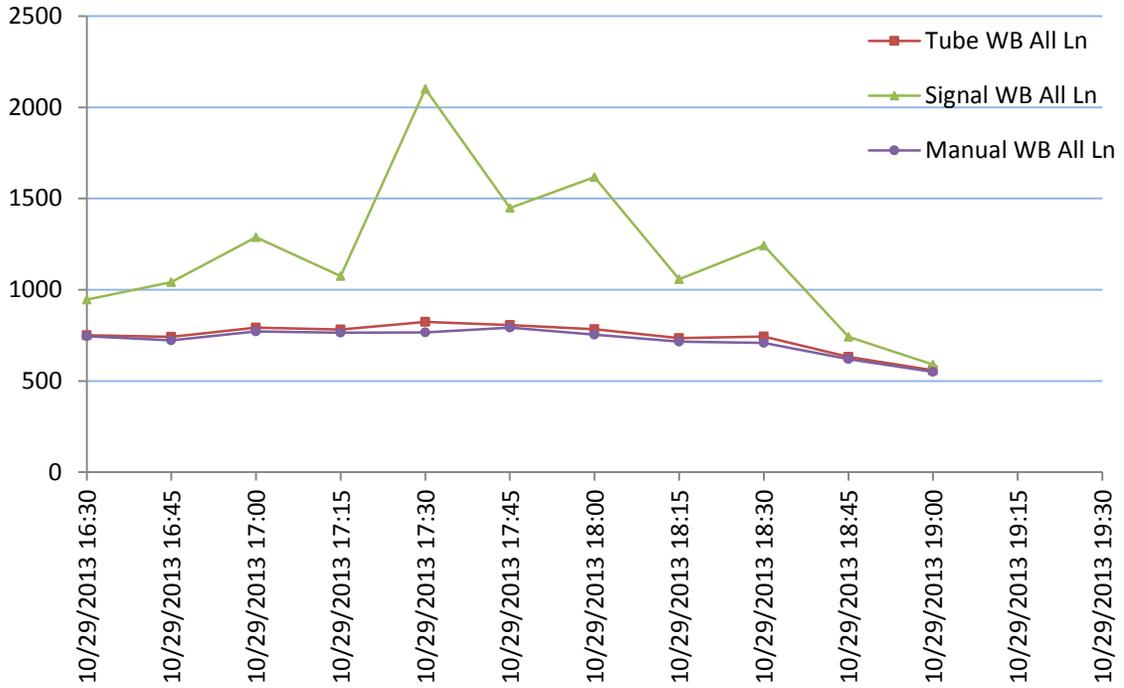


Figure 27: Time Series Plot for Manual Counts, Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Aggregates over All Lanes

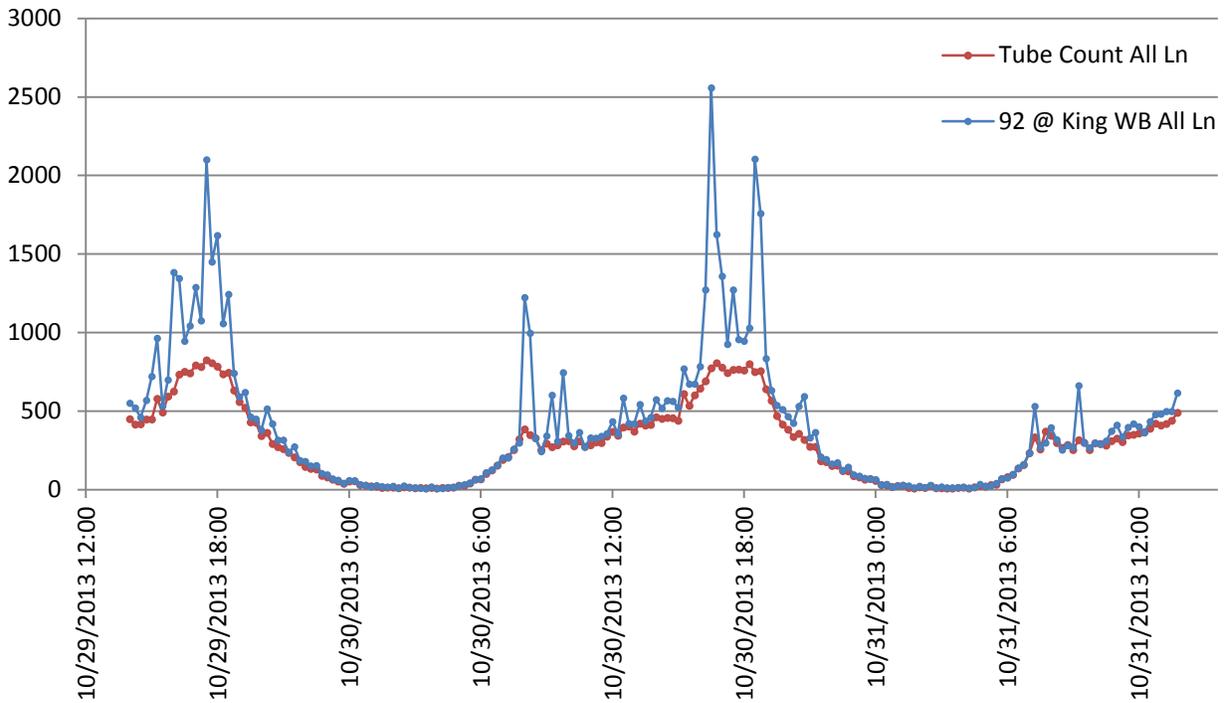


Figure 28: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes

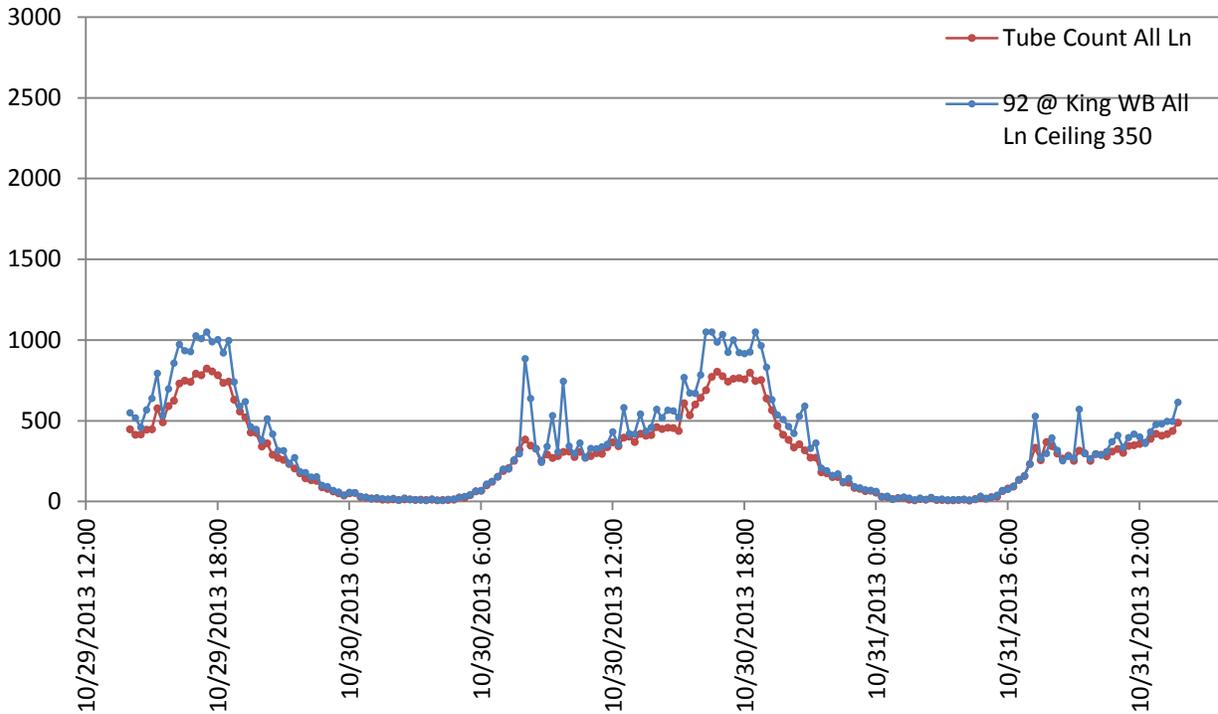


Figure 29: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes with Count Ceiling per lane at 350 vehicles

4.6.3 Low Volume Road

SR 314 near Banks Road and Creek Wood Trail was a low volume road study site (Figure 30). This site experienced some connectivity issues leading to data losses in the intersection signal data stream. The available data, matched very well with the pneumatic tube counts. The pneumatic tube counts were matched with the upstream signal counts as well to investigate if, under these low volume conditions, detection from a single intersection can be used instead of requiring a pair of intersections with available data. While Lane 1 upstream data matched very well (Figure 31), the Lane 2 upstream data match was not good (Figure 32), possibly due to differences caused by turning vehicles at the intersection.



Figure 30: Layout of Test Site Location at Intersection of SR 314 and Banks Road (Image Courtesy: Google Maps)

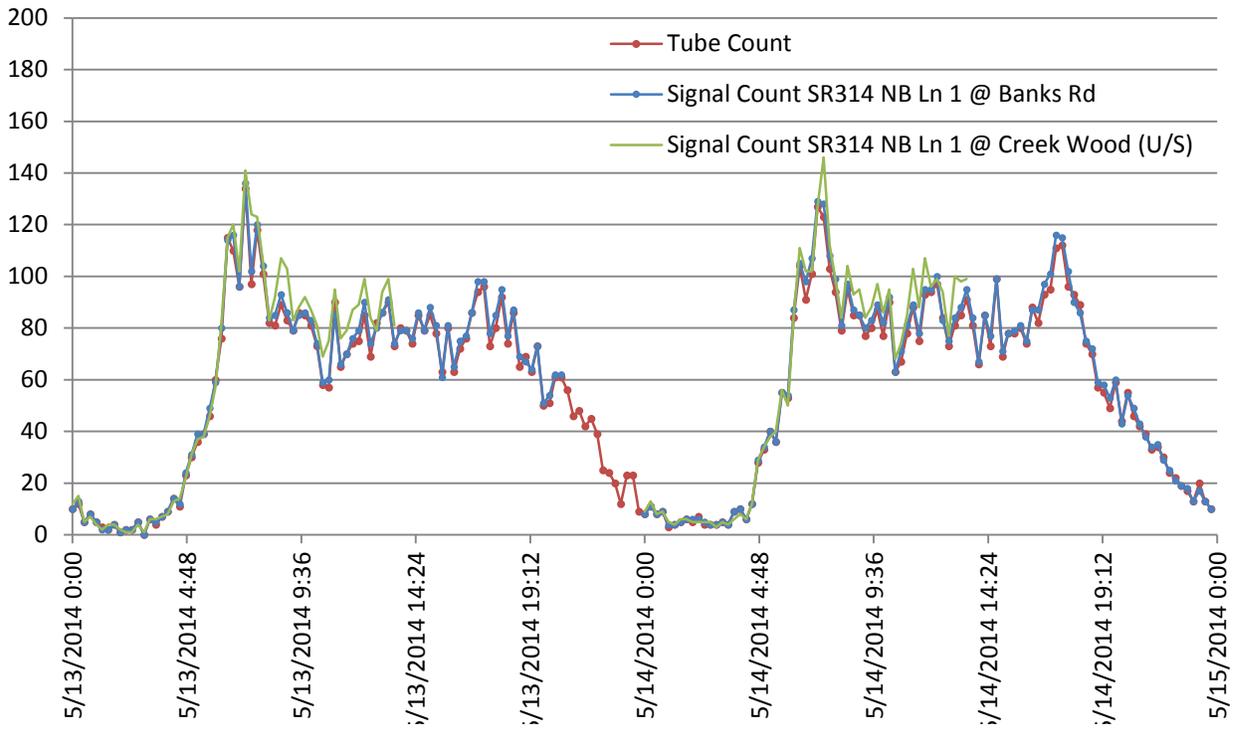


Figure 31: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 1

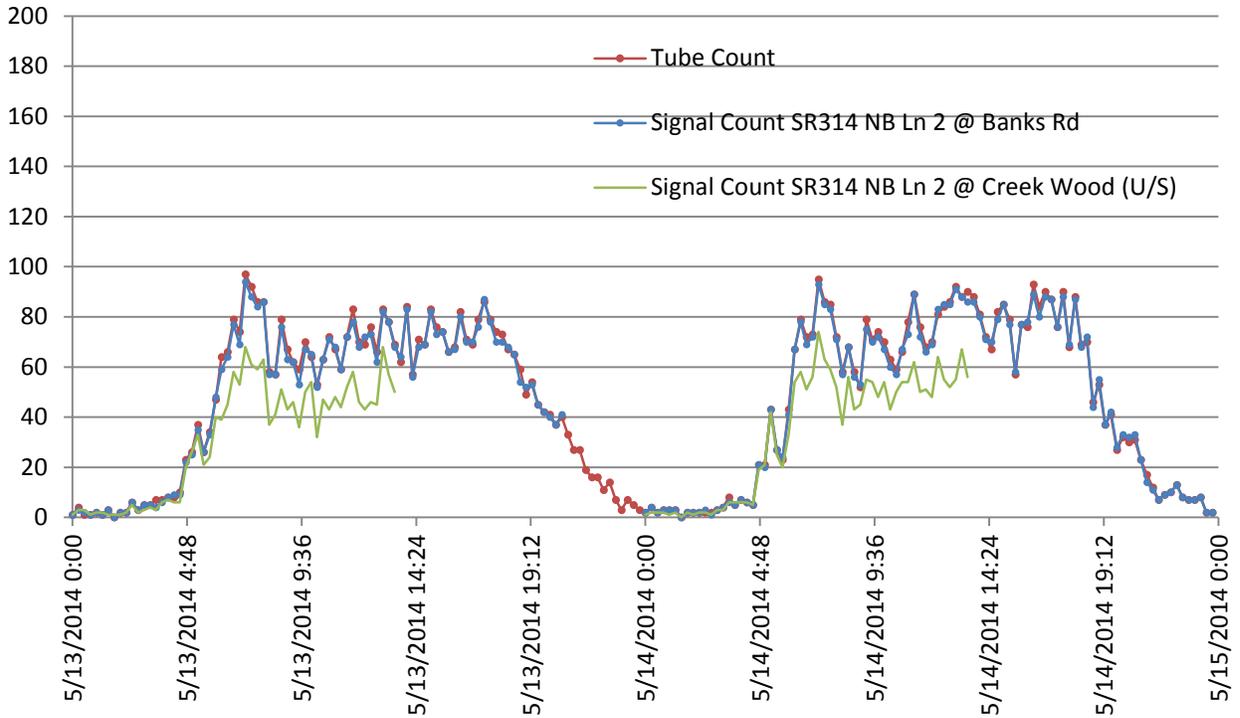


Figure 32: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 2

4.7 Effect of Detection Technology

Most of the intersections in the region have induction loop based detection. There are a handful of intersections with Video Detection System based detection. Typically, intrusive technologies such as induction loops have a higher level of accuracy of vehicle count data than video detection systems that are easily affected by external factors such as shadows, precipitation, wind and vehicle induced vibration of the camera. In this study, the accuracy of counts from a video detection system installed at the intersection of SR 237 and SR 141 (Figure 33) was tested against manual counts. The manual counts were extracted using the same video feed that was used by the video detection system. The camera is installed on the signal pole across the intersection. The detection zones are set up past the stop bar, which ensures the vehicles are moving (except in case of a gridlock) when they cross the detection zone, and thereby provides higher accuracy of detection.

The accuracy test had two major limitations:

- Given the resource intensive nature of the manual data reduction of the videos that were of low quality (Figure 34), the test was limited to a single approach (SR 141 EB) and a single morning peak period.
- The only adverse condition that was tested was the transition in lighting conditions (dawn). The other condition that might have been tested is camera vibration due to heavy vehicle traffic, but any movement of the camera was not noticeable in the observed video. Effects of precipitation, high wind, shadows etc. were not tested in this study.

As seen in Figure 35, Figure 36, and Figure 37 the errors were low except in two time periods on the middle lane. The video detection system was configured to detect vehicle counts on only three of the lanes. The left turning vehicles were not counted and are therefore unaccounted for (Figure 37). Discounting the left turn lanes, the mean percentage errors on the other three lanes were in the range of 2.6 to 11.8%.

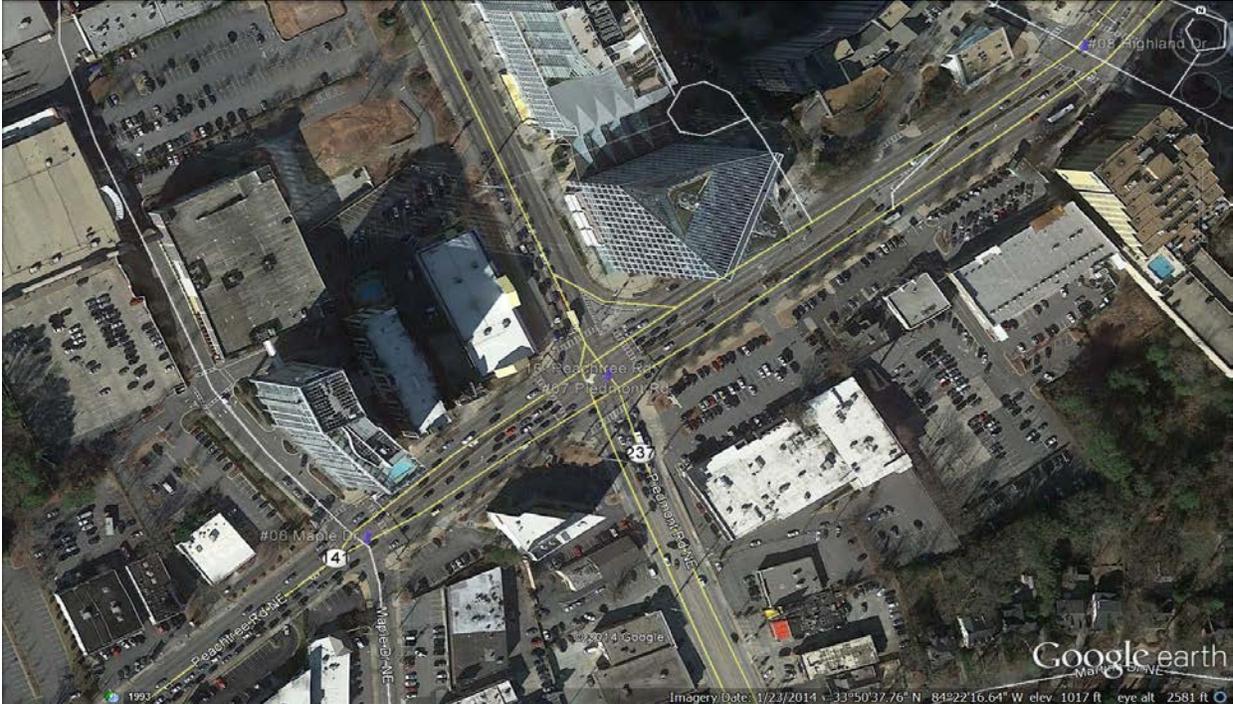


Figure 33: Layout of Test Site Location at Intersection of SR 237 and SR 141 (Image Courtesy: Google Maps)



Figure 34: Layout of Detection Zones for Tablet based Manual Counts on video at Intersection of SR 237 and SR 141 (Image Courtesy: Google Maps)

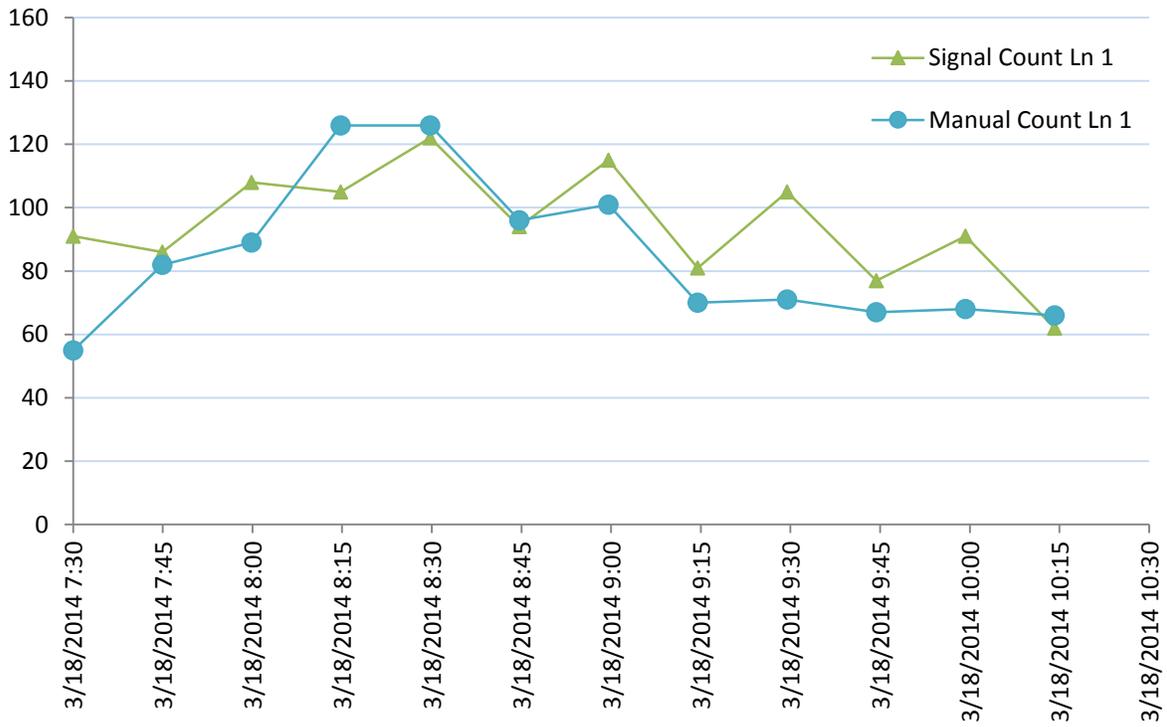


Figure 35: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for Lane 1

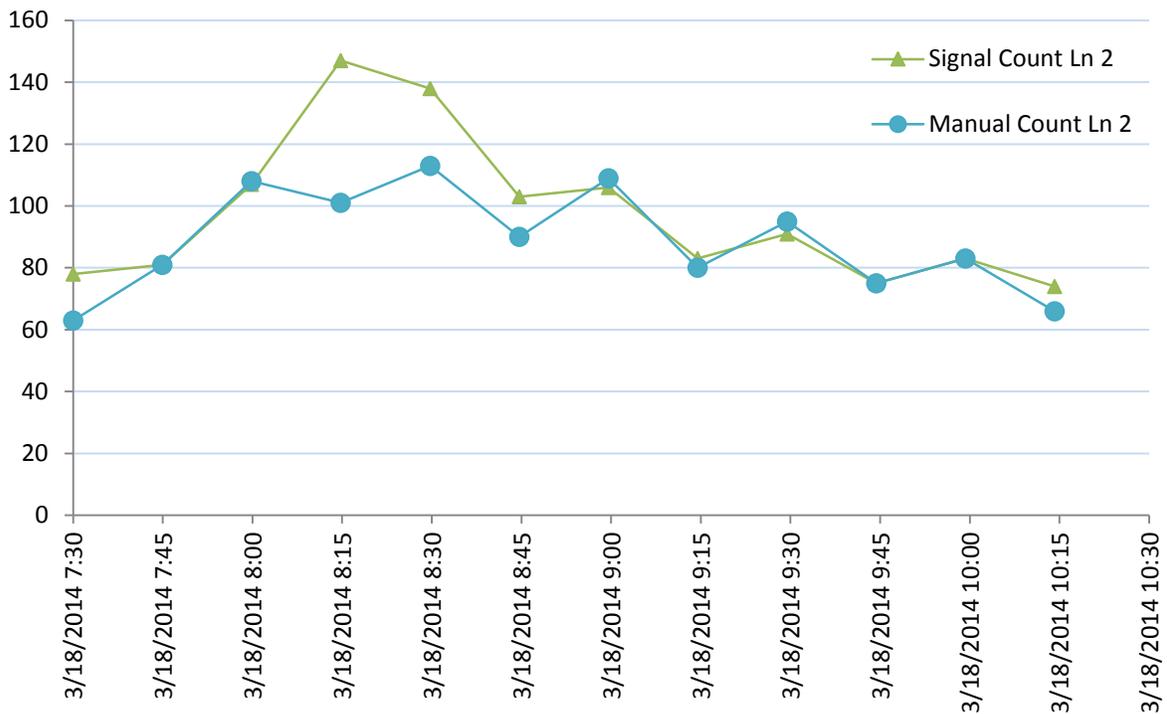


Figure 36: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for Lane 2

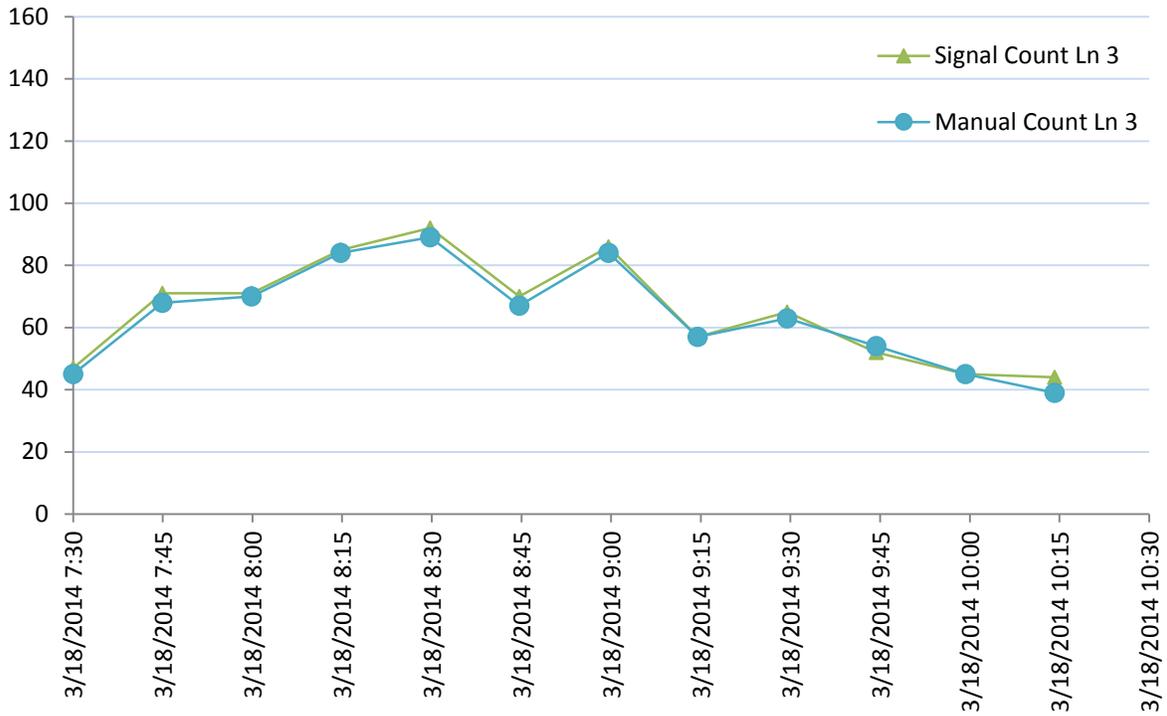


Figure 37: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for Lane 3

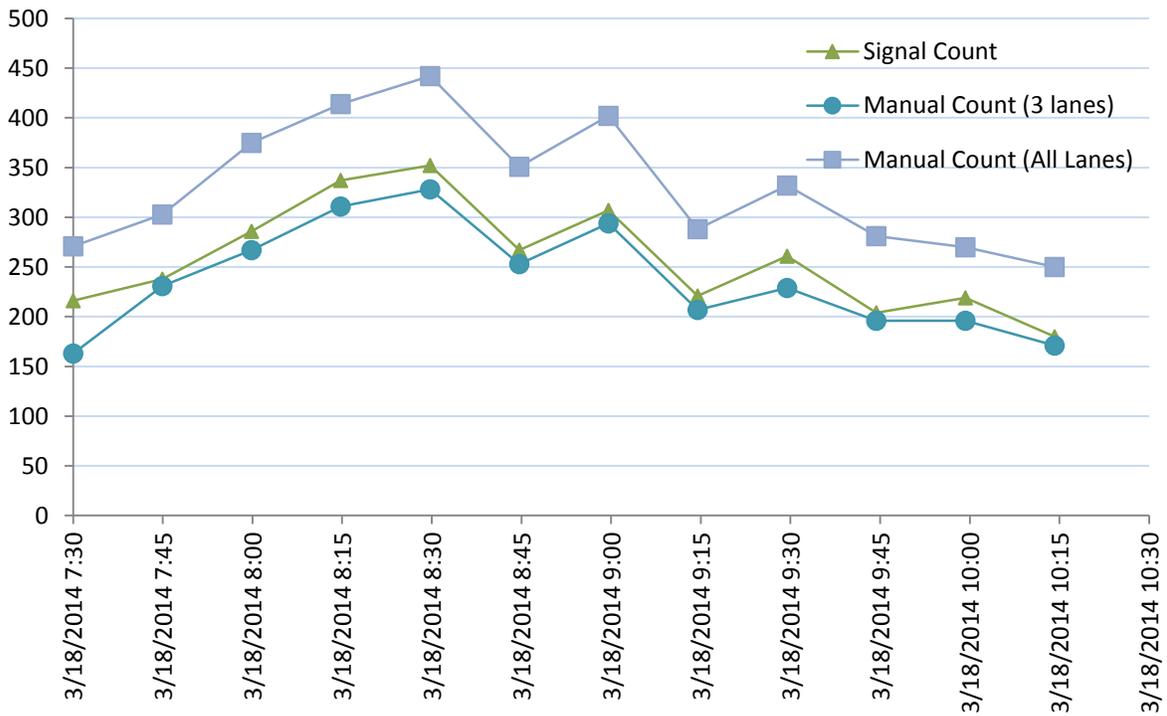


Figure 38: Time Series Plot for Manual Counts and Signal Detector Counts at Intersection of SR 237 and SR 141 for 3 Through-Lanes and All 5 Lanes Including Left Turn Lanes

4.8 Summary of Results

The results of the comparative tests at all the study sites are provided in Table 2. Table 2 provides, at a lane-by-lane level, the mean percentage errors, the 95% confidence interval around the mean percentage errors, the mean absolute percentage errors and root mean square percentage errors. The following are the major observations:

- The pneumatic tube counts, which were used as the baseline counts for the rest of the comparisons, were within 10% of the manual counts at lane-by-lane level comparison of 15-minute aggregates. The manual counts were treated as ground truth in this study.
- Intersection signal detector counts matched closely with the tube counts, with the 95% confidence intervals of the mean percentage errors within 10%. The errors increased significantly under high volume conditions where it is likely that the vehicle queues extended over the induction loop detection zone, causing over-counting under these conditions.
- One of the sites, SR 141 at East Jones Bridge, showed high differences between the intersection signal counts and the pneumatic tube counts. Comparison with the upstream and downstream detectors (time series plots available in the appendix) indicated that the adjacent intersection signal counts matched quite well between themselves but were all different from the pneumatic tube counts. Since the validity of the pneumatic tube counts at this site could not be verified after the fact, conclusions were not drawn based on data at this site. The magnitude of difference has been provided in the summary table, but should not be interpreted as error level for the intersection signal detector data in this instance.
- Higher level of variability of differences was observed in the lane level counts than the aggregate over all lanes counts. Part of this can be explained by the possible lane changes between the spatially separated detection zones of the pneumatic tube counters and the intersection signal detectors.
- Detector malfunctions were noticed at some locations such as the SR 140 and Fouts Road intersection
- It was observed that in several cases, the detection zones of the intersection signal detectors were downstream of the beginning of the turn lanes. It was confirmed in the comparisons that this causes severe undercounting in these scenarios because the turning vehicles are not accounted for.

Table 2: Summary of Percentage Errors

Location	Direction	Lane	Evaluated Count	MPE	Lower 95%	Upper 95%	MAPE	RMSPE
SR 140 @ River Exchange Dr	EB	Fast	Signal	1.9%	4.0%	-0.2%	8.0%	14.8%
SR 140 @ River Exchange Dr	EB	Slow	Signal	-5.2%	-4.0%	-6.4%	5.4%	10.1%
SR 140 @ River Exchange Dr	EB	All	Signal	-4.3%	-1.3%	-7.3%	3.6%	9.9%
SR 140 @ River Exchange Dr	WB	Fast	Signal	4.4%	5.4%	3.4%	5.6%	8.3%
SR 140 @ River Exchange Dr	WB	Slow	Signal	-9.7%	-7.8%	-11.6%	9.8%	16.6%
SR 140 @ River Exchange Dr	WB	All	Signal	-7.6%	-5.4%	-9.7%	3.7%	7.6%
SR 140 @ River Exchange Dr	EB	Fast	Tube	3.1%	-2.1%	8.4%	4.9%	7.3%
SR 140 @ River Exchange Dr	EB	Slow	Tube	2.3%	0.1%	4.4%	2.7%	3.5%
SR 140 @ River Exchange Dr	EB	All	Tube	2.7%	0.7%	4.7%	9.7%	3.7%
SR 92 @ Woodlands Rd	EB	Fast	Signal	7.4%	8.8%	6.1%	7.5%	10.0%
SR 92 @ Woodlands Rd	EB	Slow	Signal	-3.6%	-2.8%	-4.5%	3.9%	5.5%
SR 92 @ Woodlands Rd	EB	All	Signal	2.0%	2.6%	1.5%	2.2%	3.3%
SR 92 @ Woodlands Rd	WB	Fast	Signal	-1.5%	0.0%	-3.0%	4.1%	7.5%
SR 92 @ Woodlands Rd	WB	Slow	Signal	-1.1%	0.2%	-2.3%	4.0%	6.2%
SR 92 @ Woodlands Rd	WB	All	Signal	-1.3%	-0.2%	-2.3%	2.3%	5.3%
SR 140 @ Steeplechase Rd	EB	Fast	Signal	-10.0%	-6.2%	-13.8%	11.1%	21.3%
SR 140 @ Steeplechase Rd	EB	Slow	Signal	-0.5%	0.7%	-1.7%	4.1%	8.4%
SR 140 @ Steeplechase Rd	EB	All	Signal	-5.7%	-3.2%	-8.3%	7.6%	13.9%

Location	Direction	Lane	Evaluated Count	MPE	Lower 95%	Upper 95%	MAPE	RMSPE
SR 140 @ Steeplechase Rd	WB	Fast	Signal	2.9%	3.9%	1.9%	3.7%	7.7%
SR 140 @ Steeplechase Rd	WB	Slow	Signal	-2.7%	-1.9%	-3.4%	3.1%	6.0%
SR 140 @ Steeplechase Rd	WB	All	Signal	0.7%	1.4%	0.0%	2.4%	3.7%
SR141 @ E. Jones Bridge Rd*	NB	Fast	Signal	-23.3%	-17.8%	-28.8%	23.5%	36.0%
SR141 @ E. Jones Bridge Rd*	NB	Slow	Signal	-24.5%	-15.4%	-33.7%	24.6%	51.7%
SR141 @ E. Jones Bridge Rd*	NB	All	Signal	-6.2%	-5.1%	-7.3%	6.2%	8.2%
SR141 @ E. Jones Bridge Rd*	SB	Fast	Signal	24.9%	30.6%	19.1%	30.0%	38.0%
SR141 @ E. Jones Bridge Rd*	SB	Slow	Signal	-27.2%	-20.9%	-33.5%	30.4%	41.4%
SR141 @ E. Jones Bridge Rd*	SB	All	Signal	-20.1%	-15.3%	-24.8%	21.6%	31.0%
SR 314 @ Banks Rd	NB	Fast	Signal	-1.4%	0.7%	-3.6%	6.2%	15.4%
SR 314 @ Banks Rd	NB	Slow	Signal	-3.4%	-2.1%	-4.7%	4.3%	9.7%
SR 314 @ Banks Rd	NB	All	Signal	0.5%	0.8%	0.2%	1.4%	2.1%
SR 314 @ Banks Rd	SB	Fast	Signal	6.2%	8.1%	4.3%	7.3%	11.8%
SR 314 @ Banks Rd	SB	Slow	Signal	-2.0%	-1.5%	-2.6%	2.1%	3.5%
SR 314 @ Banks Rd	SB	All	Signal	-0.1%	0.4%	-0.6%	1.6%	2.5%
SR 141 @ Old Alabama Rd	NB	All	Signal	-2.6%	-1.6%	-3.7%	2.1%	4.1%
SR 141 @ Old Alabama Rd	SB	All	Signal	0.7%	1.4%	0.0%	2.1%	4.1%
SR 92@ Roswell Crossing	EB	Fast	Signal	1.3%	2.3%	0.4%	4.2%	6.6%
SR 92@ Roswell Crossing	EB	Middle	Signal	-9.6%	-8.4%	-10.8%	9.7%	12.9%
SR 92@ Roswell Crossing	EB	Slow	Signal	24.3%	27.9%	20.6%	24.3%	35.4%
SR 92@ Roswell Crossing	EB	All	Signal	4.3%	5.3%	3.3%	5.0%	8.3%

Location	Direction	Lane	Evaluated Count	MPE	Lower 95%	Upper 95%	MAPE	RMSPE
SR 92@ Roswell Crossing	EB	Fast	Signal D/S	-2.1%	-0.1%	-4.1%	11.0%	13.9%
SR 92@ Roswell Crossing	EB	Middle	Signal D/S	-10.1%	-7.5%	-12.6%	15.3%	20.5%
SR 92@ Roswell Crossing	EB	Slow	Signal D/S	21.7%	25.2%	18.2%	22.1%	32.6%
SR 92@ Roswell Crossing	EB	All	Signal D/S	2.1%	3.2%	1.1%	4.9%	7.4%
SR 92@ Roswell Crossing	WB	Fast	Signal	-4.1%	0.0%	-8.2%	9.3%	28.7%
SR 92@ Roswell Crossing	WB	Middle	Signal	2.5%	3.2%	1.9%	4.0%	5.2%
SR 92@ Roswell Crossing	WB	Slow	Signal	0.3%	0.8%	-0.1%	2.1%	3.3%
SR 92@ Roswell Crossing	WB	All	Signal	-0.5%	0.9%	-2.0%	4.0%	10.0%
SR 141 @ SR 237	EB	Slow	Signal/VDS	11.8%	0.7%	22.9%	17.9%	19.9%
SR 141 @ SR 237	EB	Middle	Signal/VDS	9.6%	0.2%	18.9%	11.1%	18.5%
SR 141 @ SR 237	EB	Fast	Signal/VDS	2.6%	1.0%	4.2%	3.1%	3.8%
SR 141 @ SR 237	EB	All	Signal/VDS	6.1%	3.9%	8.3%	6.1%	7.1%
SR 92 @ Woodstock	WB	Fast	Tube	4.5%	2.6%	6.4%	4.5%	5.5%
SR 92 @ Woodstock	WB	Middle	Tube	-6.0%	-8.4%	-3.7%	6.5%	7.1%
SR 92 @ Woodstock	WB	Slow	Tube	8.7%	4.3%	13.2%	8.9%	11.3%
SR 92 @ Woodstock	WB	All	Tube	3.0%	1.8%	4.2%	3.0%	3.5%
SR 92 @ Woodstock	EB	Fast	Signal	12.9%	19.2%	6.6%	19.1%	46.0%
SR 92 @ Woodstock	EB	Middle	Signal	58.1%	72.7%	43.6%	58.5%	118.0%
SR 92 @ Woodstock	EB	Slow	Signal	-8.0%	-3.9%	-12.1%	20.5%	30.0%
SR 92 @ Woodstock	EB	All	Signal	19.6%	25.1%	14.0%	19.6%	21.8%
SR 92@ Bowen Road	EB	Fast	Signal	6.4%	8.9%	3.9%	12.6%	18.7%

Location	Direction	Lane	Evaluated Count	MPE	Lower 95%	Upper 95%	MAPE	RMSPE
SR 92@ Bowen Road	EB	Middle	Signal	19.1%	22.0%	16.2%	20.0%	27.9%
SR 92@ Bowen Road	EB	Slow	Signal	4.4%	6.6%	2.1%	11.1%	16.3%
SR 92@ Bowen Road	EB	All	Signal	11.9%	14.0%	9.8%	13.4%	18.9%

* Possibly faulty baseline counts

5.0 Conclusions and Recommendations

5.1 Findings

The objective of this study was to perform an evaluation of the feasibility of integrating intersection traffic signal data into a traffic monitoring program. About six hundred and eighty hours of directional data across nine study sites around Metro Atlanta was analyzed at a lane-by-lane level in this study. The following are the major findings and related observations:

- Accuracy of 15-minute aggregates of vehicle counts is above 90% at a 95% level of confidence at majority of the study sites.
- Data quality at some intersections (SR 92 at Woodstock Rd) are affected by insufficient offset of the detection zone from the stop bar, leading to queuing of vehicles over the detector and resulting in over-counting of vehicles.
- Results of tests at other high volume intersections did not reveal any severe quality issues as observed at the Woodstock Rd intersection. The quality of data varies from site to site and nature of installation.
- Data from intersections using video based detection are of comparable quality as other intersections using inductive loop detectors. Like other technologies, video based detection is sensitive to calibration. At the video detection test site two out of three lanes reported data with less than 10% errors (MPE) while one of the lanes reported a mean percentage error of 12%. While it was not verified via a re-calibration and re-evaluation in this study, it is likely that the detection accuracy could be improved by better placement of the detection zone in the camera view.

5.2 Intersection Eligibility Criteria

On GDOT's Regional Traffic Operations corridors, the signals had detectors installed only on the major roads. No volumes are available from minor roads. Based on this information alone, it is not possible to accurately determine the volumes downstream of an intersection. Therefore the volumes at a single screenline (midblock location) cannot be generated based on the detectors at a single intersection. It is necessary to use a pair of adjacent intersection's detectors, preferably with no other cross-streets in between, to estimate a midblock screenline count (see Figure 39)

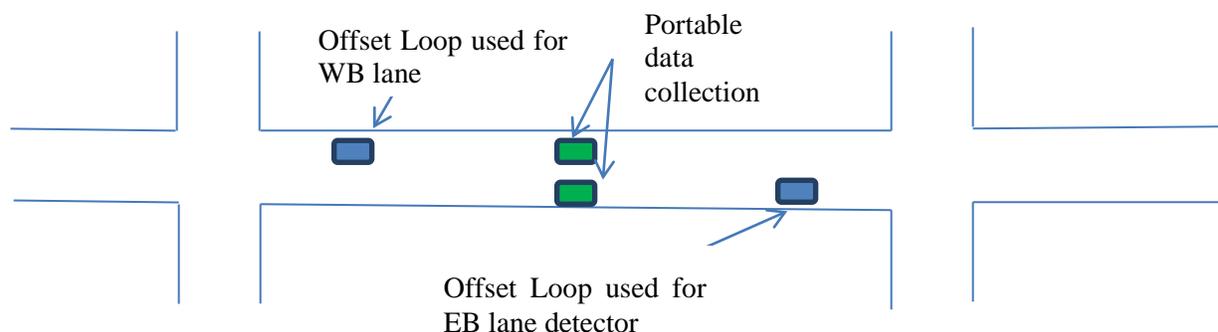


Figure 39: Detection Layout Schematic

For using the intersection signal detector data for traffic monitoring the following caution need to be exercised:

- Discard locations with data spikes i.e. detectors reporting more than 500 vehicles per lane per 15 minutes (threshold can be fine-tuned) at any single data-point (See Figure 40)
- Ensure stability of data connection for completeness of data at remote locations which use wireless data transfers
- Data availability does not guarantee data quality. Check plot of historical data for expected traffic patterns before considering use of data in traffic monitoring (see Figure 41)
- Use data from signal detector downstream of midblock location (i.e. use data from two intersections instead of one) (see Figure 39)
- Use data from locations where the inductive loop detectors are physically located upstream of the beginning of turn lanes (if any) (see Figure 42)
- Avoid locations where there is evidence (can be confirmed with site visit during peak period) of vehicles queuing over the detection zone

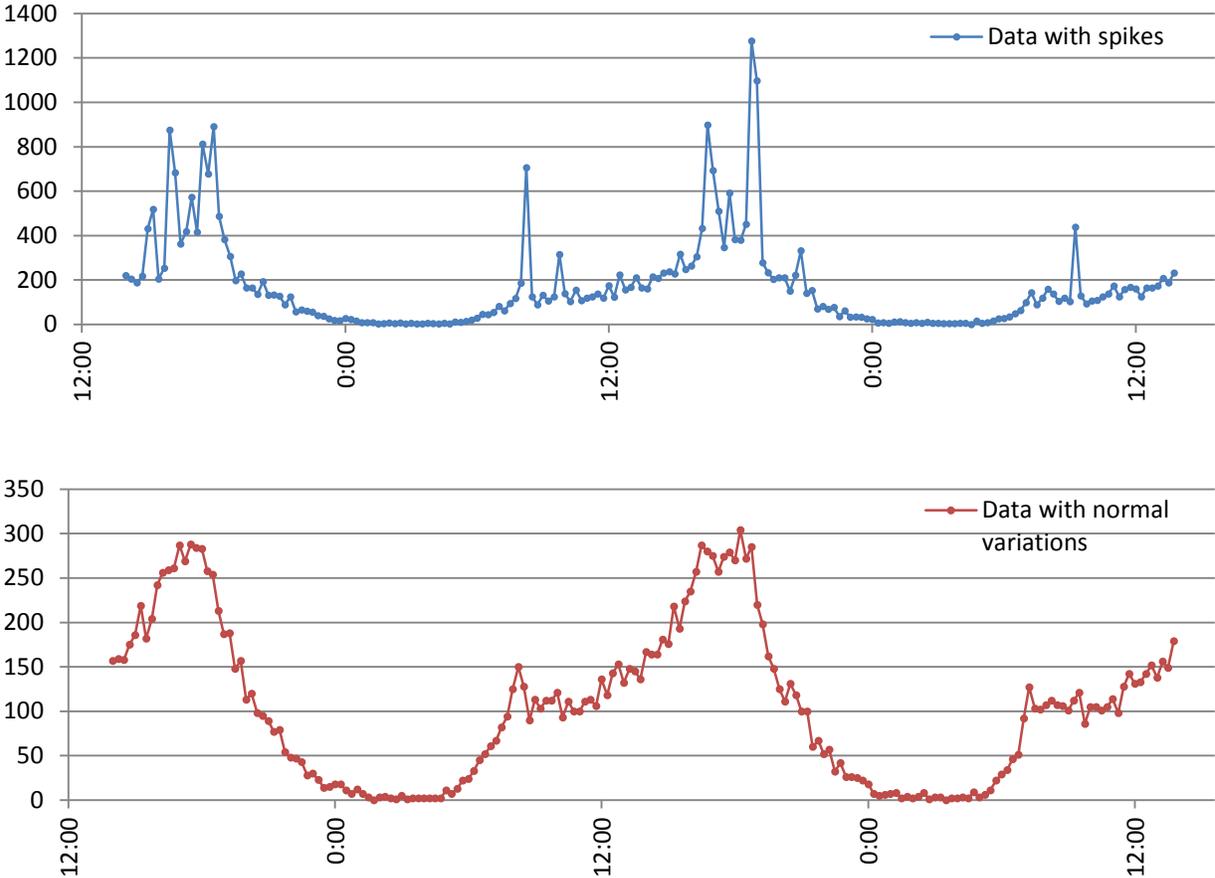


Figure 40: Example of Traffic Counts with and without Data Spikes

Note the different scales in the figures

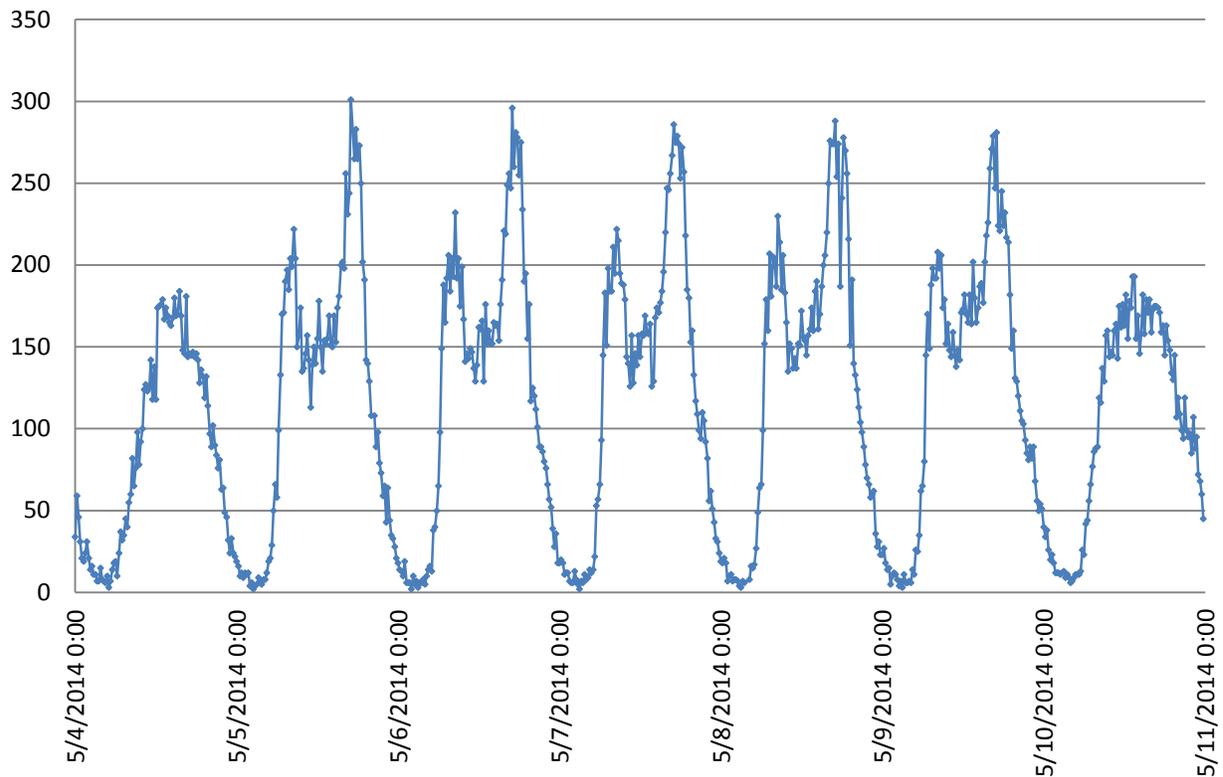


Figure 41: Example of Time Series Plot with well Defined Traffic Volume Pattern

5.3 Ideal Intersection for Data Use

Based on the above eligibility criteria the following are the characteristics of a site that would be ideal for use in traffic monitoring:

- Detector data does not display any sudden spikes on a regular basis and there is no known occurrence of queuing of vehicles over the detector. Here a spike is defined as the existence of a few data points within a series that deviate significantly from the other data points. At least one week of data should be used to generate time series plots of the data to visually check for data spikes.
- The signal cabinet communicates with the central server via a stable wired connection. Wireless connections have been found to be unreliable, and may not guarantee completeness of data.
- Data plots agree with expected increases and decreases in traffic demand during peak and off peak travel periods. At least one typical week of data should be used to generate time series plots of the data to visually check for expected data patterns (see Figure 41). Here a typical week is defined as a week that does not have any holidays, weather events etc. and is not adjacent to long weekends.
- Data is available from two adjacent intersections. Data from signal detector downstream of midblock location will be used for traffic monitoring (see Figure 39).

- The intersection signal's inductive loop detectors are physically located upstream of the beginning of turn lanes (if any) (see Figure 42)

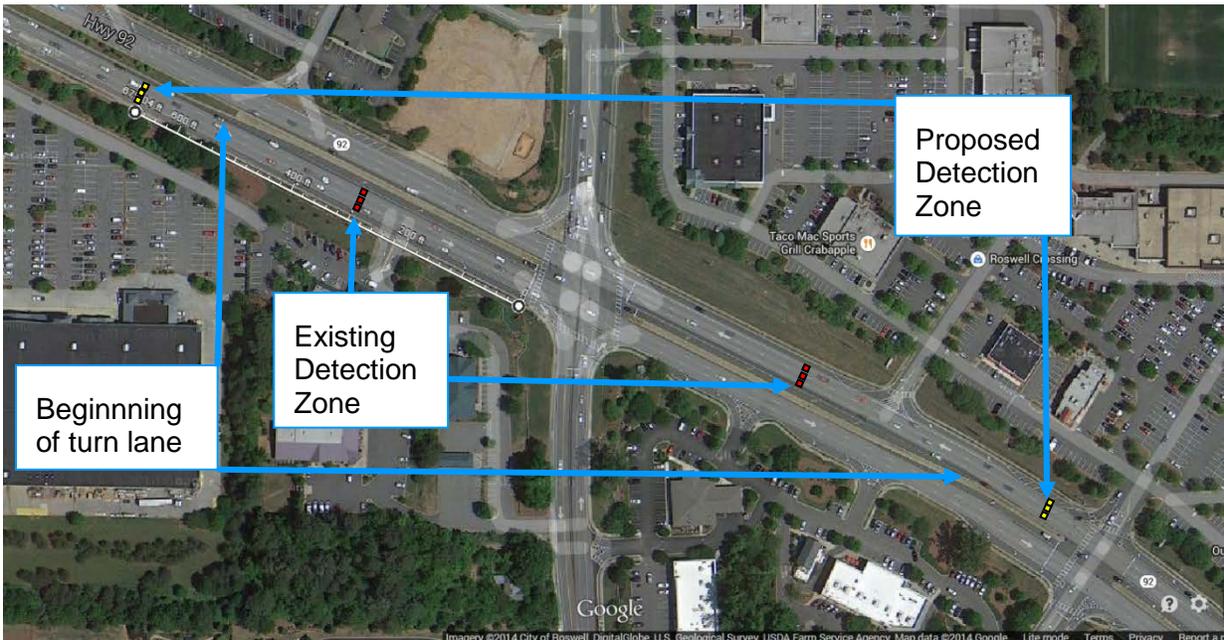


Figure 42: Proposed Detection Zone Placement Upstream of Beginning of Turn Lanes (Image Courtesy: Google Maps)

5.4 Recommendations

The comparison results in this study indicate that in majority of the cases, the intersection signal detector data is similar in quality to pneumatic tube count data in terms of both the mean and variability of the errors. While there is variability in the level of error from site to site, in general following the intersection eligibility criteria guidelines should help ensure high quality of data for use in the traffic monitoring program. If the data from a particular site is expected to be used extensively on a long term basis, validation of the data via short term counts is recommended.

The intersection signal detectors do not provide vehicle classification information. Therefore the intersection signal detectors cannot be expected to replace the permanent traffic counting stations used in the traffic monitoring program. However, these detectors provide continuous data throughout the year and can possibly be used for other purposes such as determining seasonality factors.

5.4.1 Installation Considerations

To improve the usability of intersection signal detector data for traffic monitoring it is recommended that for future installations and maintenance on existing detectors, detection zones are moved further upstream beyond the maximum queue length of a typical peak hour queue and beyond the beginning of the turn lanes. If it is not possible to move detections zones upstream of turn lanes, detectors should be installed on turn lanes as well.

5.4.2 Communication

A significant amount of effort was spent in the early stages of the project to establish the communication connections required to access the data. The signal detector data accessed via

SOAP XML requests to the TACTICS server did not provide guaranteed data quality and was therefore deemed unusable for traffic monitoring purposes. The signal detector data is stored on local memory on the controller in the form of 15 minute counts (by-lane). This data is polled out by a central server on a periodic basis (one to two times daily) and pushed into an archive. The TACTICS interface provides a graphical user interface to query out data for specific intersections. However this process is not favorable for automation. For this project, a procedure was set up to automatically query the database (by GDOT's database administrator) and transfer a text file with the queried data to Georgia Tech's server via Secure Copy Protocol (SCP). While this setup is acceptable for a research project with temporary and transient data needs, a stable setup needs to be designed if the data is to be used for traffic monitoring purposes.

In addition there are other communication hurdles that need to be surmounted before the signal detector data can be reliably used in the traffic monitoring program:

- The remote site (SR 314) that used communication over cellular network for the periodic polls of the 15 minute archives failed regularly to transfer the entire dataset. This created availability issues in the dataset and prevented the study from obtaining complete 24 hour counts at the site. In the absence of more reliable communications, this issue needs to be addressed by either increasing the frequency of the polls or increasing the aggregation interval length to reduce amount of data transferred per poll.
- There are signals in the RTOP corridors that are not connected to the central TACTICS server. Hence the data from these signal detectors are not available in GDOT's data archive. If data from these corridors are to be used in the traffic monitoring program, the data needs to be retrieved periodically and archived by GDOT in a manner similar to the corridors currently connected to the central server.

5.4.3 Future Research

The results of this study indicate that the quality of data varies from site to site. Deployment characteristics, quality of calibration, communication faults, location of loops with respect to the beginning of turn lanes, presence of queues extending over the detection zone etc. are some of the factors that affect the quality of the data as it pertains to the use of this data in the traffic monitoring program. However several of these factors are either theoretically difficult to quantify or is too resource intensive to measure for a large number of sites. Typically, the quality of data at a site can be determined by performing baseline counts near the existing detectors i.e. by looking at the resulting data stream rather than trying to determine the cause of the anomaly. However, such quality checks need to be performed on a periodic basis to ensure that the quality of data has not degraded over time due to changes in any of the above mentioned factors. One of the purposes of the current study was to investigate the feasibility of eliminating short-term counts where signal detector counts are available. Unless the higher quality data requirement is justified by real time traffic operations, performing validation checks would defeat the purpose of resource conservation because it will require more resources for the validation effort than it saves by eliminating temporary counts. Under these resource constraints, it would be helpful to have a mechanism for estimating, in lieu of measuring, the quality of the data without performing extensive field measurements.

Further research needs to be conducted to develop a methodology for estimating data quality based on readily available information and without requiring additional data collection. It is envisioned that a system for assigning "Quality Ratings" for Signal detector data at each intersection with offset detectors can be developed. The quality rating will be based on

comparisons of data from roads with similar volumes and demands. The comparison data can be obtained from nearby permanent count stations, or data from Signals detectors from nearby intersections. At the lane level, comparisons can be done with data from adjacent lanes to detect anomalies. Rational rule based checks such as variation of volumes with time of day, location of detection loops with respect to turn lanes etc. can be used along with the data comparison statistics to determine the quality ratings. The quality ratings would be available at the approach level. The quality ratings will provide a ready reference for choosing intersection approaches with acceptable data quality for use in the traffic monitoring program. In addition, this methodology provides a scalable architecture where new installations can be easily integrated in the list of rated intersections, without requiring additional short-term data collection for every new installation site.

Once the base data patterns are established, this framework can be leveraged for monitoring data for real-time operations as well, by developing correlation factors and ranges of expected variation that will help identify deviation of data at individual detectors which could be linked to potential degradation in data quality.

6.0 References

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7.0 Appendix

List of Figures (Appendix)

Figure A-1: Time Series Plots for Pneumatic Tube Counts and Signal Detector Counts Aggregated over All Lanes at Intersection of SR 141 and Old Alabama Road for NB (Top) and SB (Bottom) (Note: Lane-by-lane data was not provided for this site for the intersection signal data) 7-5

Figure A-2: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 1 7-6

Figure A-3: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 2 7-6

Figure A-4: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 3 7-7

Figure A-5: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Aggregates over All Lanes 7-7

Figure A-6: Y-Y Plots for Pneumatic Tube Counts Vs Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 1 (Top-Left), Lane 2 (Top-Right), Lane 3 (Bottom-Left) and Aggregates over All Lanes (Bottom Right) 7-8

Figure A-7: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 1 7-9

Figure A-8: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 2 7-9

Figure A-9: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 3 7-10

Figure A-10: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Aggregates over All Lanes 7-10

Figure A-11: Y-Y Plots for Pneumatic Tube Counts Vs Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 1 (Top-Left), Lane 2 (Top-Right), Lane 3 (Bottom-Left) and Aggregates over All Lanes (Bottom Right) 7-11

Figure A-12: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Lane 1 7-12

Figure A-13: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Lane 2 7-13

Figure A-14: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Lane 1 7-13

Figure A-15: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Lane 2 7-14

Figure A-16: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Aggregates over All Lanes 7-14

Figure A-17: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes 7-15

Figure A-18: Time Series Plot for Manual Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes 7-15

Figure A-19: Time Series Plot for Manual Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes 7-16

Figure A-20: Time Series Plot for Manual Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes 7-16

Figure A-21: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 1 7-17

Figure A-22: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 2 7-17

Figure A-23: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 3 7-18

Figure A-24: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes 7-18

Figure A-25: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes with Count Ceiling per lane at 350 vehicles 7-19

Figure A-26: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 1 7-19

Figure A-27: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 2 7-20

Figure A-28: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 3 7-20

Figure A-29: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Aggregates over All Lanes 7-21

Figure A-30: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 1 7-21

Figure A-31: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 2 7-22

Figure A-32: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 3 7-22

Figure A-33: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes 7-23

Figure A-34: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple ChaseDr for Lane 1..... 7-24

Figure A-35: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple ChaseDr for Lane 2..... 7-24

Figure A-36: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 WB and Woodlands Parkway for Lane 1 7-25

Figure A-37: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 WB and Woodlands Parkway for Lane 2..... 7-25

Figure A-38: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple Chase Drive for Aggregates over All Lanes..... 7-26

Figure A-39: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 WB and Woodland Parkway for Aggregates over All Lanes 7-26

Figure A-40: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 1 7-27

Figure A-41: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 2 7-27

Figure A-42: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 SB and Creek Wood Trl for Lane 1 7-28

Figure A-43: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 SB and Creek Wood Trl for Lane 2 7-28

Figure A-44: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 EB and Banks Rd for Aggregates over All Lanes..... 7-29

Figure A-45: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 WB and Creek Wood Trl for Aggregates over All Lanes..... 7-29

Figure A-46: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 EB and SR 237 for Lane 1..... 7-30

Figure A-47: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 EB and SR 237 for Lane 2..... 7-30

Figure A-48: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 WB and SR 237 for Lane 3 7-31

Figure A-49: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 WB and SR 237 for Aggregates over All Lanes 7-31

Figure A-50: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 NB and East Jones Bridge Road for Lane 1 7-32

Figure A-51: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 NB and East Jones Bridge Road for Lane 2..... 7-32

Figure A-52: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 SB and Forum Drive for Lane 1 7-33

Figure A-53: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 SB and Forum Drive for Lane 2..... 7-33

Figure A-54: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 NB and East Jones Bridge Road for Aggregates over All Lanes..... 7-34

Figure A-55: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 SB and Forum Drive for Aggregates over All Lanes..... 7-34

Figure A-56: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 1..... 7-35

Figure A-57: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 2..... 7-35

Figure A-58: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Woodlands Parkway for Lane 1..... 7-36

Figure A-59: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Woodlands Parkway for Lane 2..... 7-36

Figure A-60: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Drive for Aggregates over All Lanes..... 7-37

Figure A-61: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Woodland Parkway for Aggregates over All Lanes 7-37

Figure A-62: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Lane 1 7-38

Figure A-63: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Lane 2 7-38

Figure A-64: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Lane 3 7-39

Figure A-65: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Aggregates over All Lanes 7-39

7.1 SR 141 at Old Alabama Road

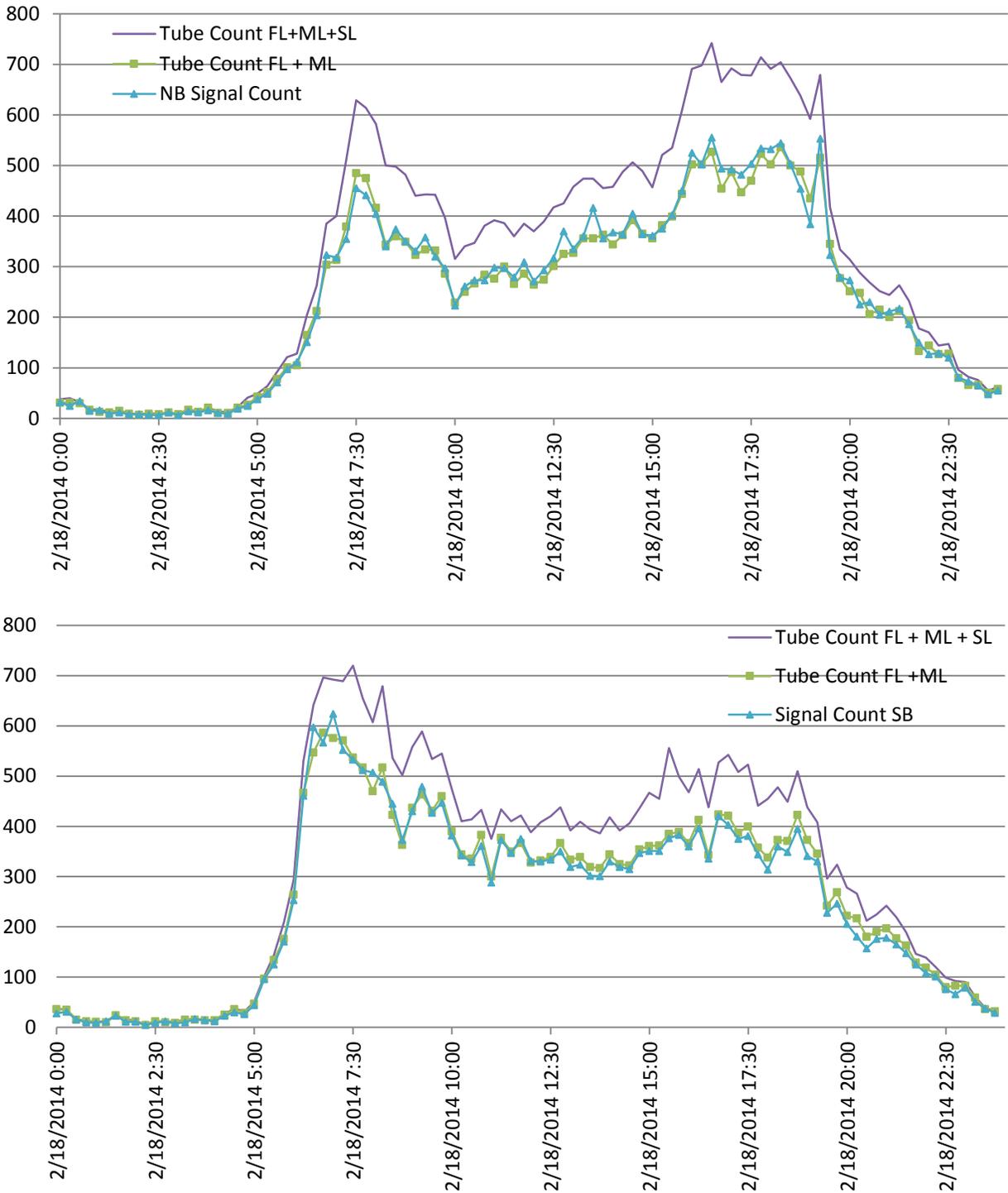


Figure A-1: Time Series Plots for Pneumatic Tube Counts and Signal Detector Counts Aggregated over All Lanes at Intersection of SR 141 and Old Alabama Road for NB (Top) and SB (Bottom) (Note: Lane-by-lane data was not provided for this site for the intersection signal data)

7.2 SR 92 at Roswell Crossing

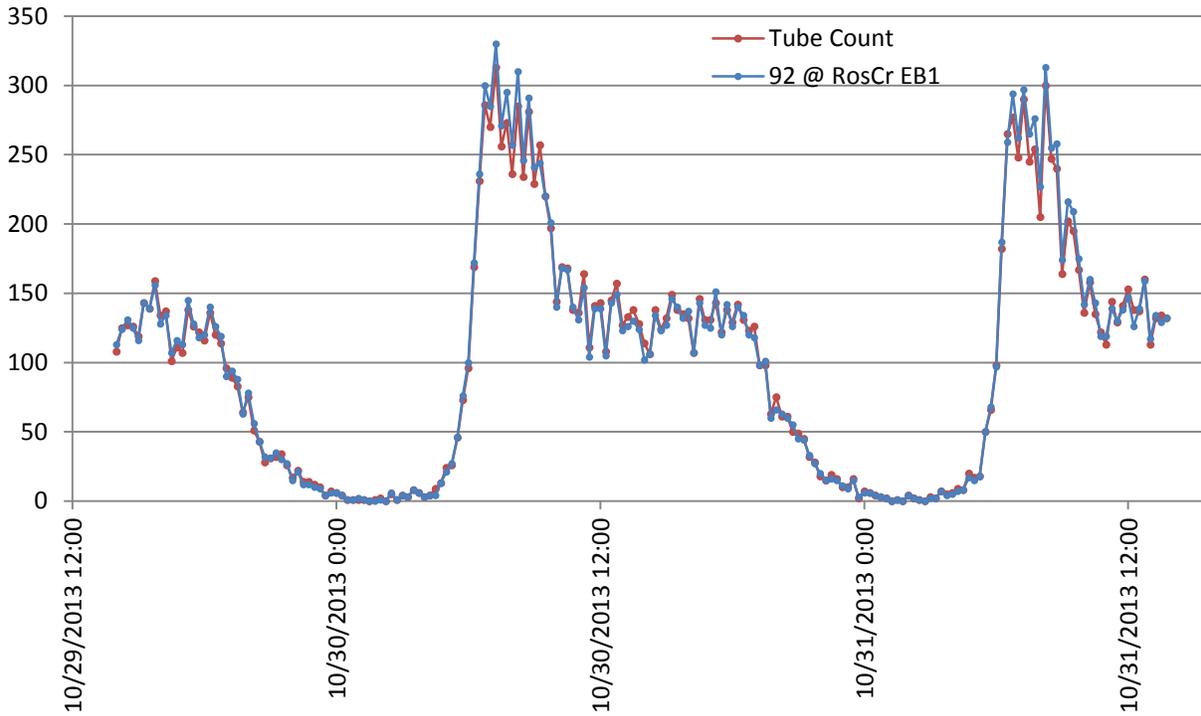


Figure A-2: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 1

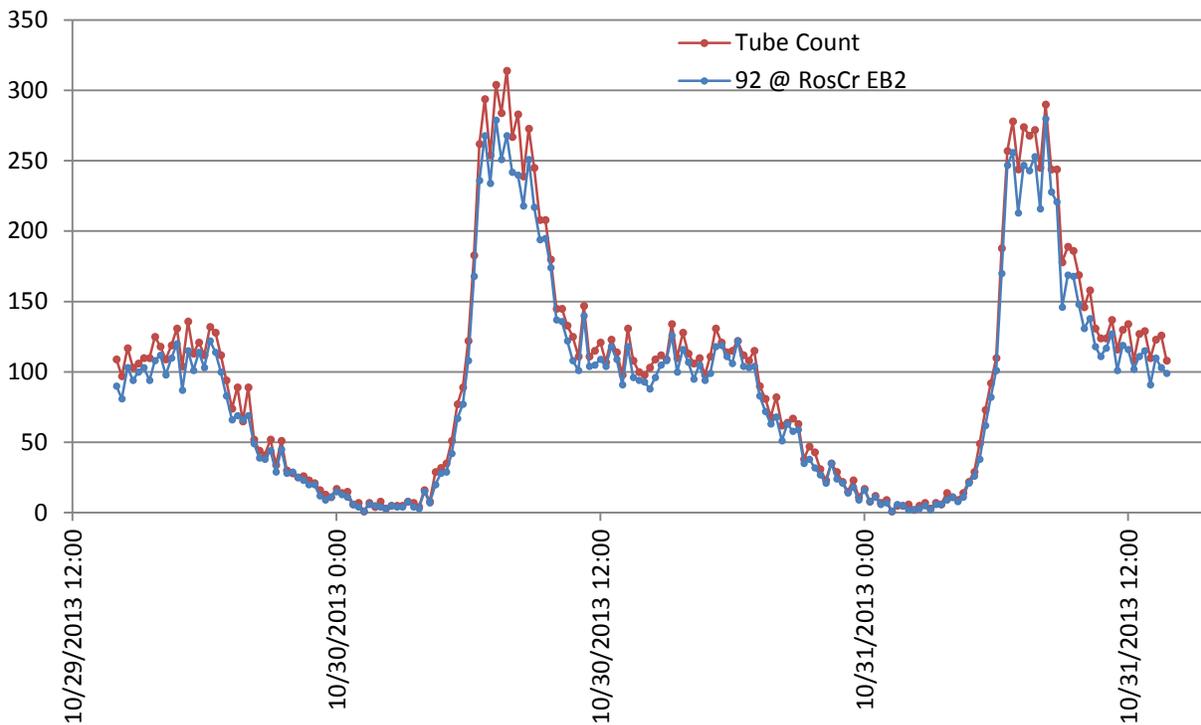


Figure A-3: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 2

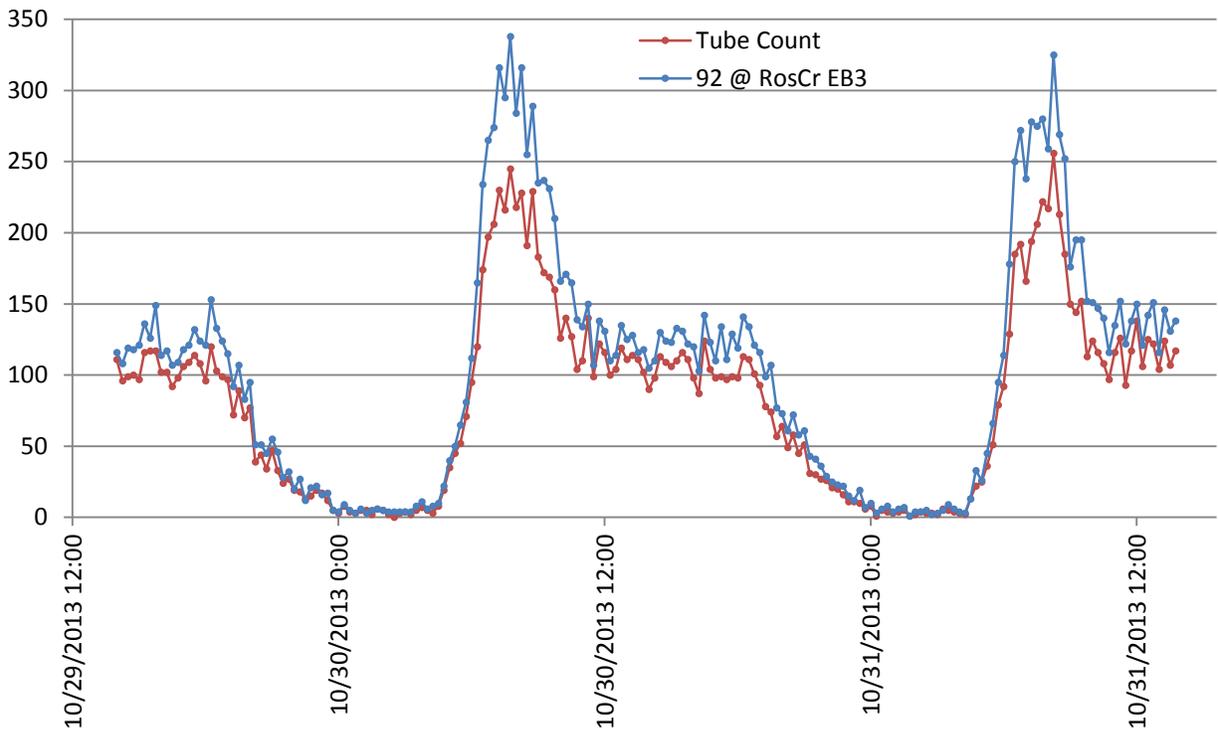


Figure A-4: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Lane 3

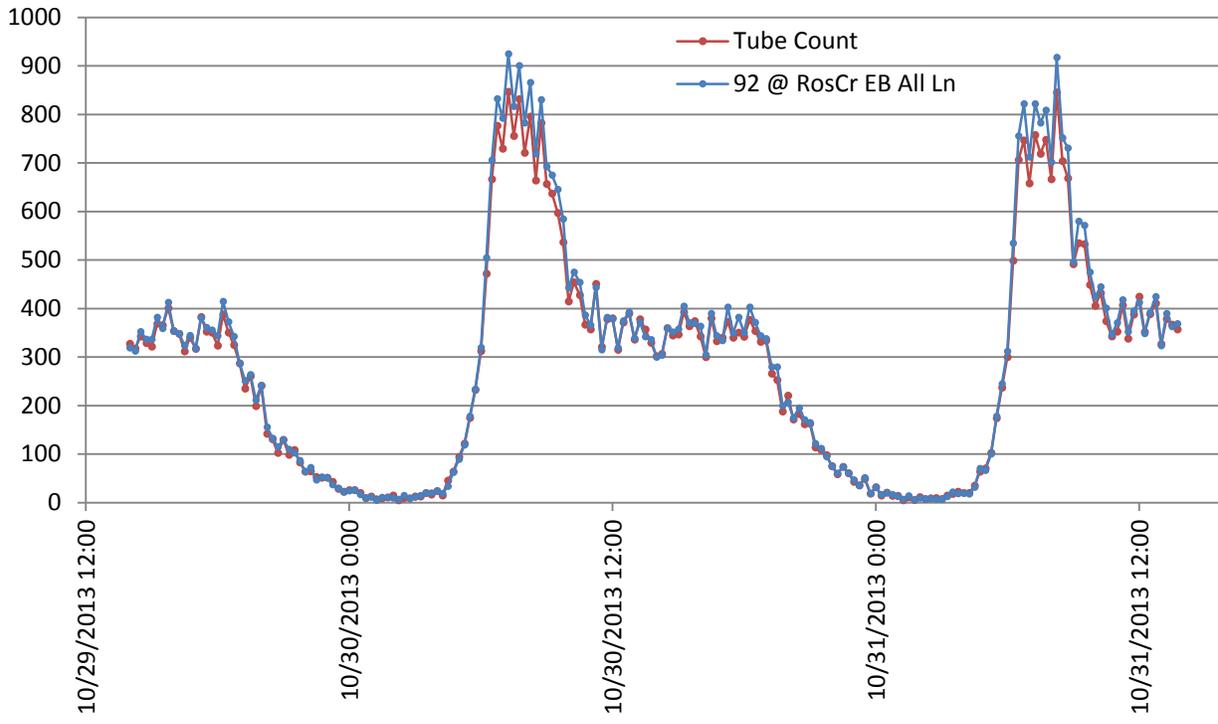


Figure A-5: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Roswell Crossing for Aggregates over All Lanes

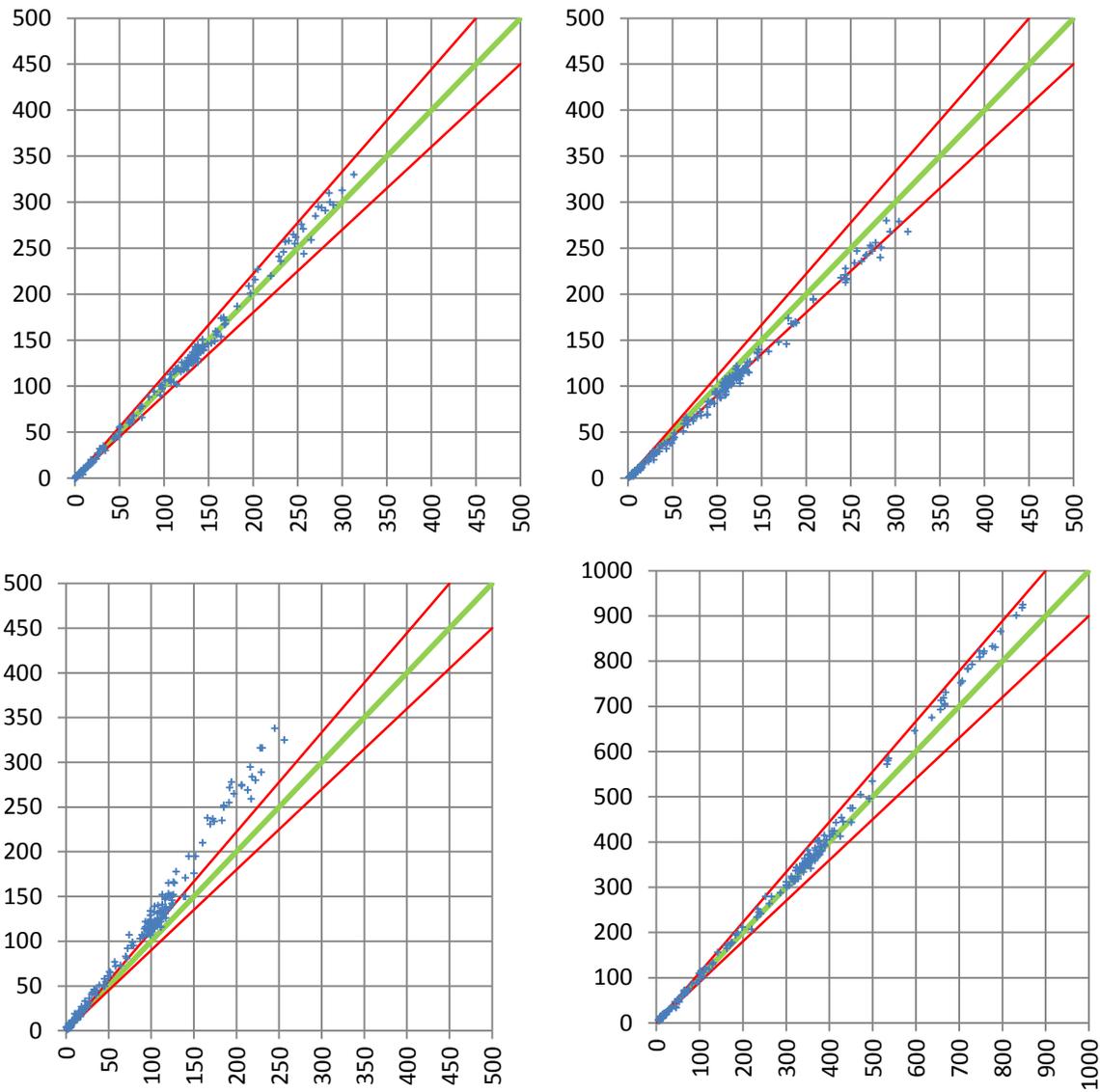


Figure A-6: Y-Y Plots for Pneumatic Tube Counts Vs Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 1 (Top-Left), Lane 2 (Top-Right), Lane 3 (Bottom-Left) and Aggregates over All Lanes (Bottom Right)

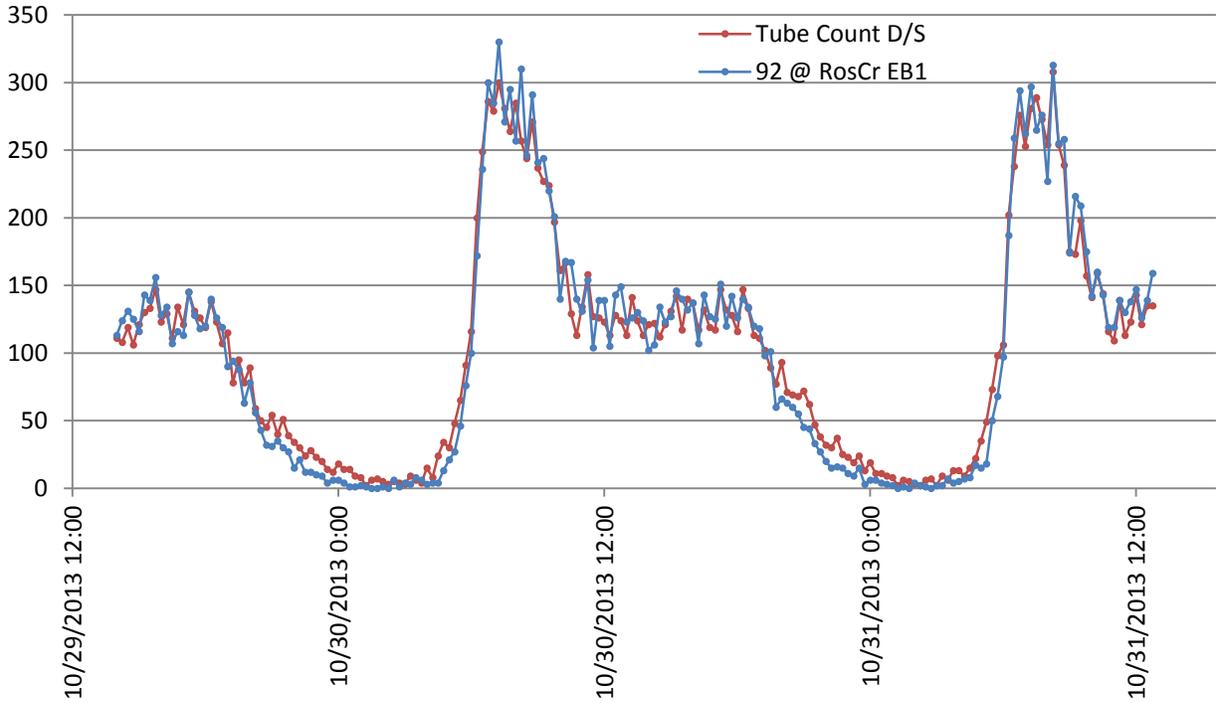


Figure A-7: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 1

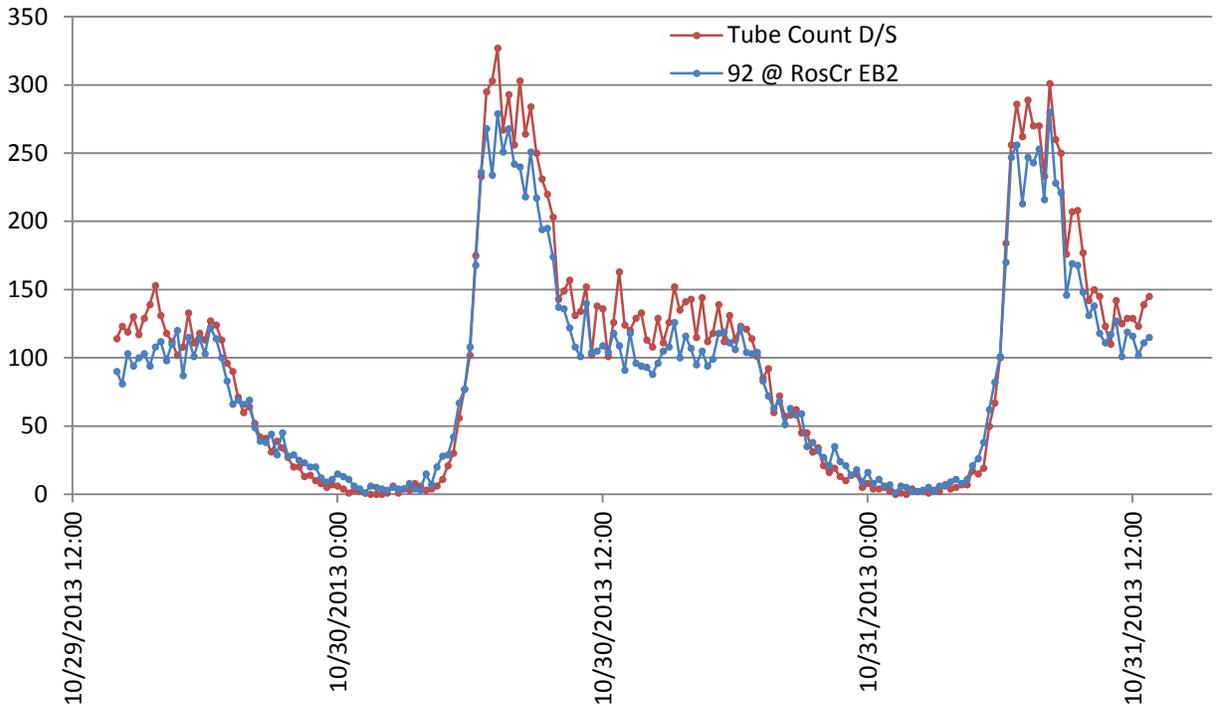


Figure A-8: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 2

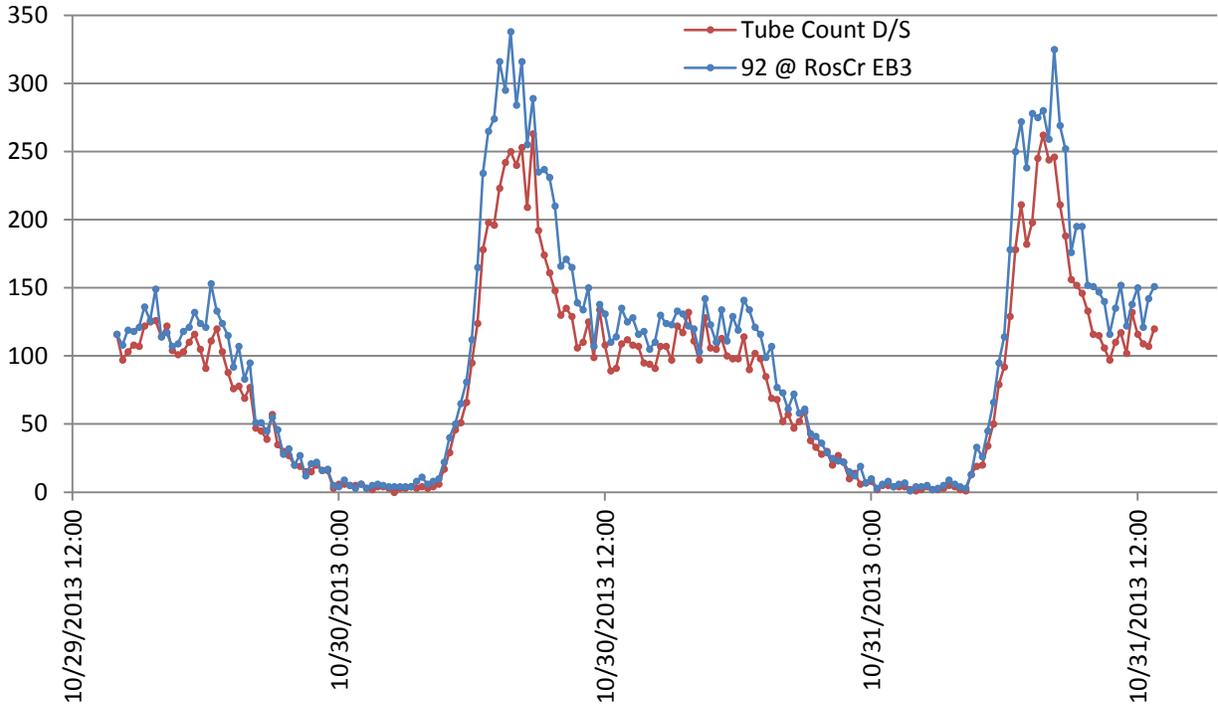


Figure A-9: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 3

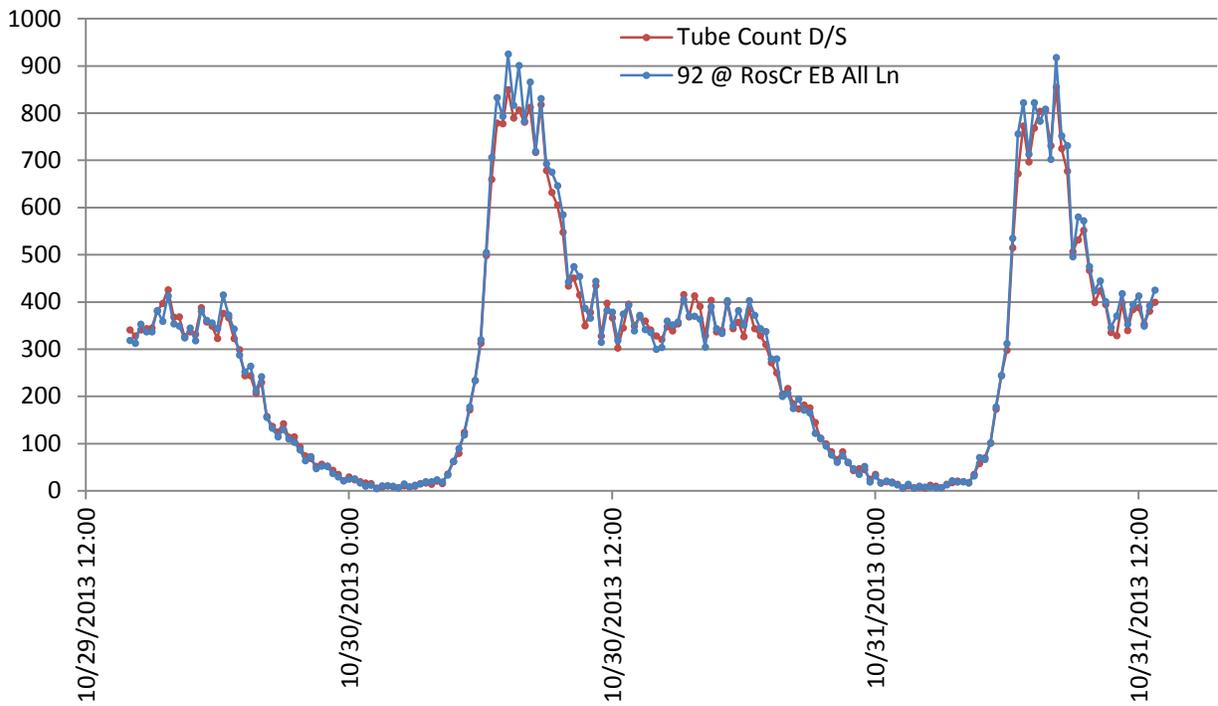


Figure A-10: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Aggregates over All Lanes

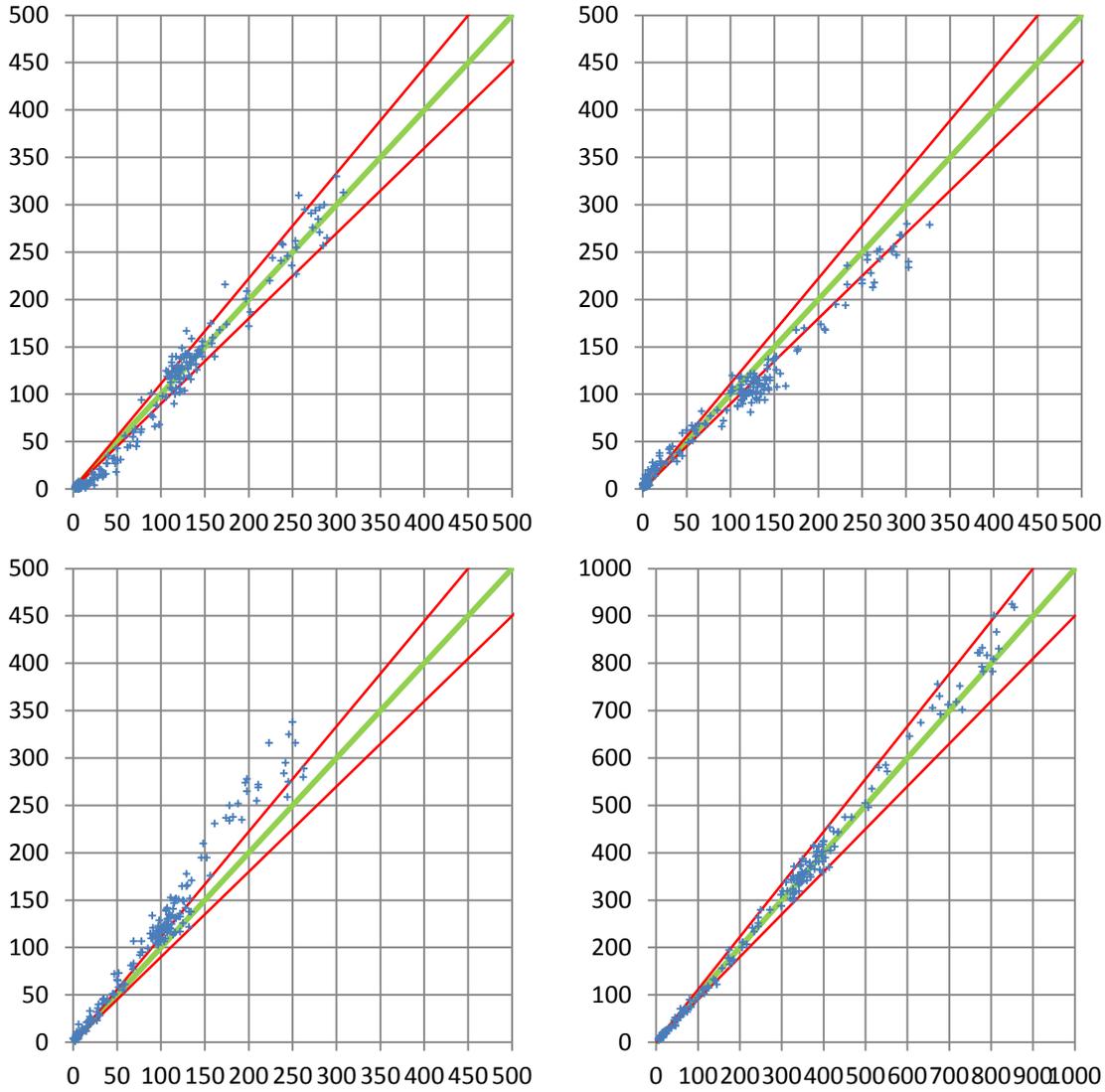


Figure A-11: Y-Y Plots for Pneumatic Tube Counts Vs Signal Detector Counts at Intersection of SR 92 EB and Roswell Crossing for Lane 1 (Top-Left), Lane 2 (Top-Right), Lane 3 (Bottom-Left) and Aggregates over All Lanes (Bottom Right)

7.3 SR 140 at River Exchange Parkway

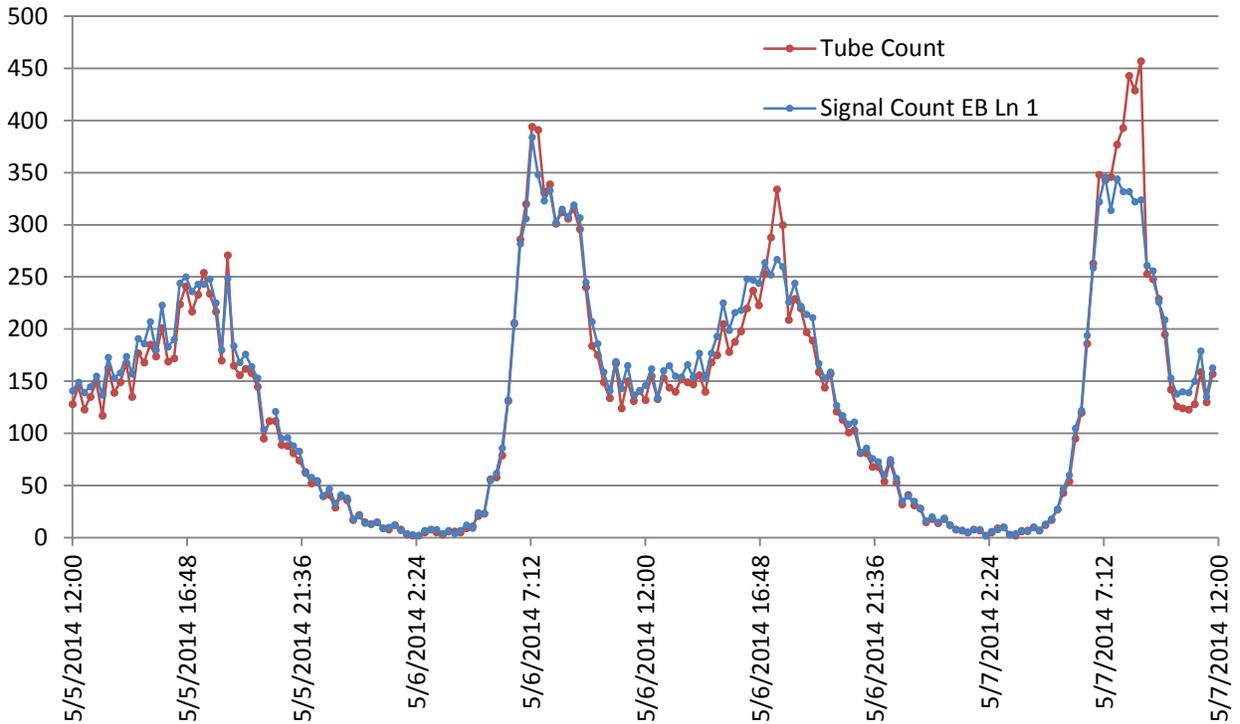


Figure A-12: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Lane 1

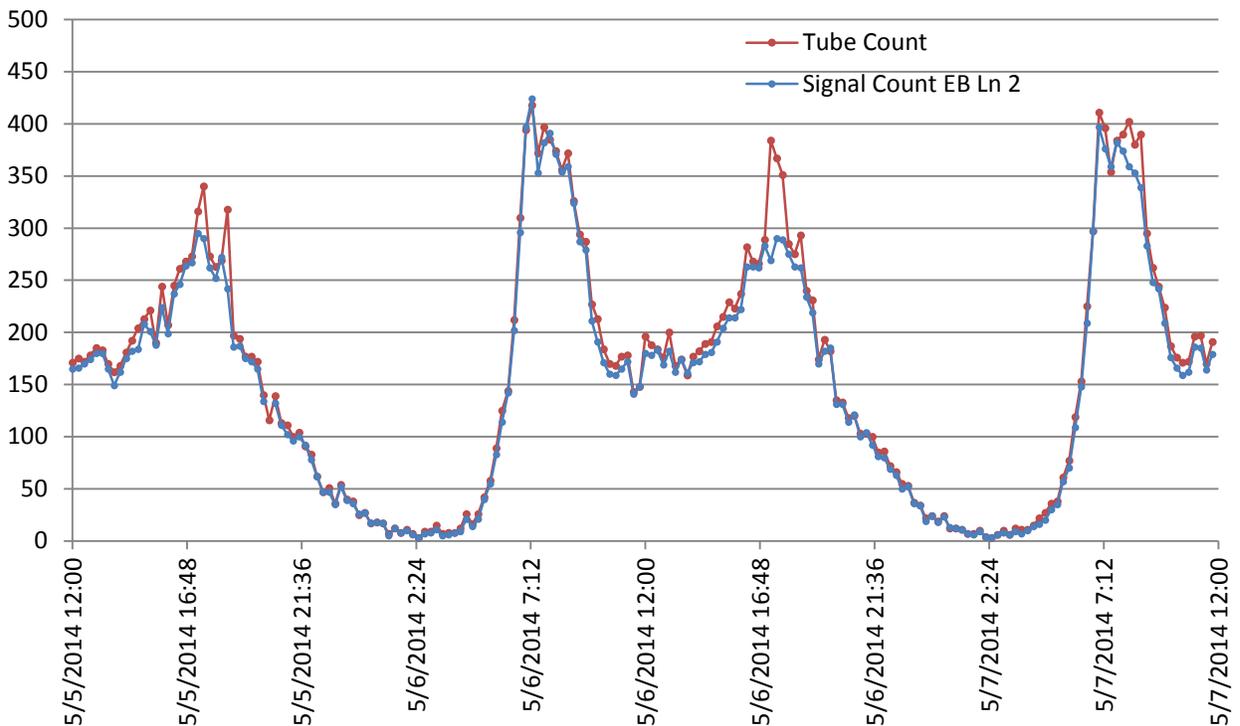


Figure A-13: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Lane 2

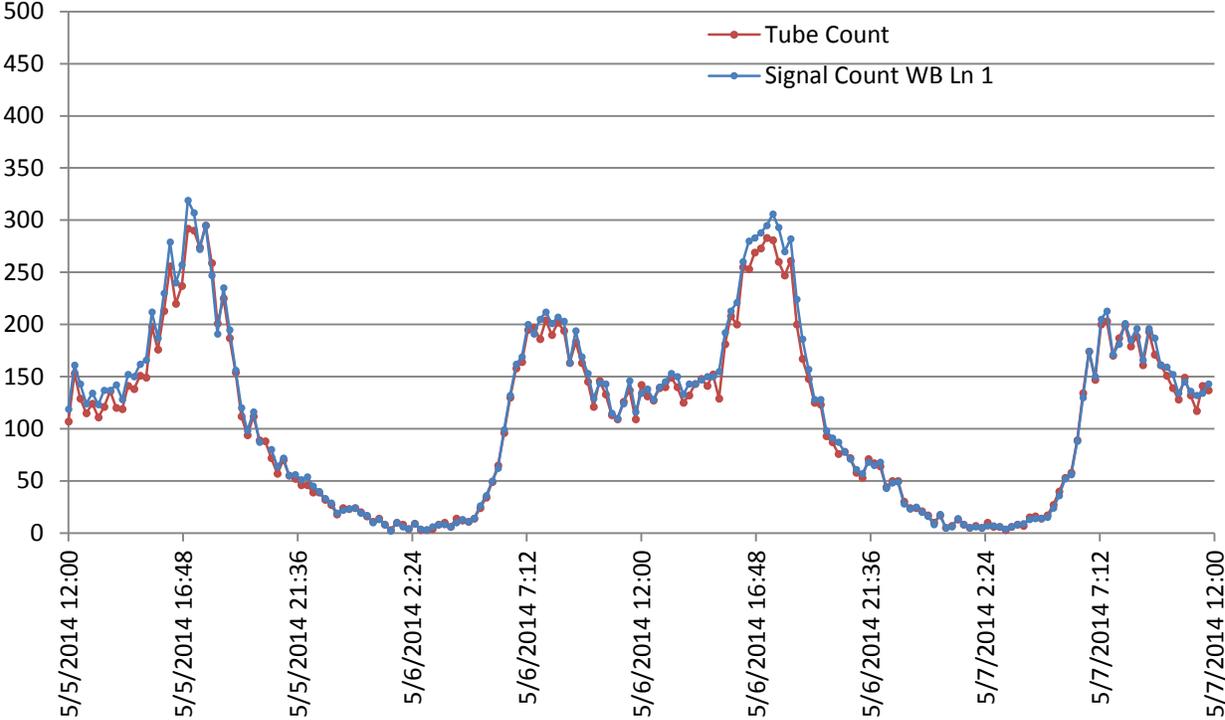


Figure A-14: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Lane 1

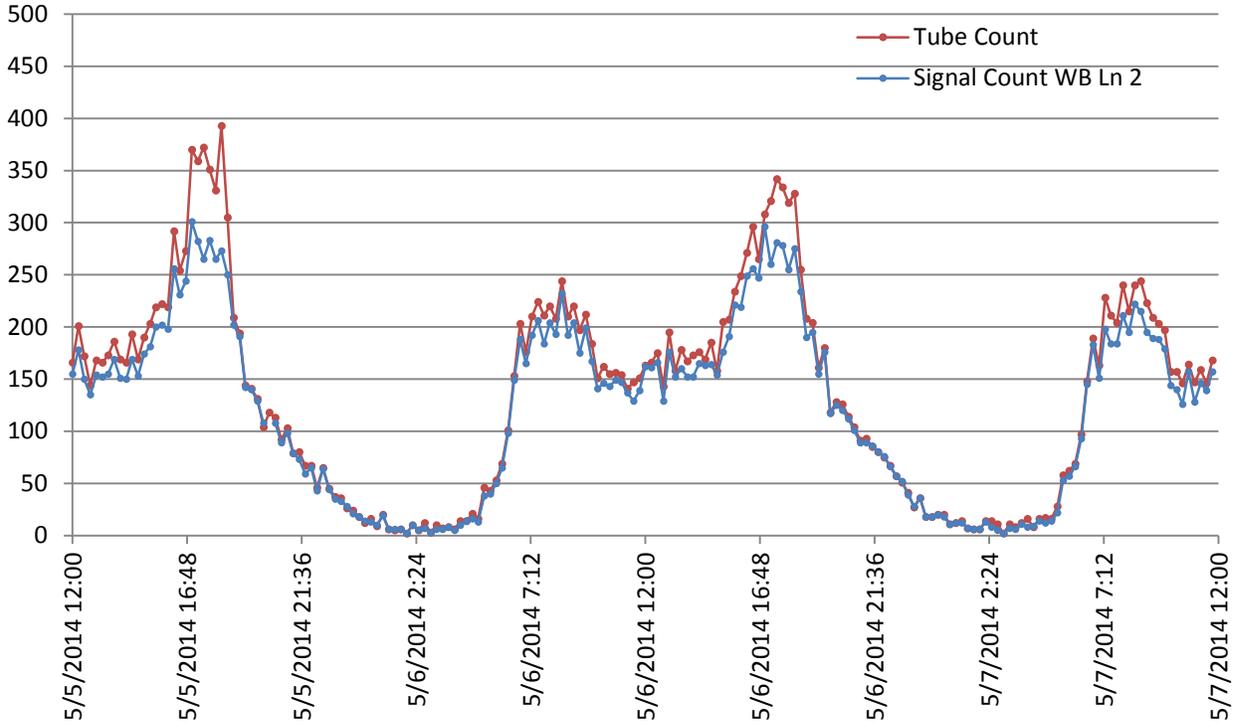


Figure A-15: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Lane 2

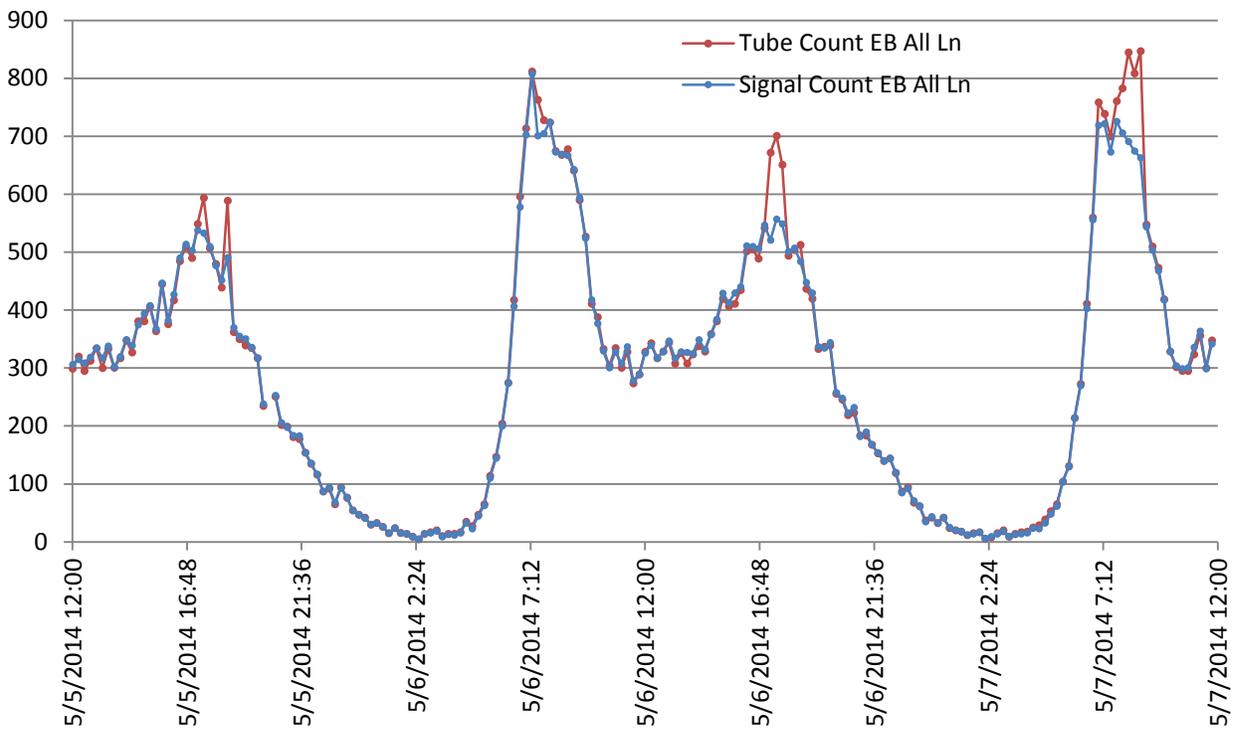


Figure A-16: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 EB and River Exchange Parkway for Aggregates over All Lanes

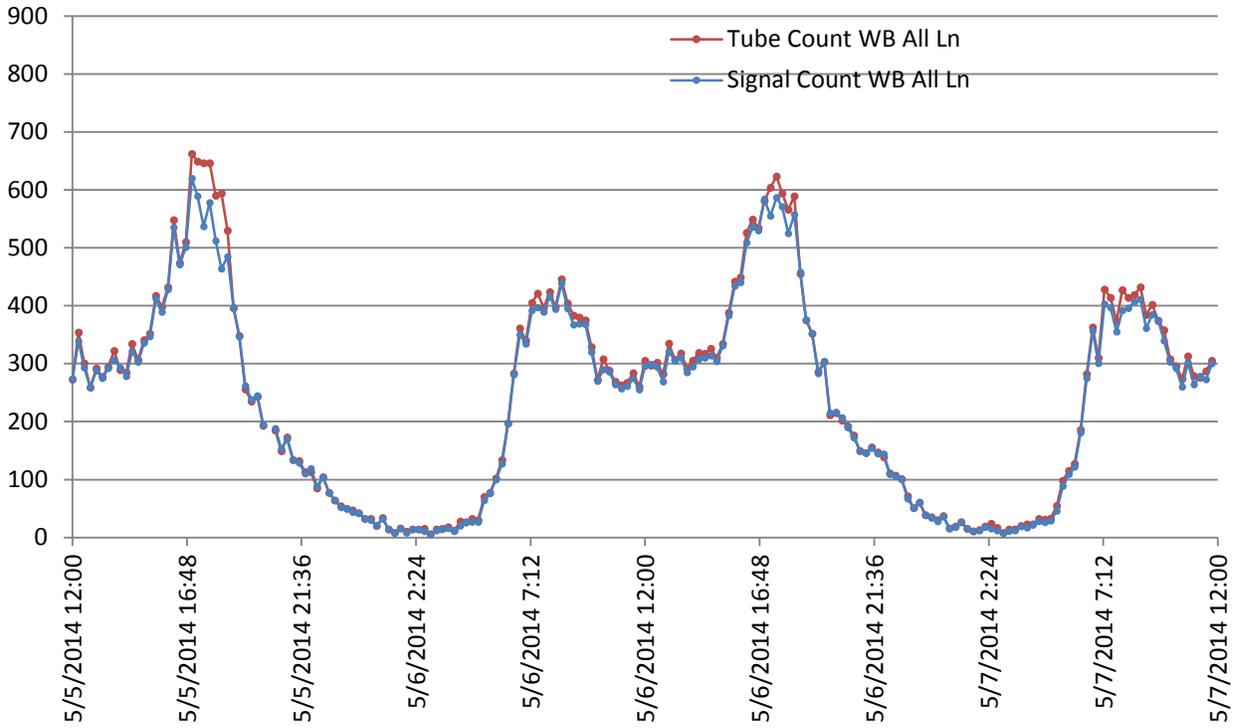


Figure A-17: Time Series Plot for Pneumatic Tube Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes

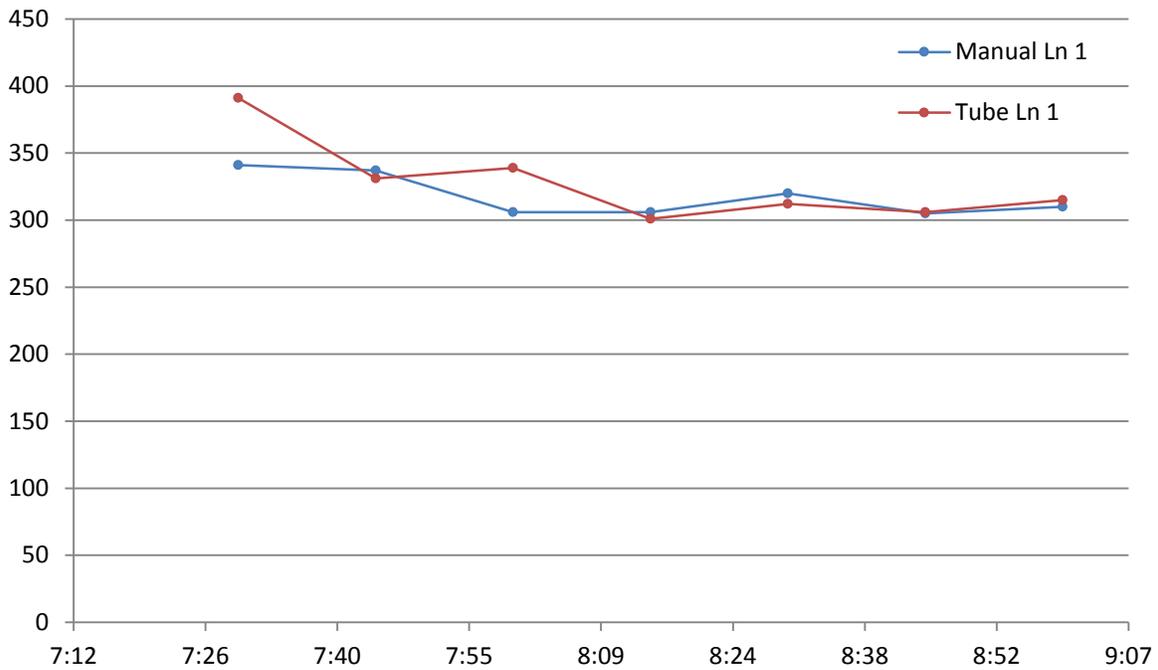


Figure A-18: Time Series Plot for Manual Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes

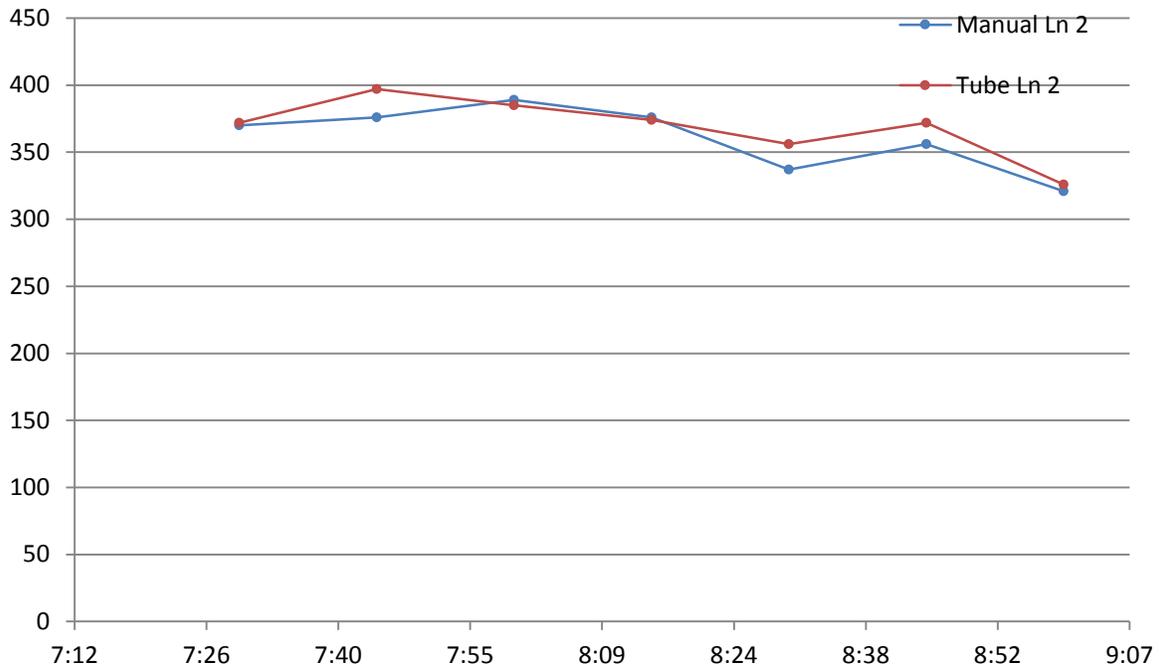


Figure A-19: Time Series Plot for Manual Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes

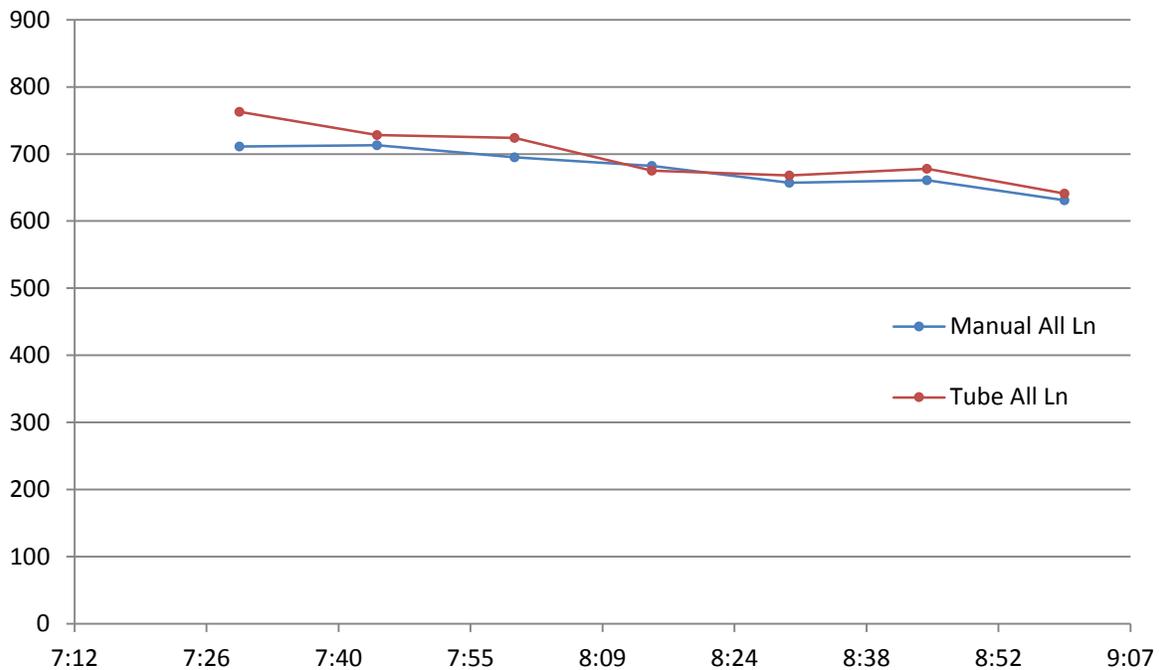


Figure A-20: Time Series Plot for Manual Counts Downstream of Intersection and Signal Detector Counts at Intersection of SR 140 WB and River Exchange Parkway for Aggregates over All Lanes

7.4 SR 92 at King Road / Woodstock Road

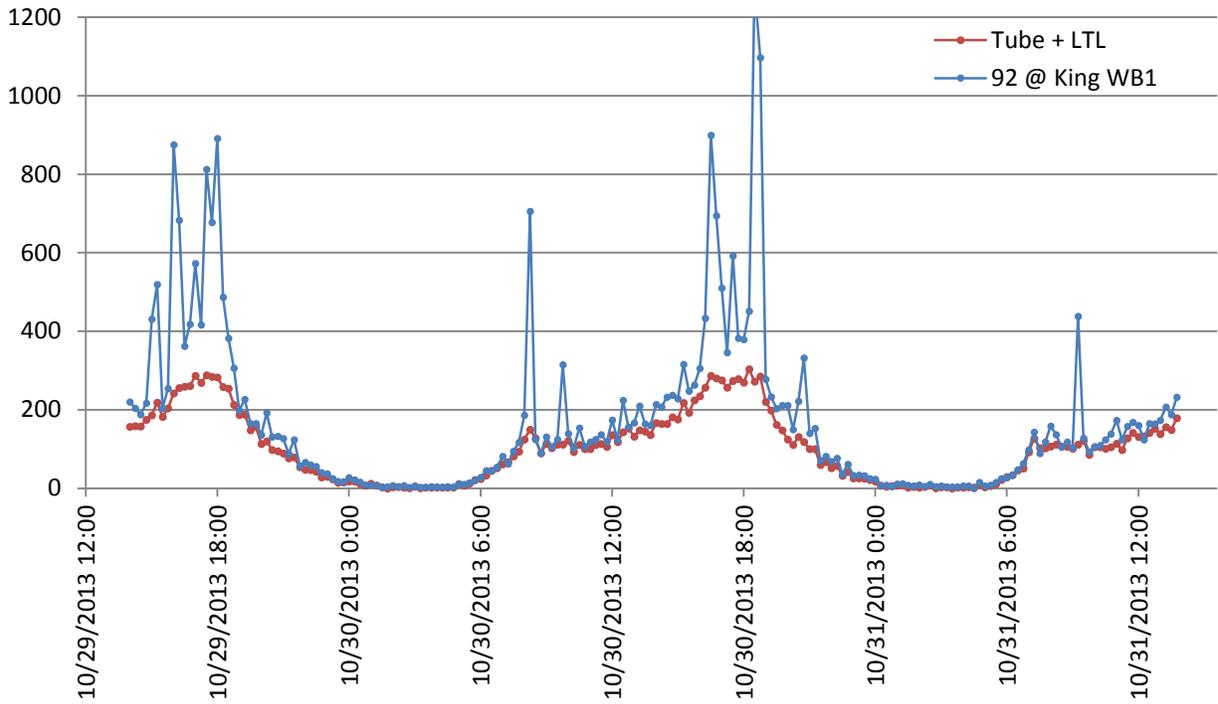


Figure A-21: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 1

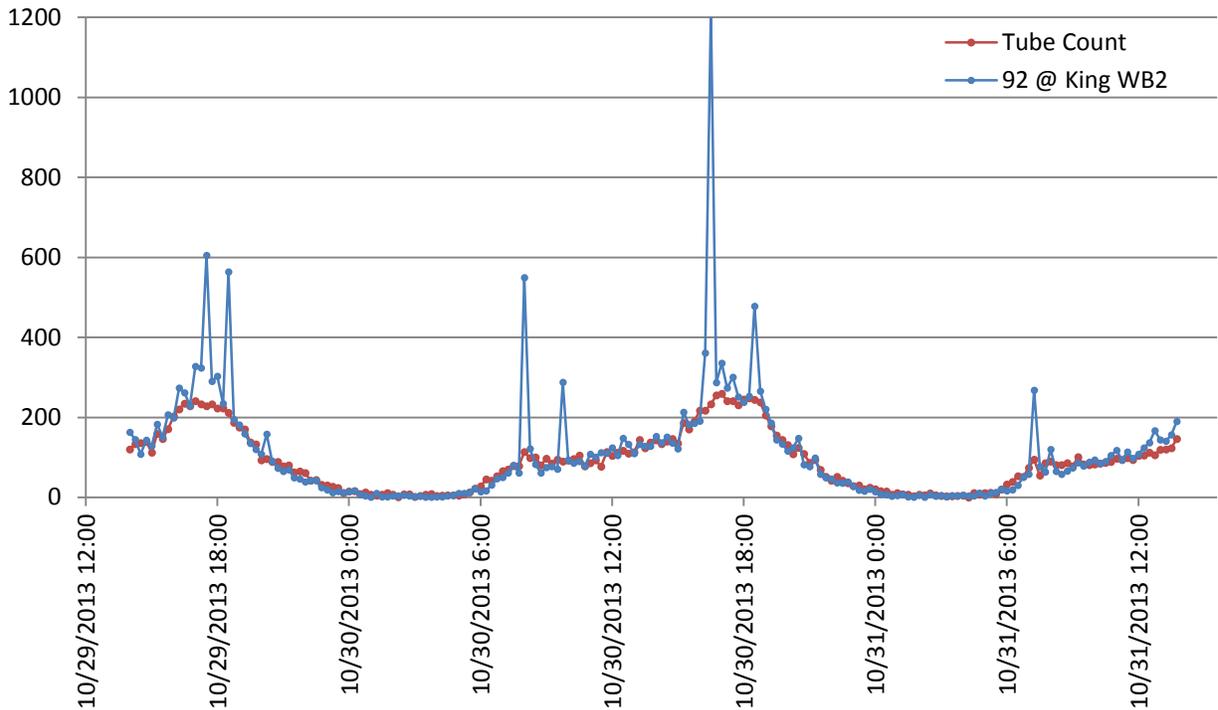


Figure A-22: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 2

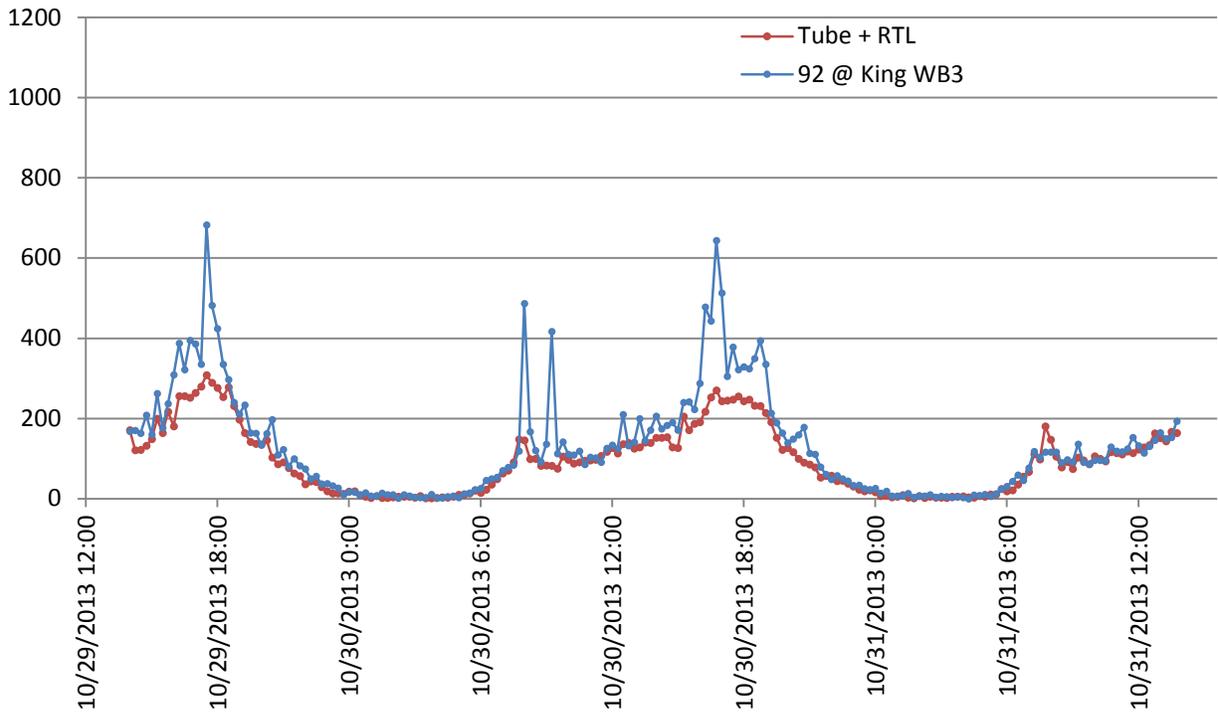


Figure A-23: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 3

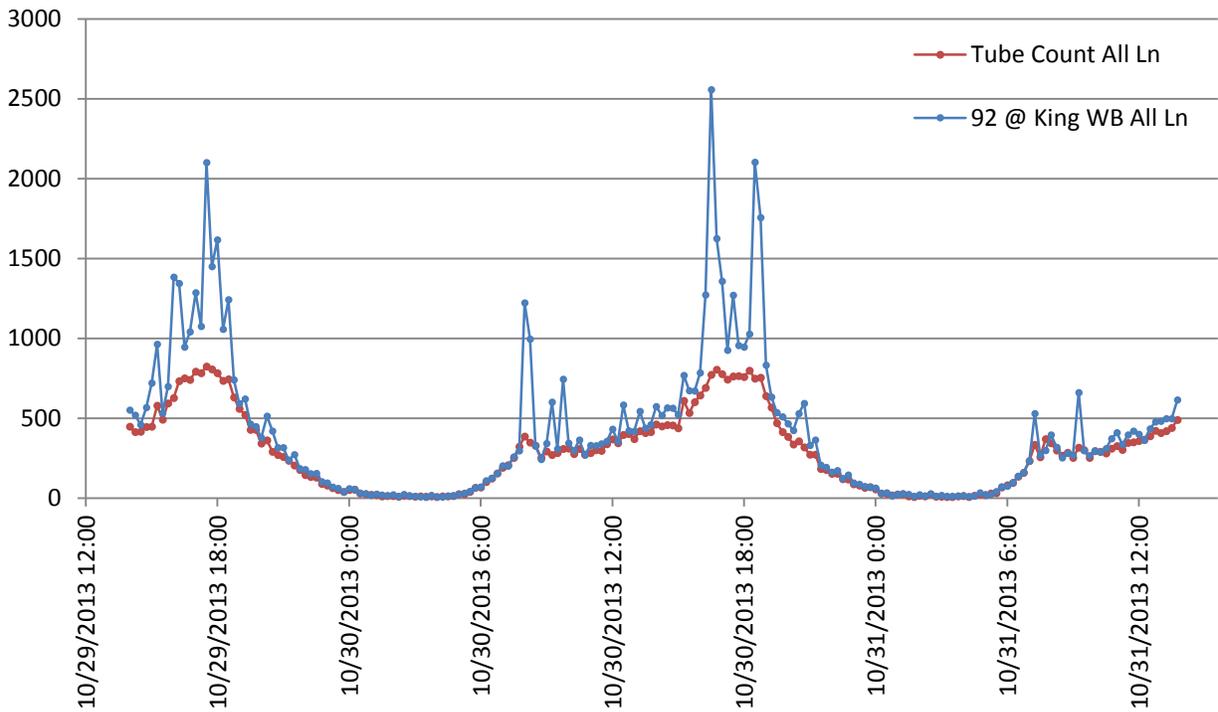


Figure A-24: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes

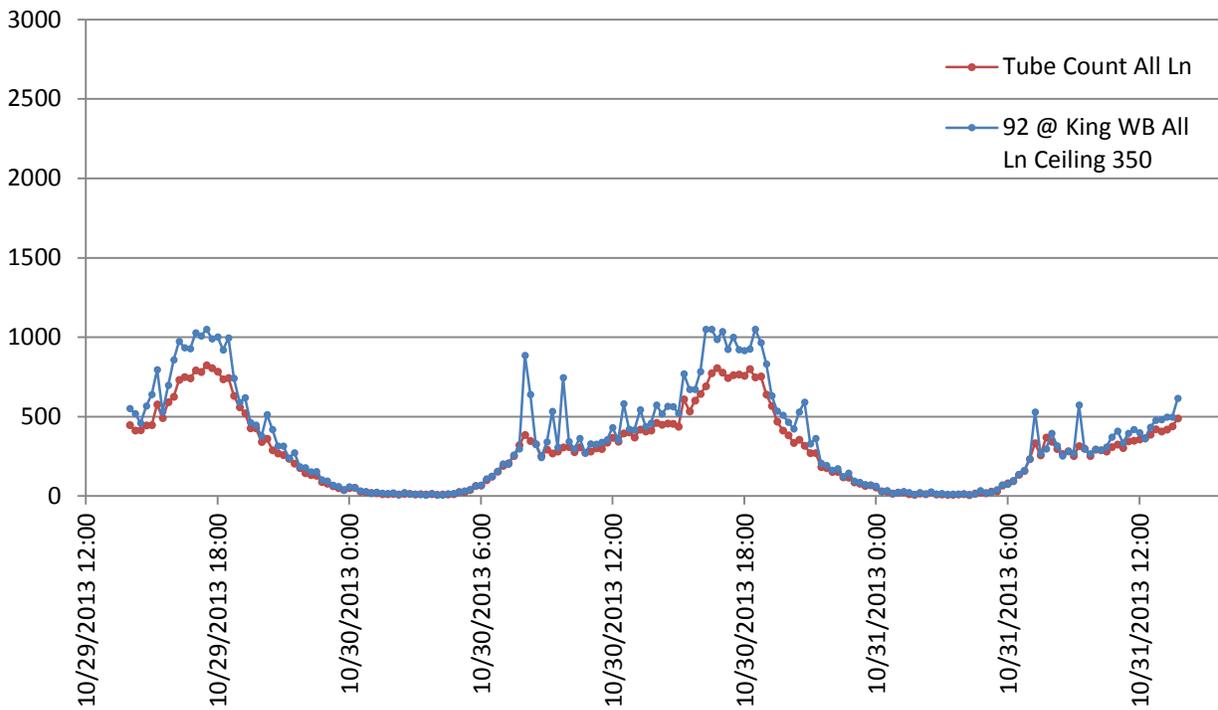


Figure A-25: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes with Count Ceiling per lane at 350 vehicles

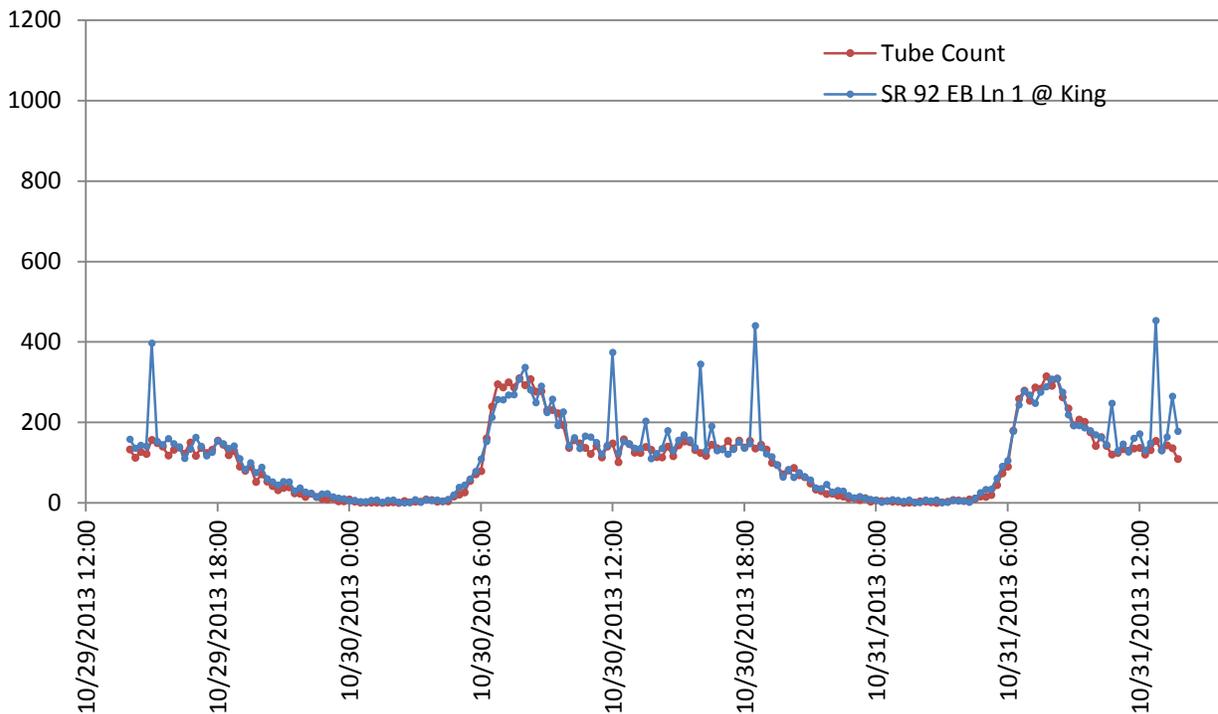


Figure A-26: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 1

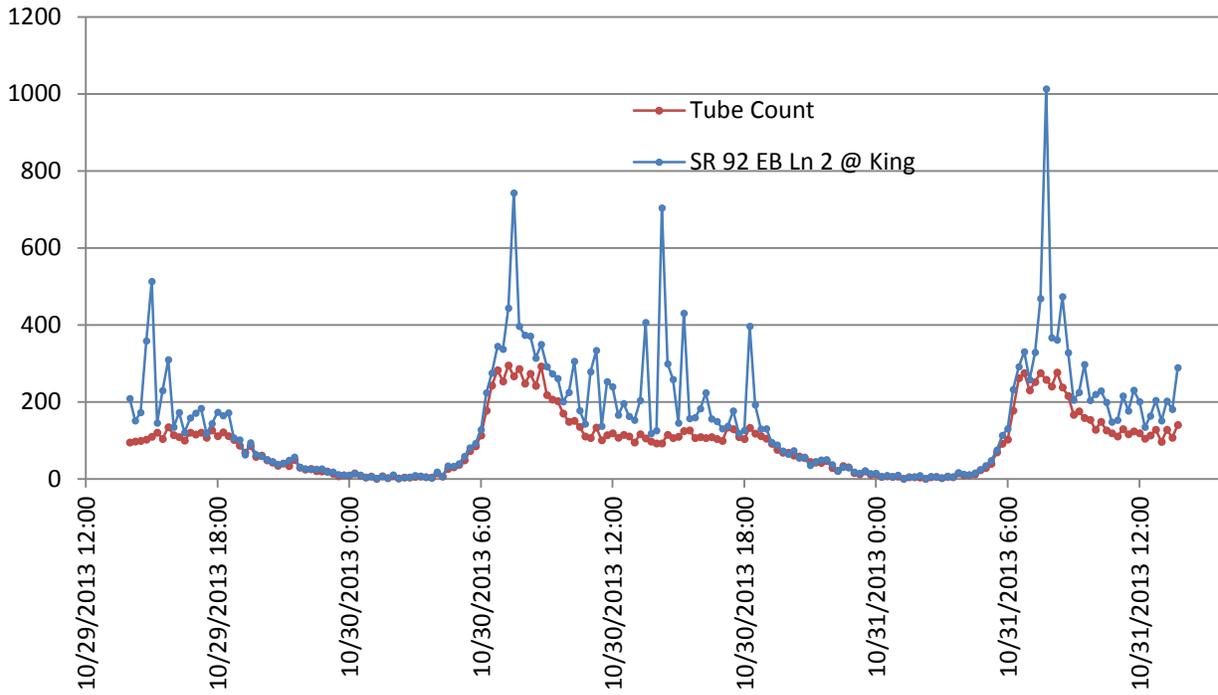


Figure A-27: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 2

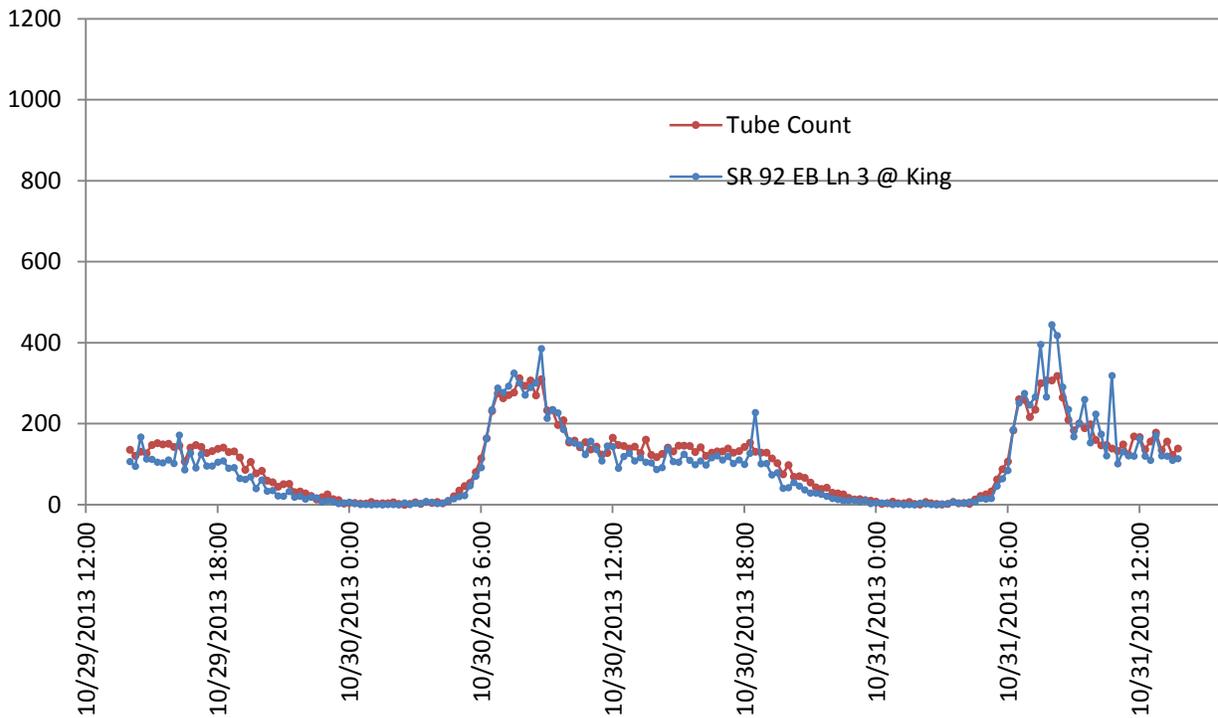


Figure A-28: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Lane 3

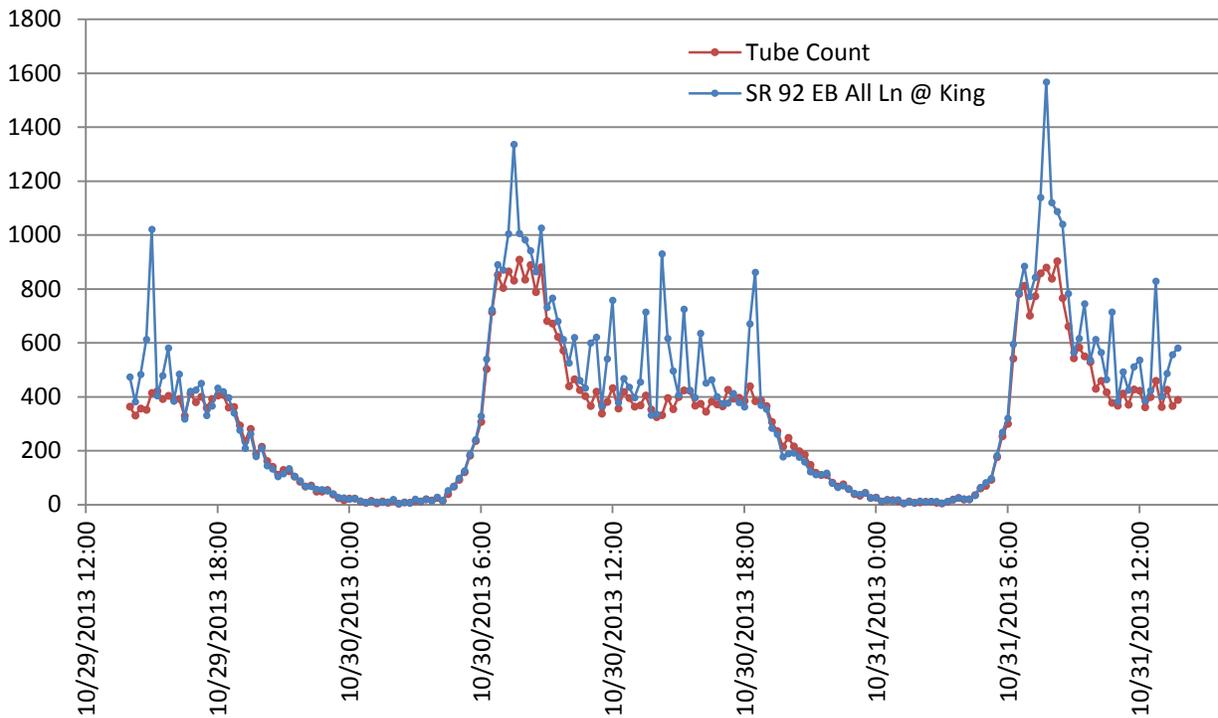


Figure A-29: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and King Road for Aggregates over All Lanes

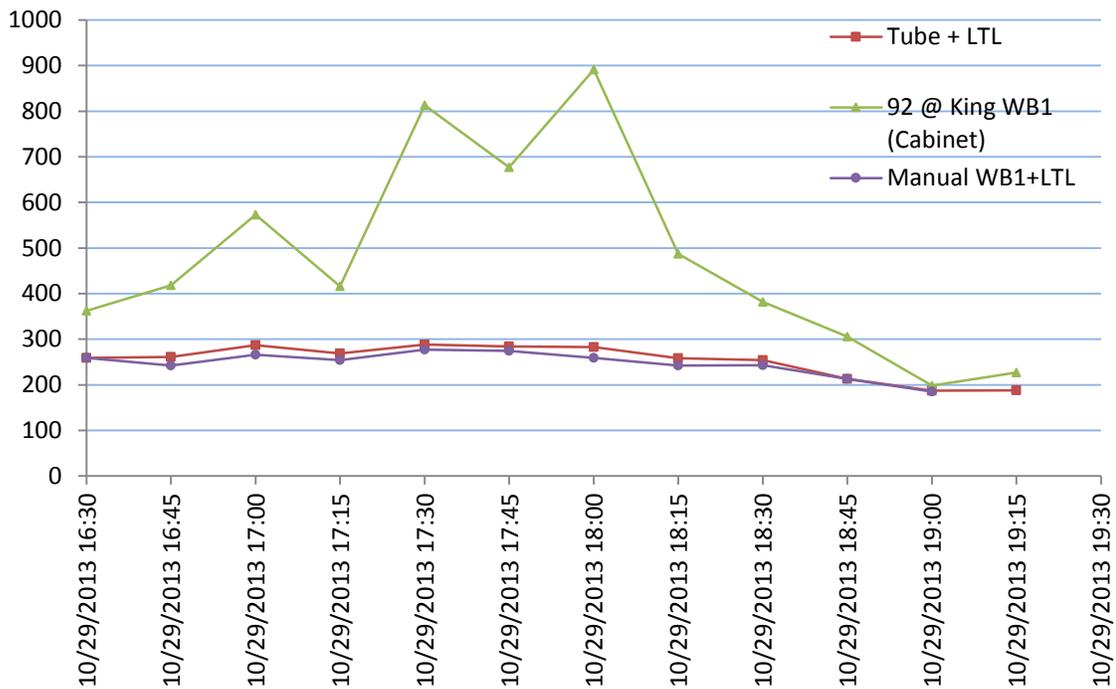


Figure A-30: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 1

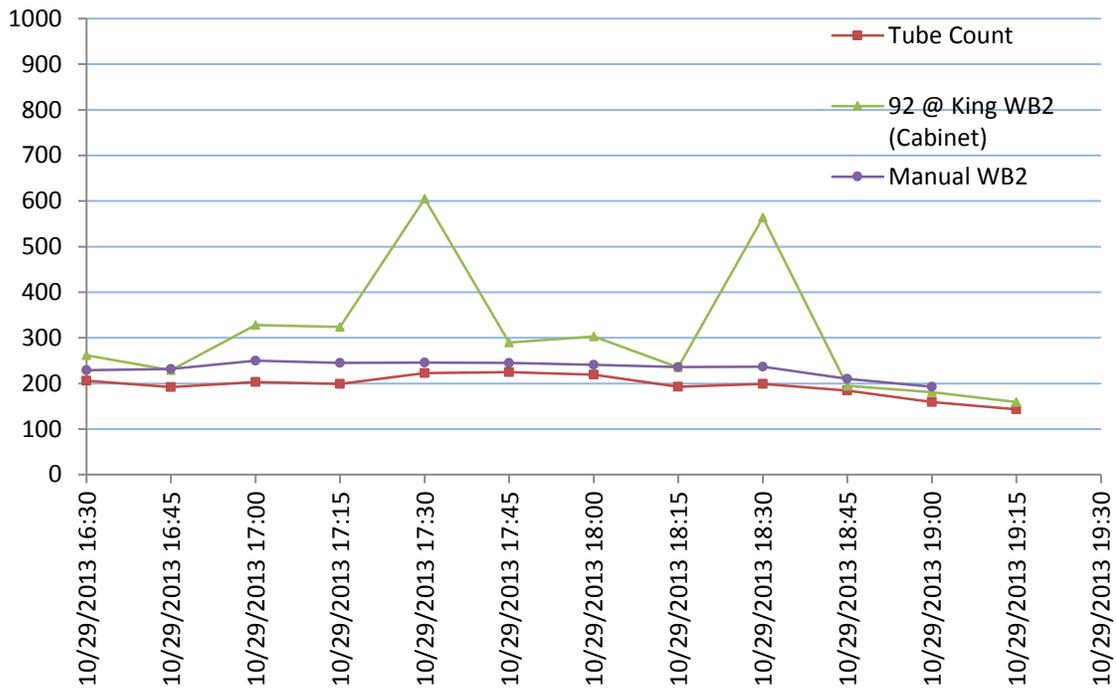


Figure A-31: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 2

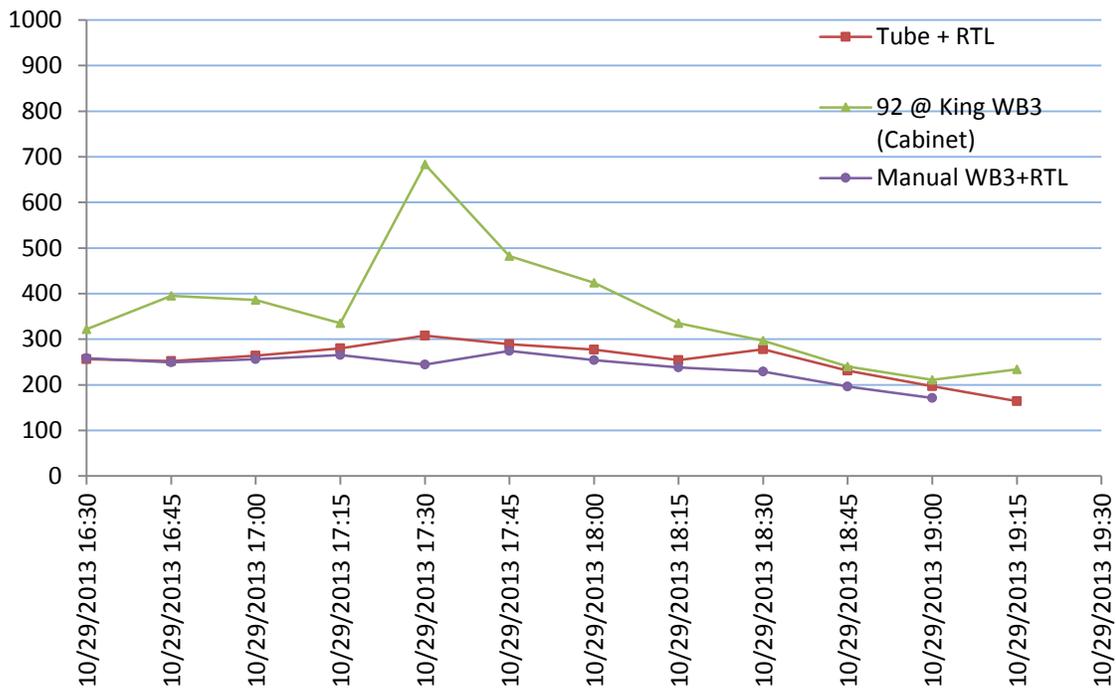


Figure A-32: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Lane 3

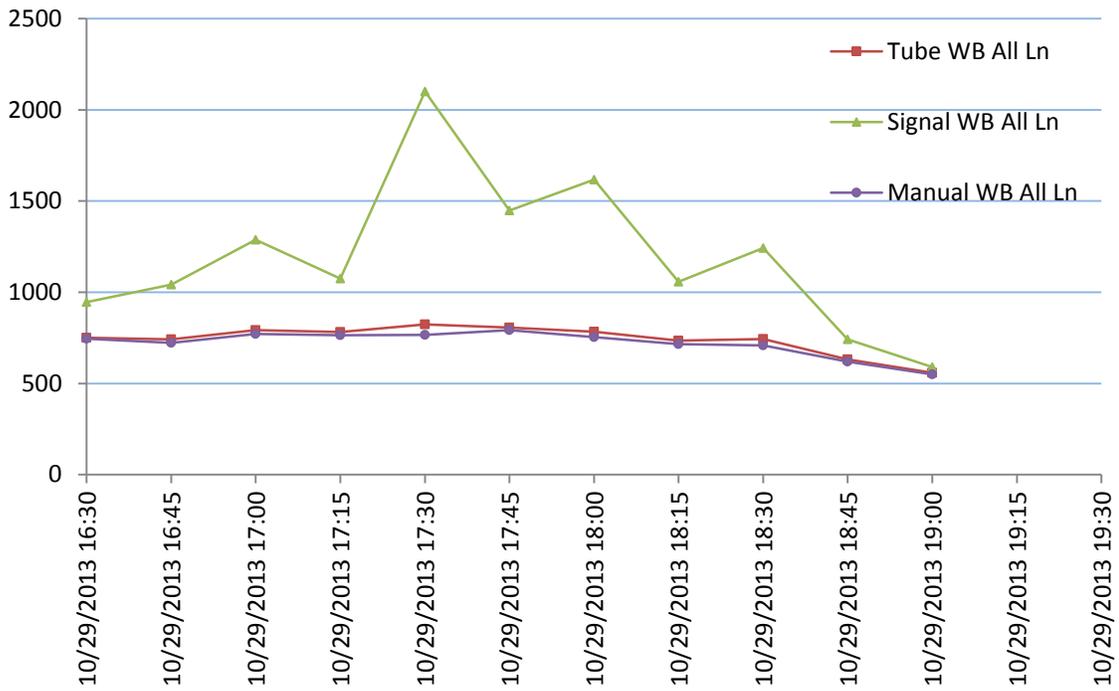


Figure A-33: Time Series Plot for Manual Counts, Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and King Road for Aggregates over All Lanes

7.5 SR140 at Steeple Chase Drive

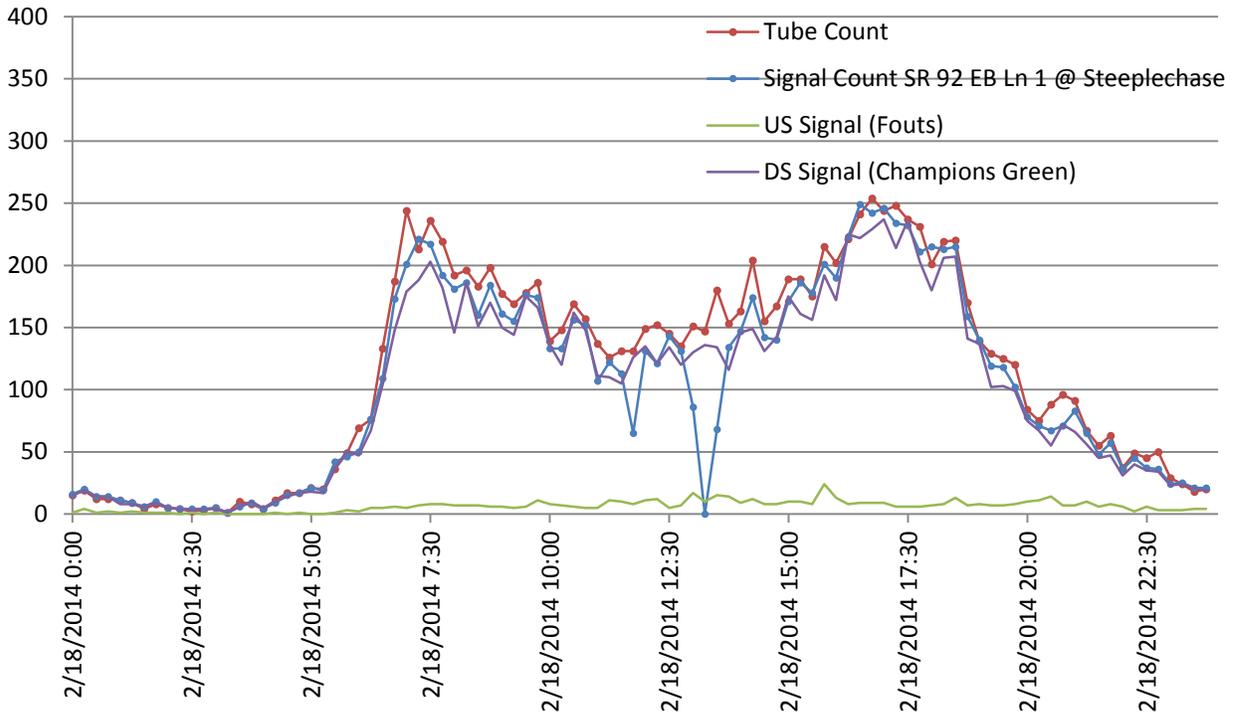


Figure A-34: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple ChaseDr for Lane 1

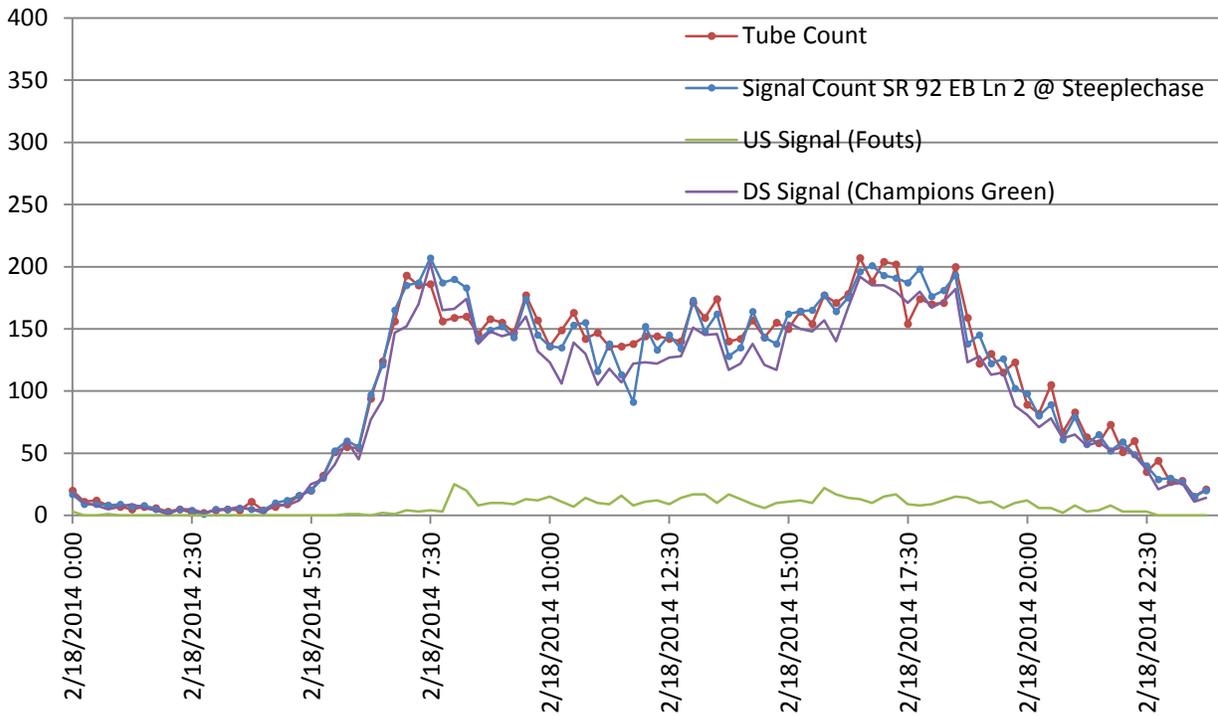


Figure A-35: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple ChaseDr for Lane 2

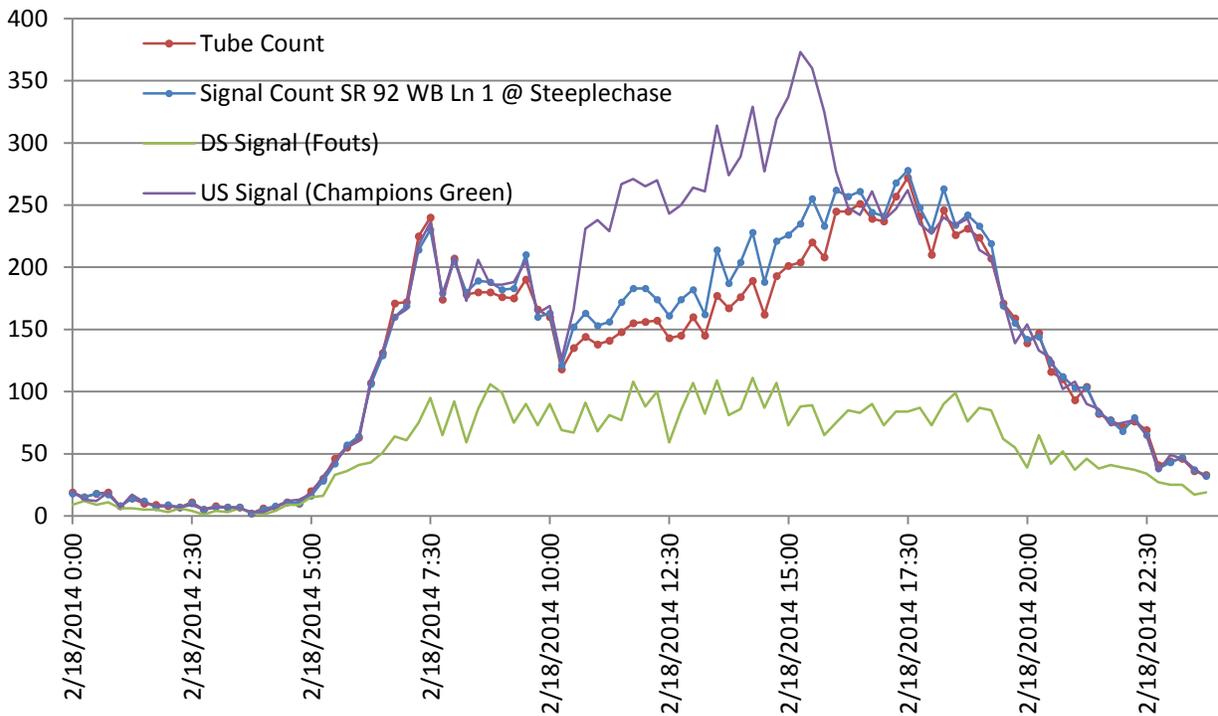


Figure A-36: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 WB and Woodlands Parkway for Lane 1

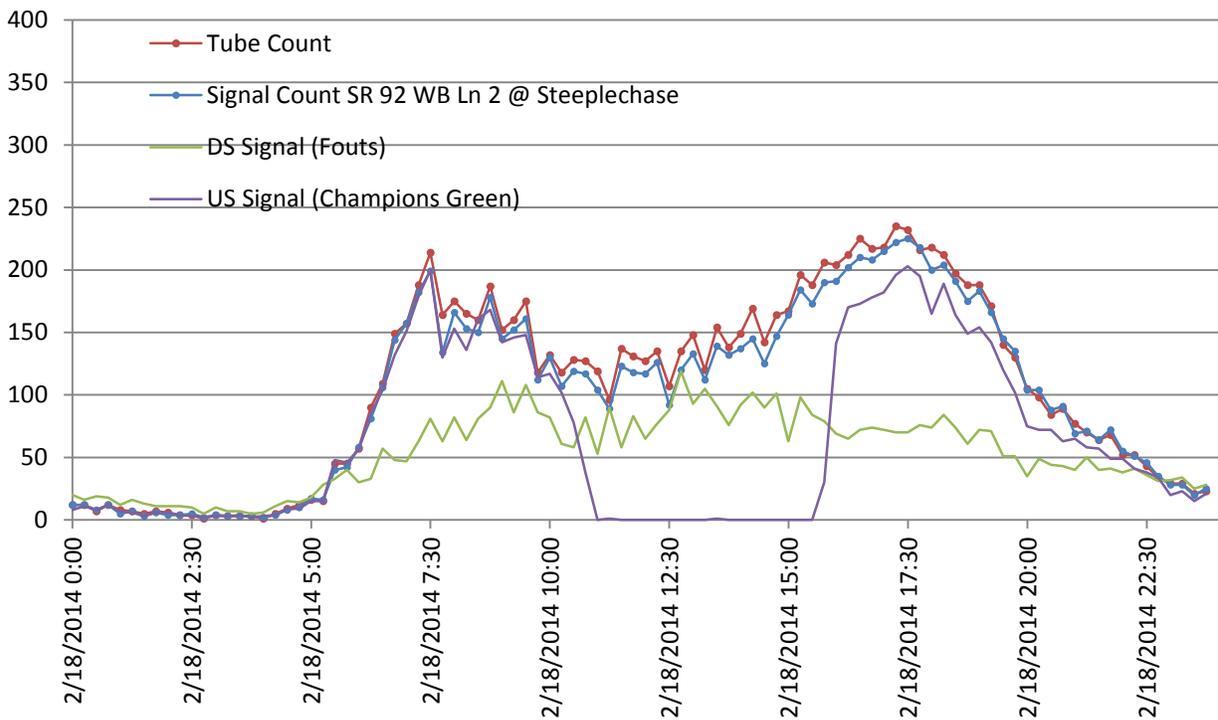


Figure A-37: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 WB and Woodlands Parkway for Lane 2

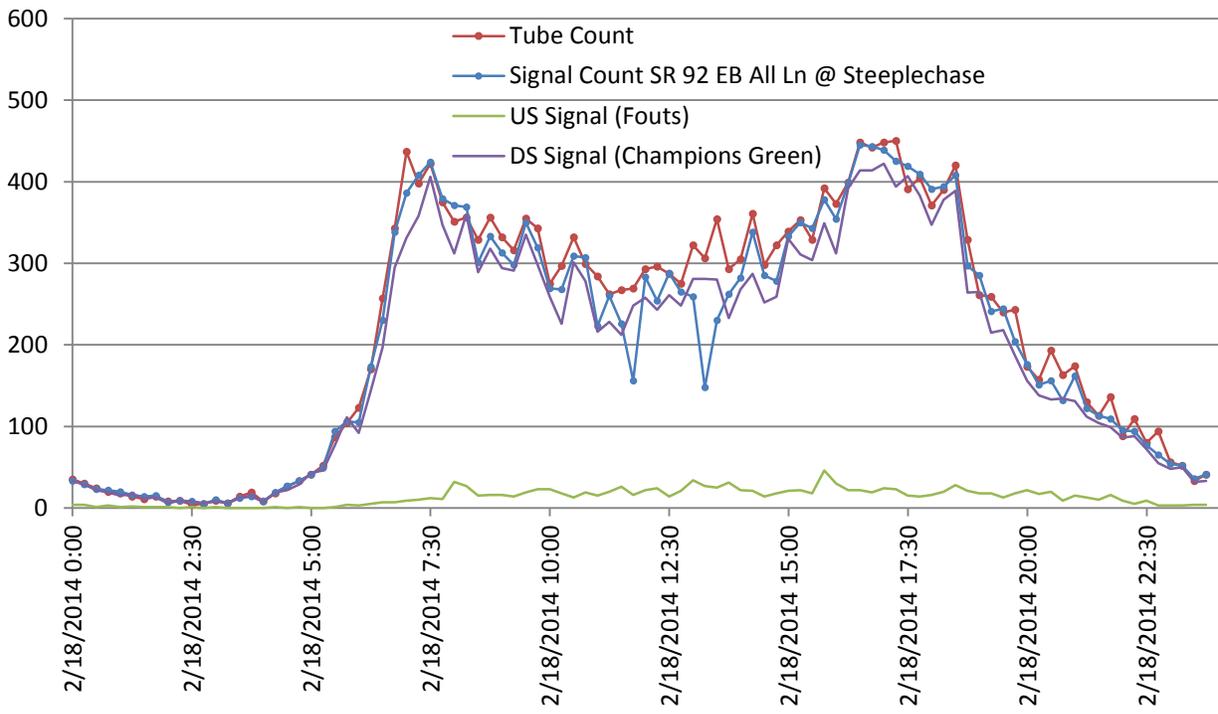


Figure A-38: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 EB and Steeple Chase Drive for Aggregates over All Lanes

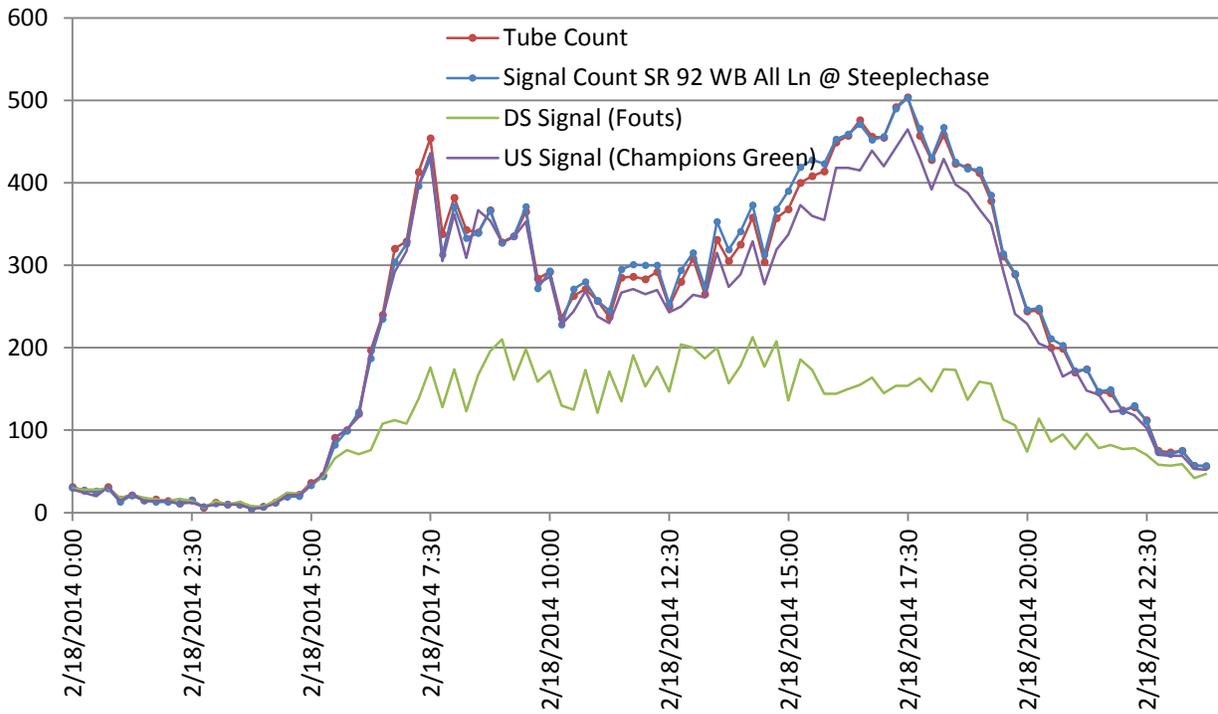


Figure A-39: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 140 WB and Woodland Parkway for Aggregates over All Lanes

7.6 SR 314 at Banks Road and Creek Wood Trail

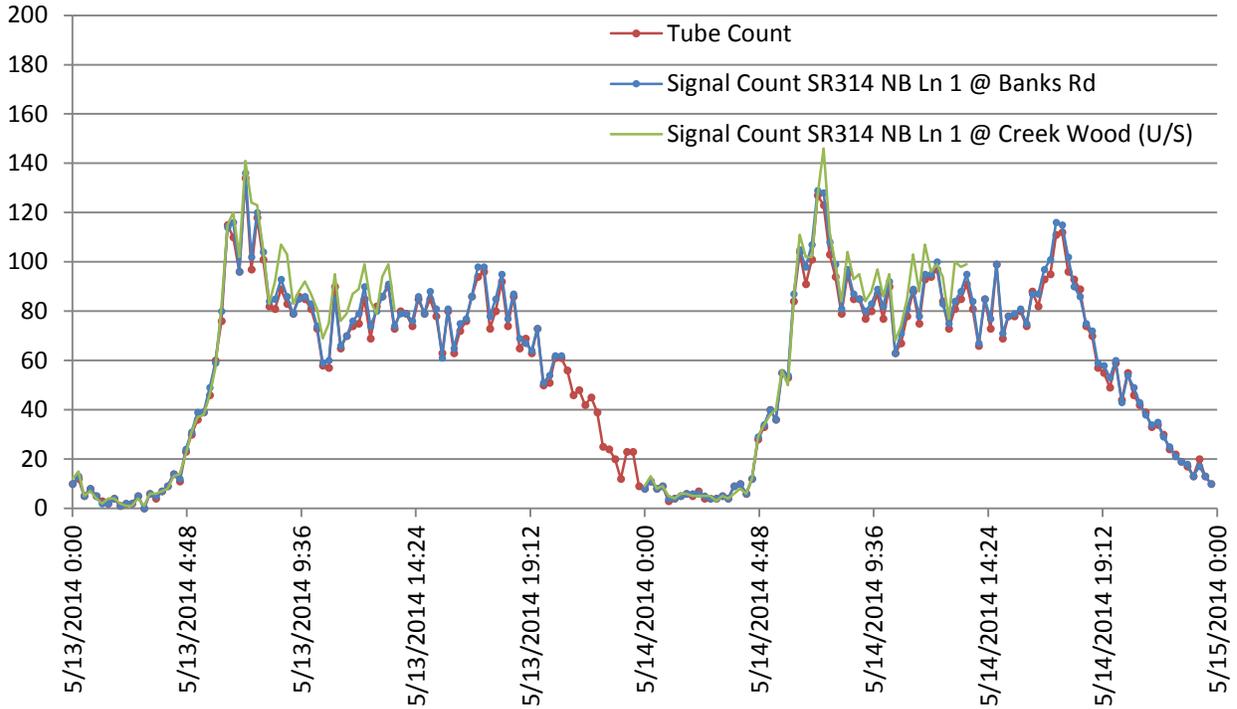


Figure A-40: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 1

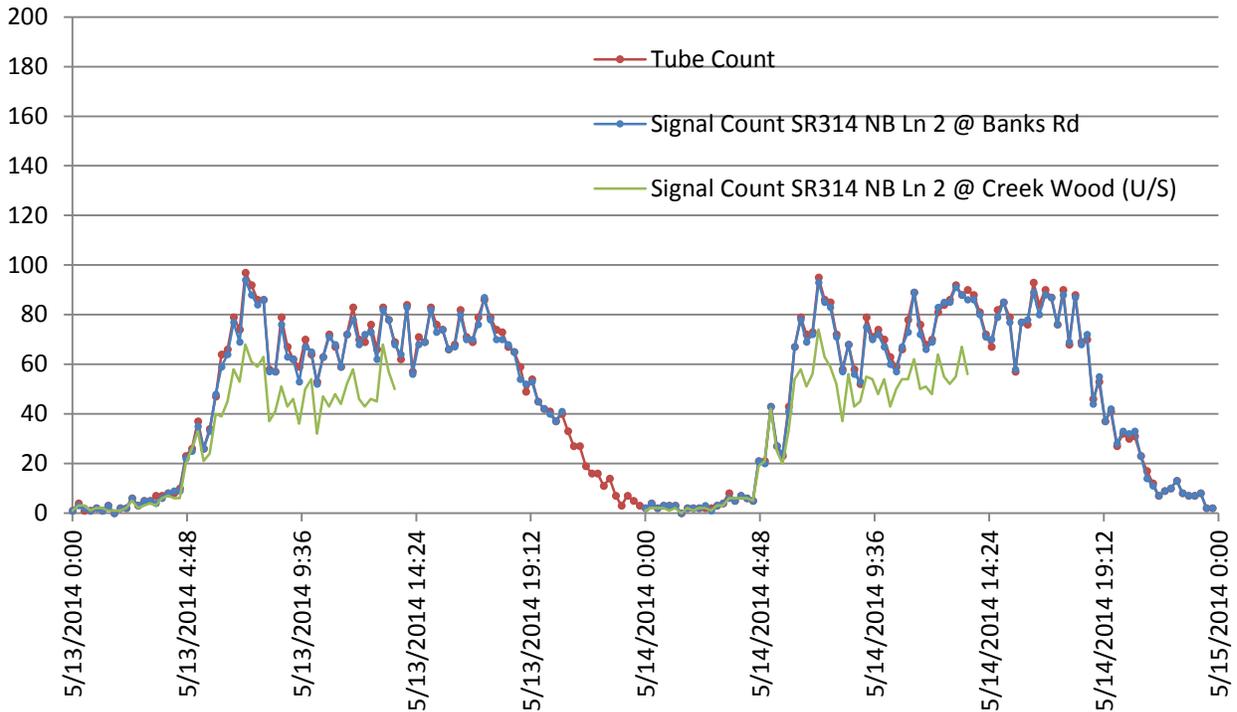


Figure A-41: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 NB and Banks Rd for Lane 2

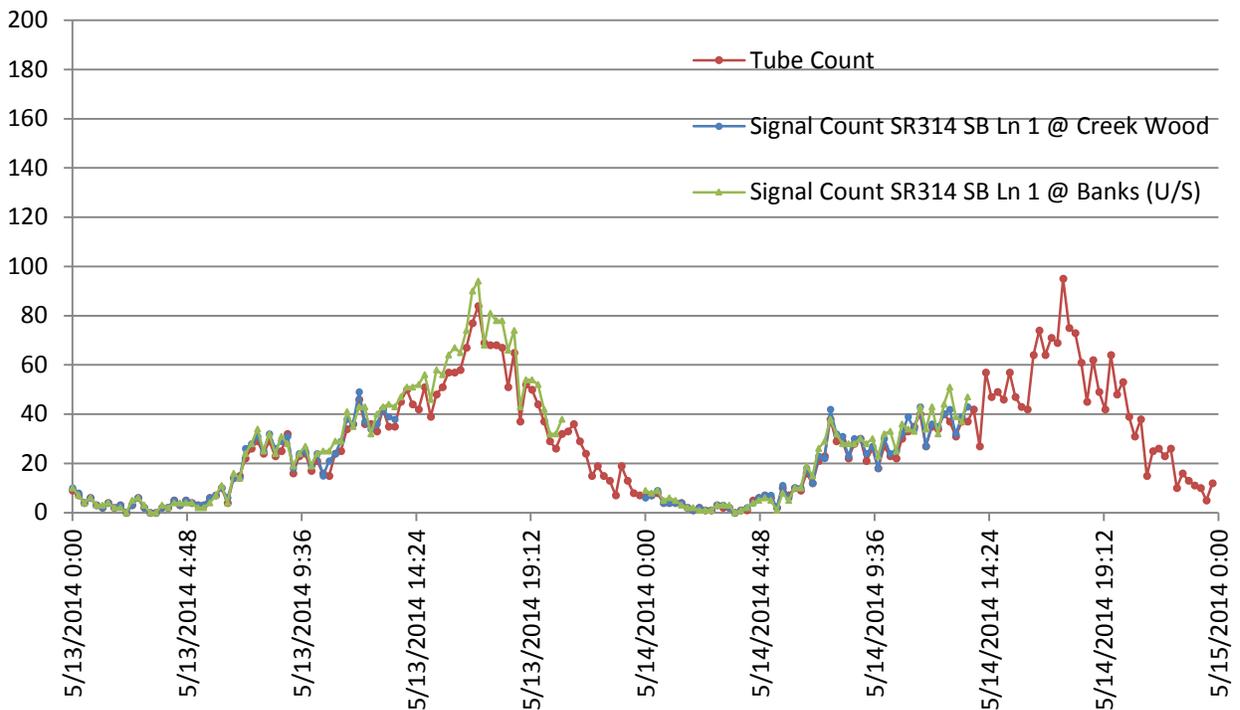


Figure A-42: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 SB and Creek Wood Trl for Lane 1

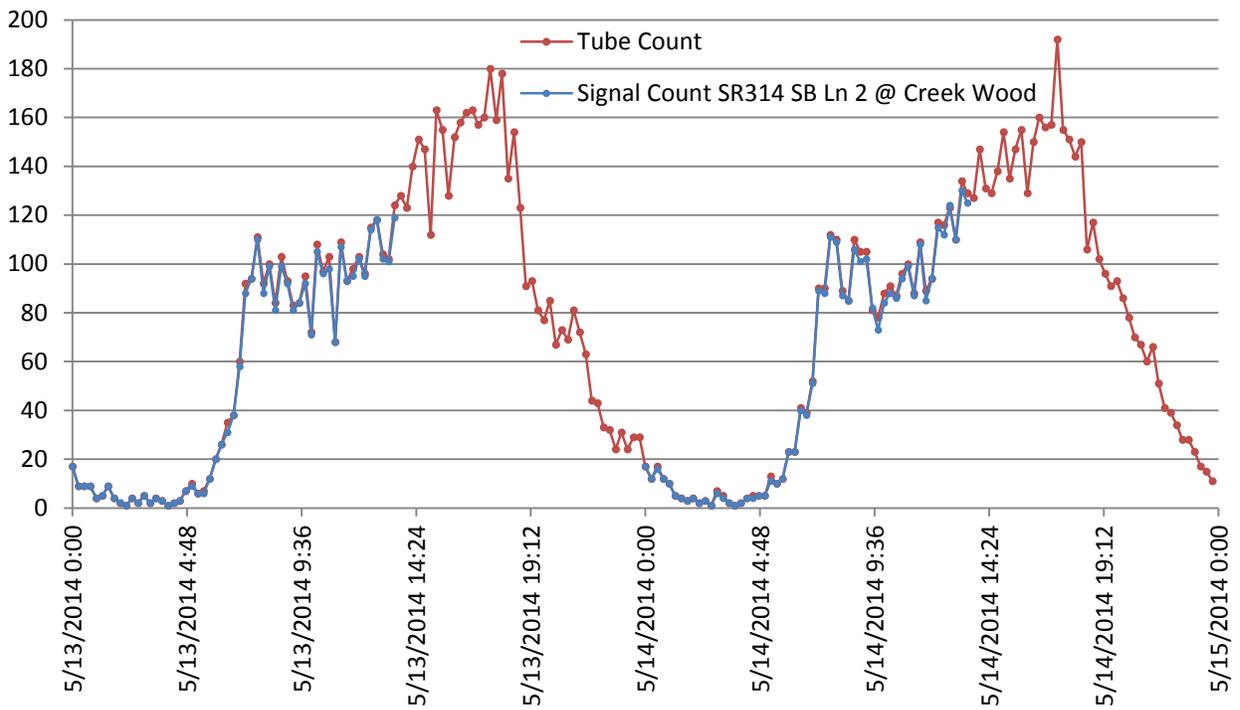


Figure A-43: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 SB and Creek Wood Trl for Lane 2

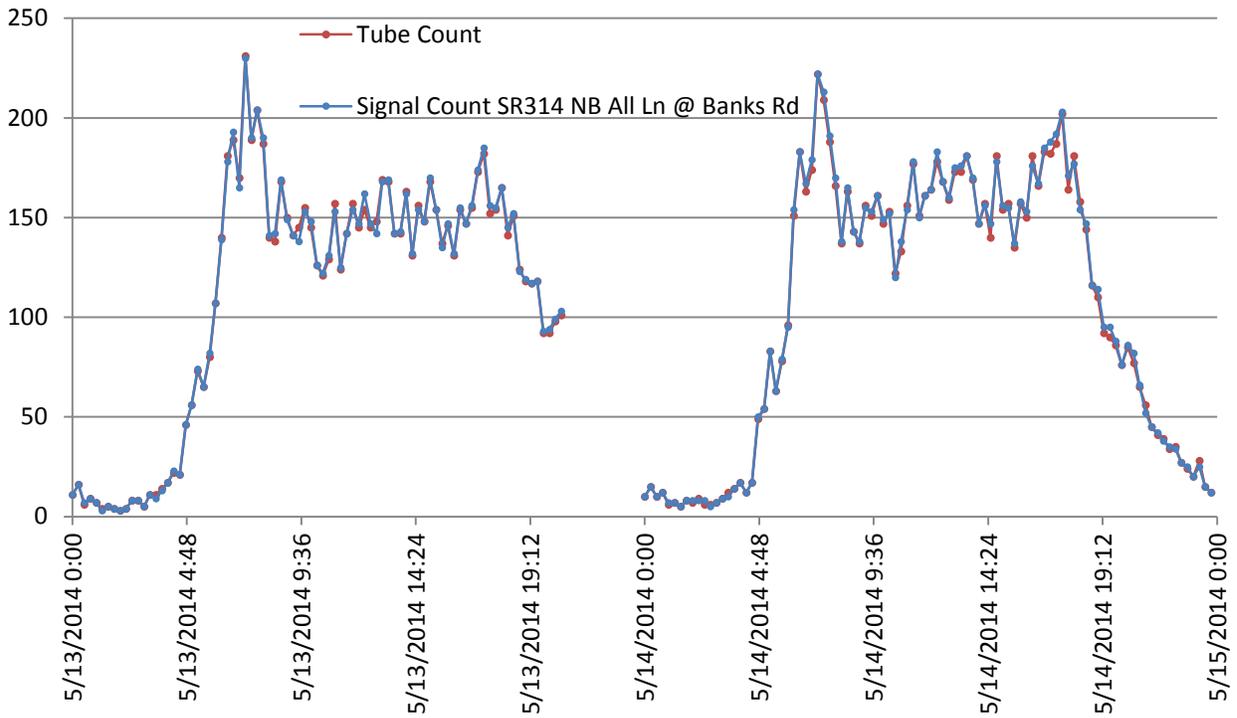


Figure A-44: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 EB and Banks Rd for Aggregates over All Lanes

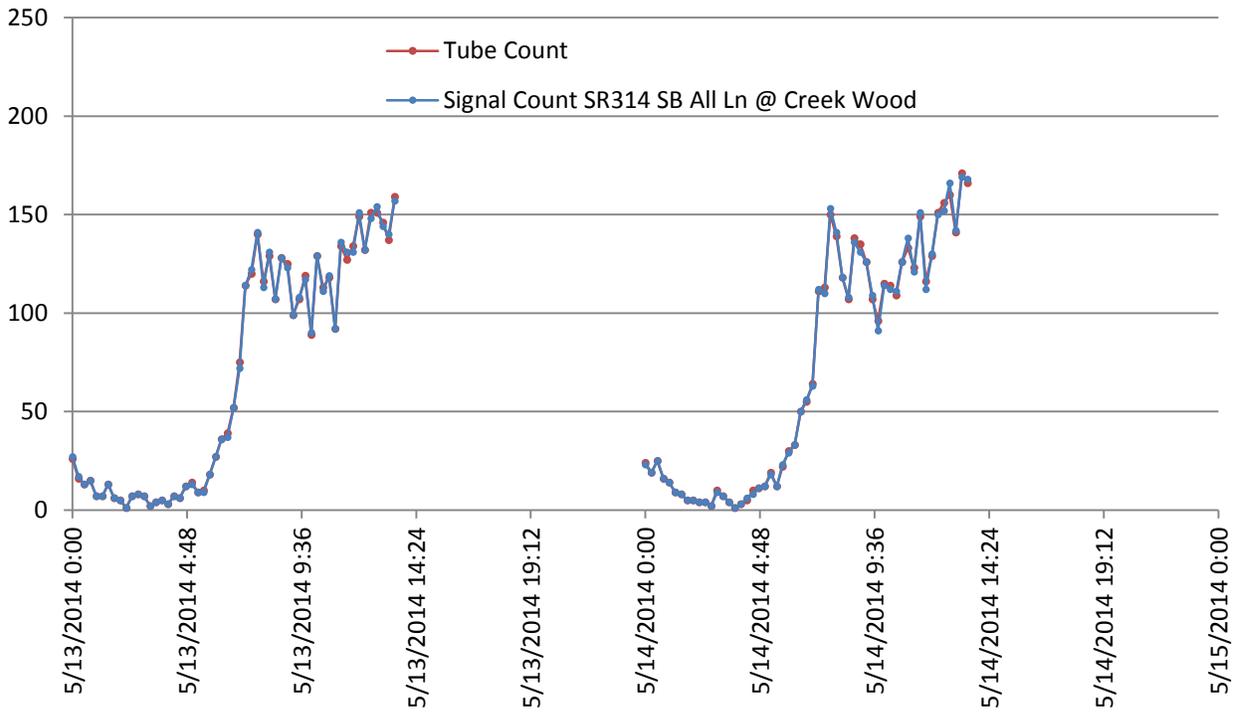


Figure A-45: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 314 WB and Creek Wood Trl for Aggregates over All Lanes

7.7 SR 141 (Peachtree Road) EB at SR 237 (Piedmont Road)

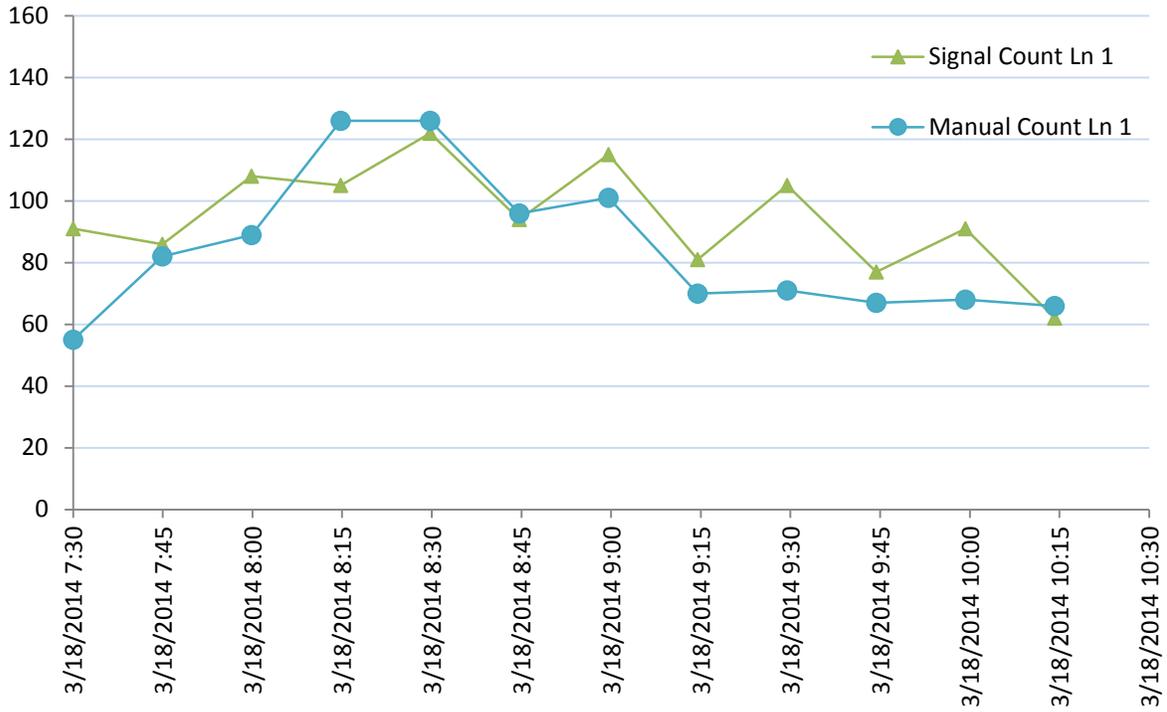


Figure A-46: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 EB and SR 237 for Lane 1

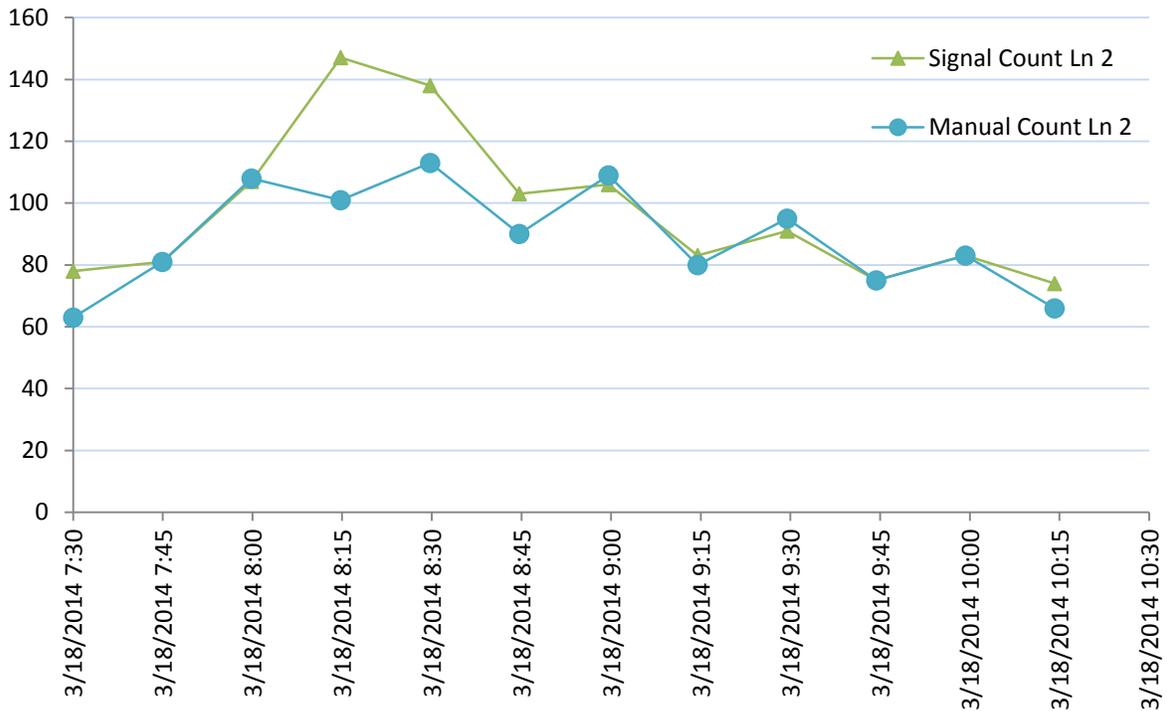


Figure A-47: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 EB and SR 237 for Lane 2

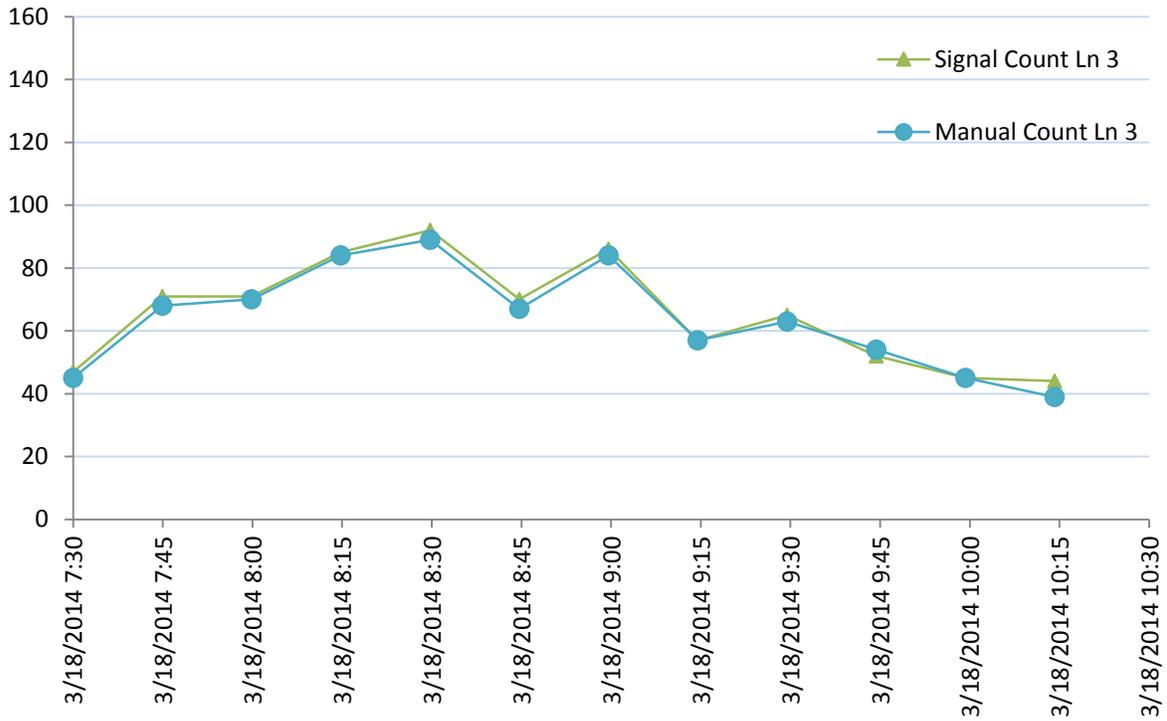


Figure A-48: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 WB and SR 237 for Lane 3

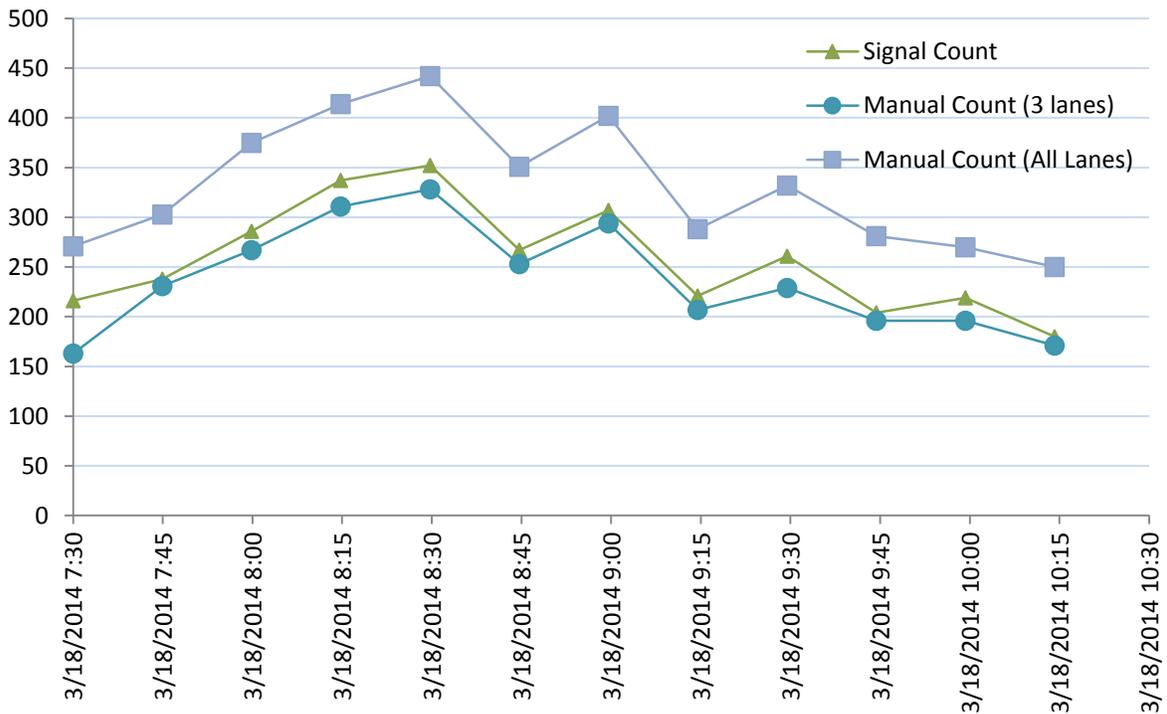


Figure A-49: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 WB and SR 237 for Aggregates over All Lanes

7.8 SR 141 at East Jones Bridge Rd

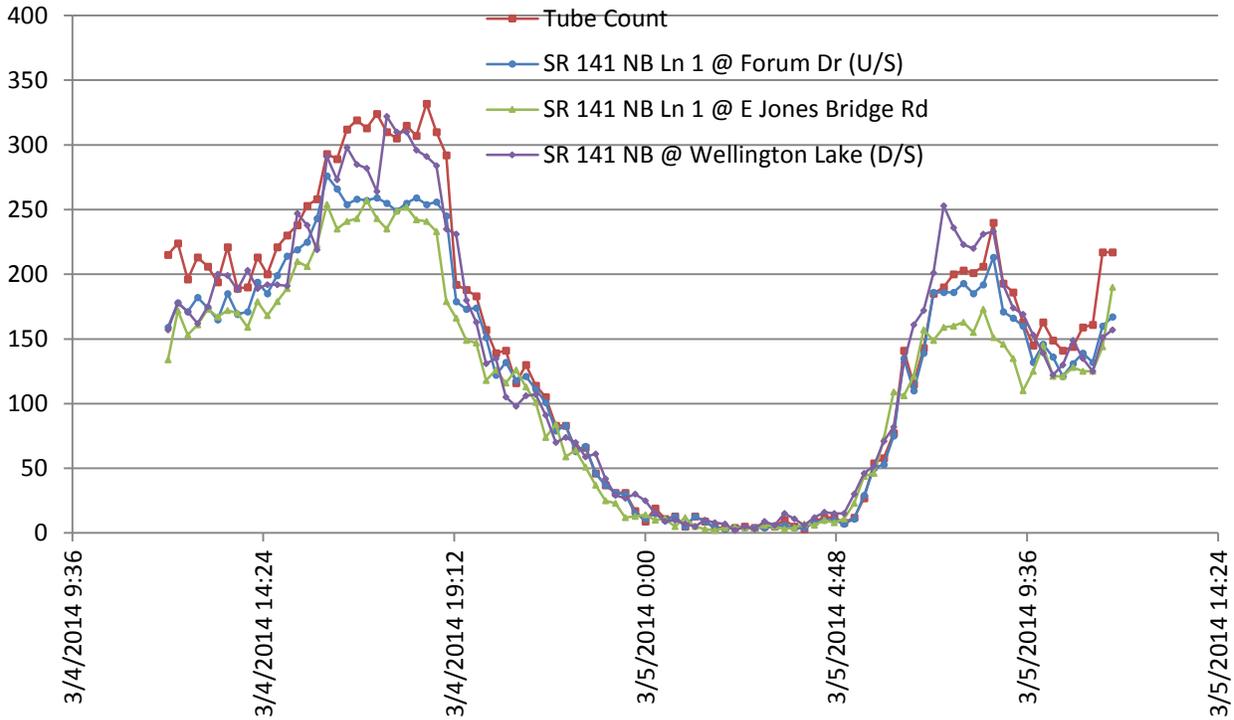


Figure A-50: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 NB and East Jones Bridge Road for Lane 1

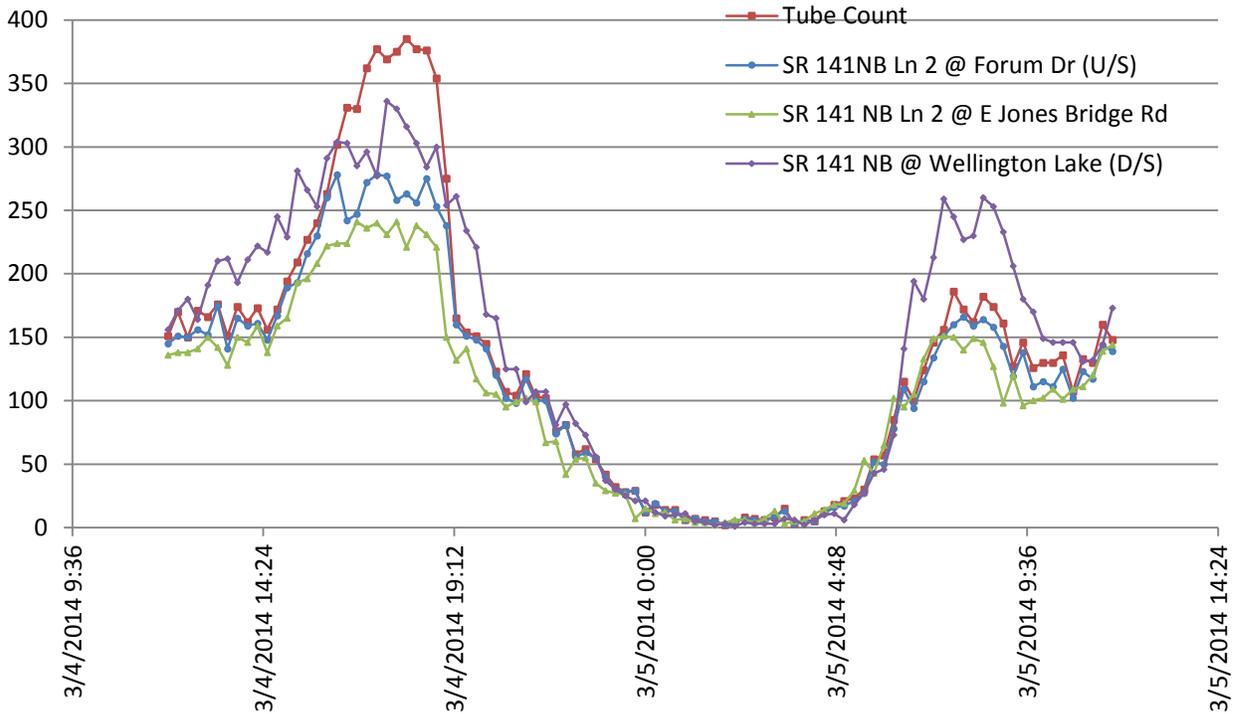


Figure A-51: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 NB and East Jones Bridge Road for Lane 2

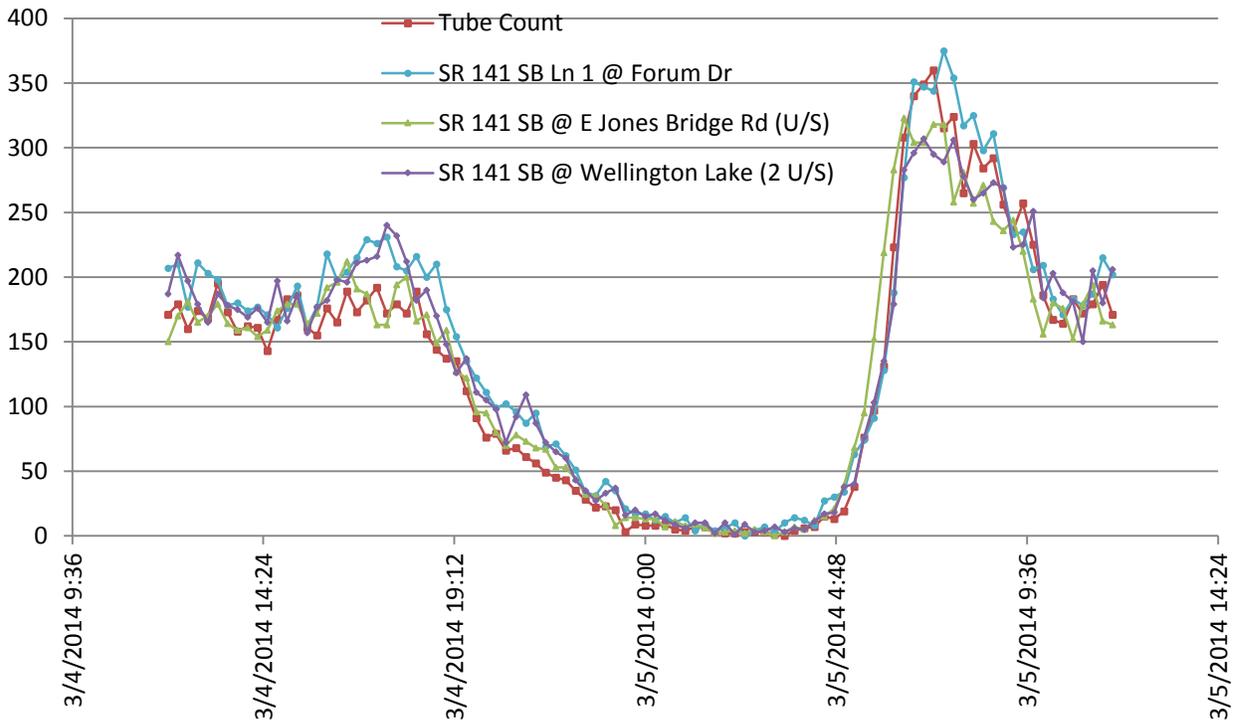


Figure A-52: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 SB and Forum Drive for Lane 1

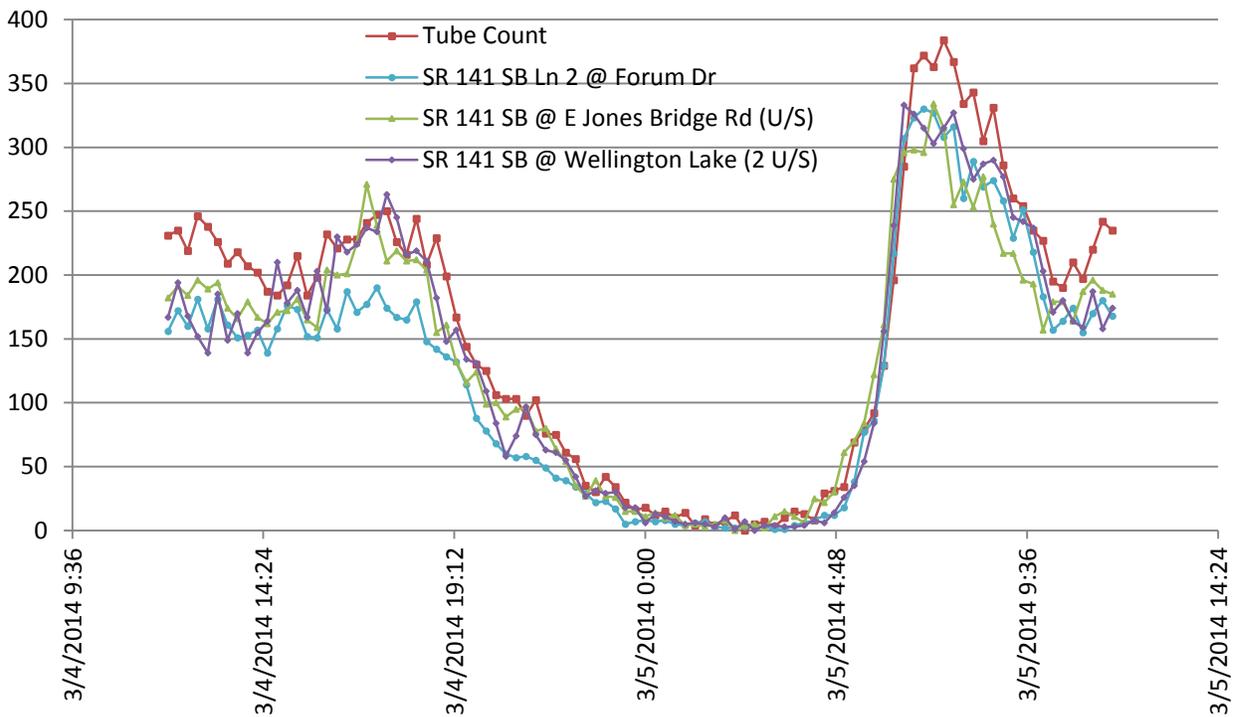


Figure A-53: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 SB and Forum Drive for Lane 2

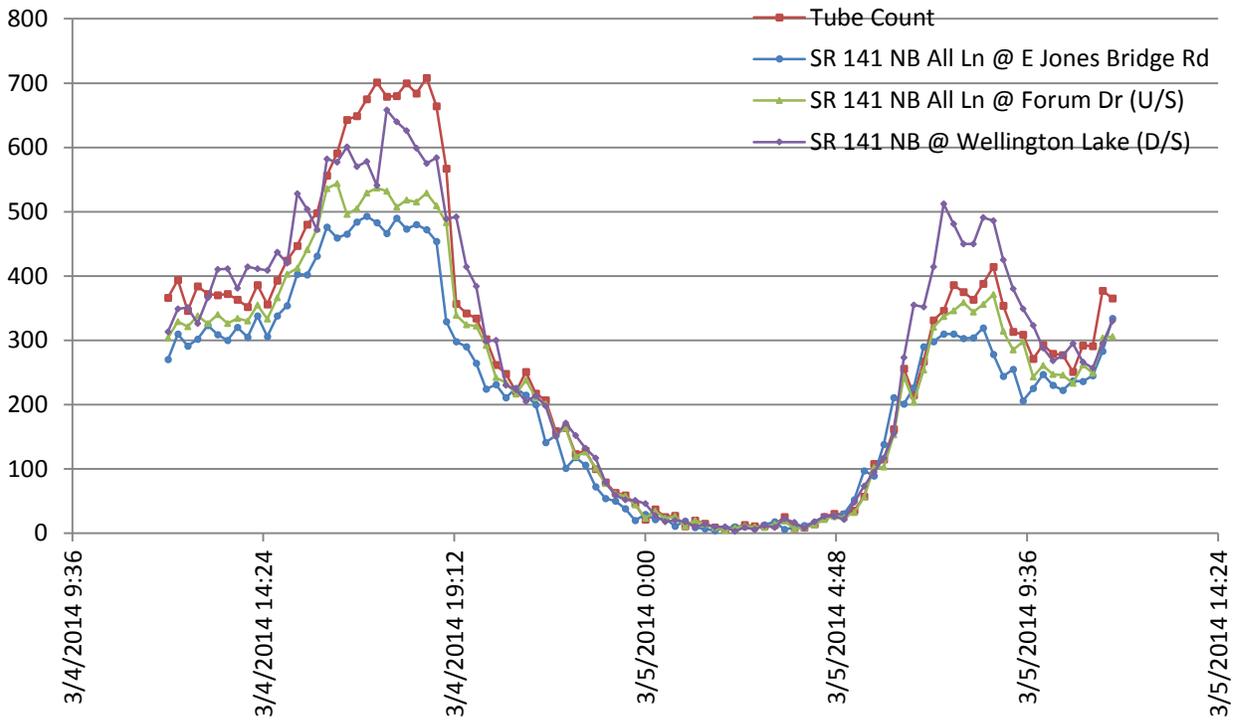


Figure A-54: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 NB and East Jones Bridge Road for Aggregates over All Lanes

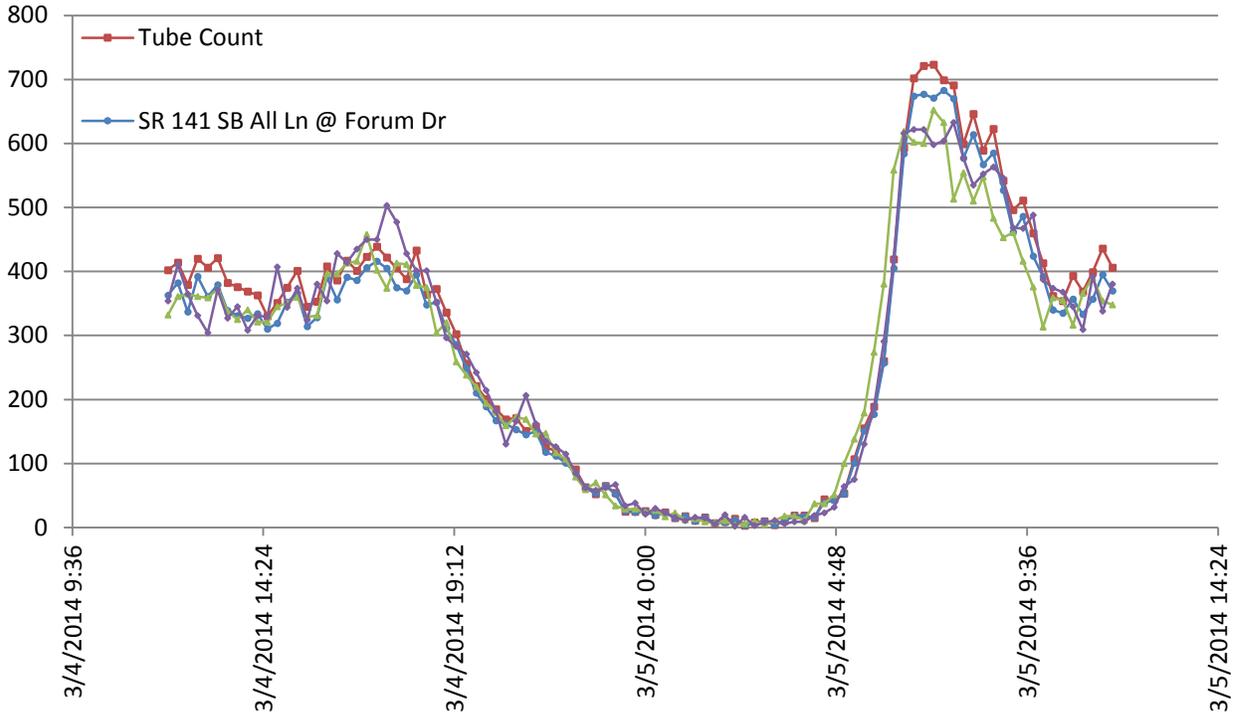


Figure A-55: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 141 SB and Forum Drive for Aggregates over All Lanes

7.9 SR 92 at Dials Drive / Woodlands Parkway

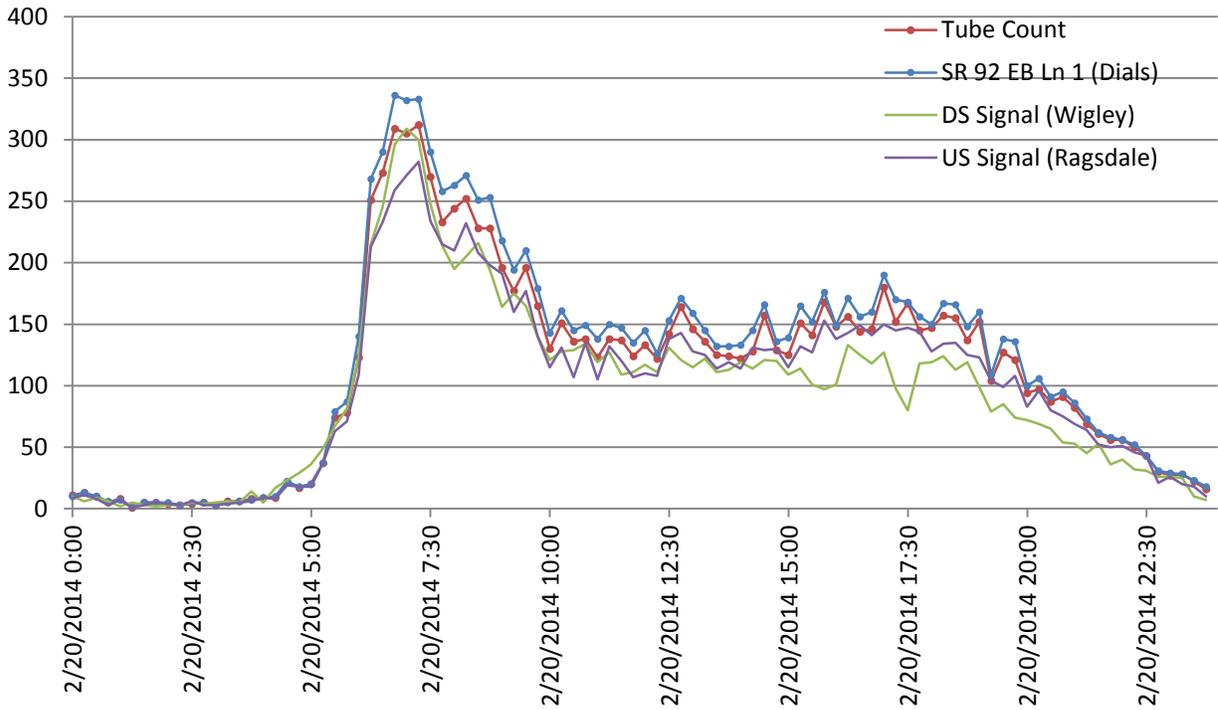


Figure A-56: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 1

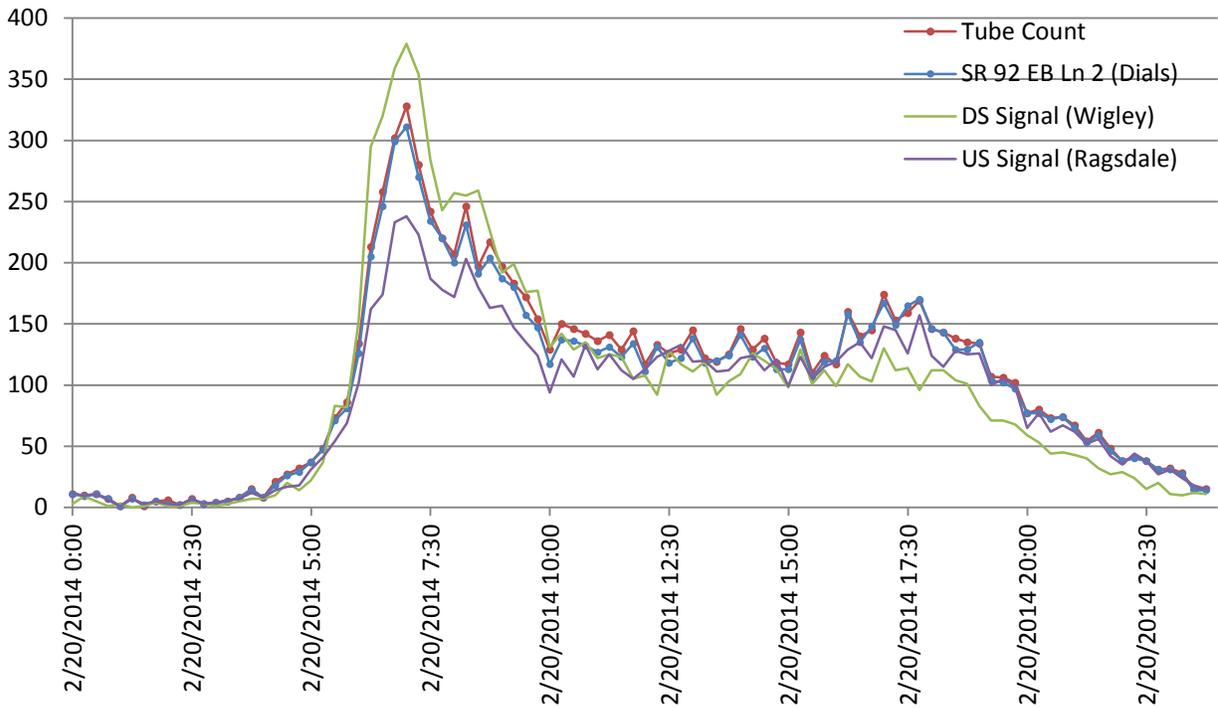


Figure A-57: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Dr for Lane 2

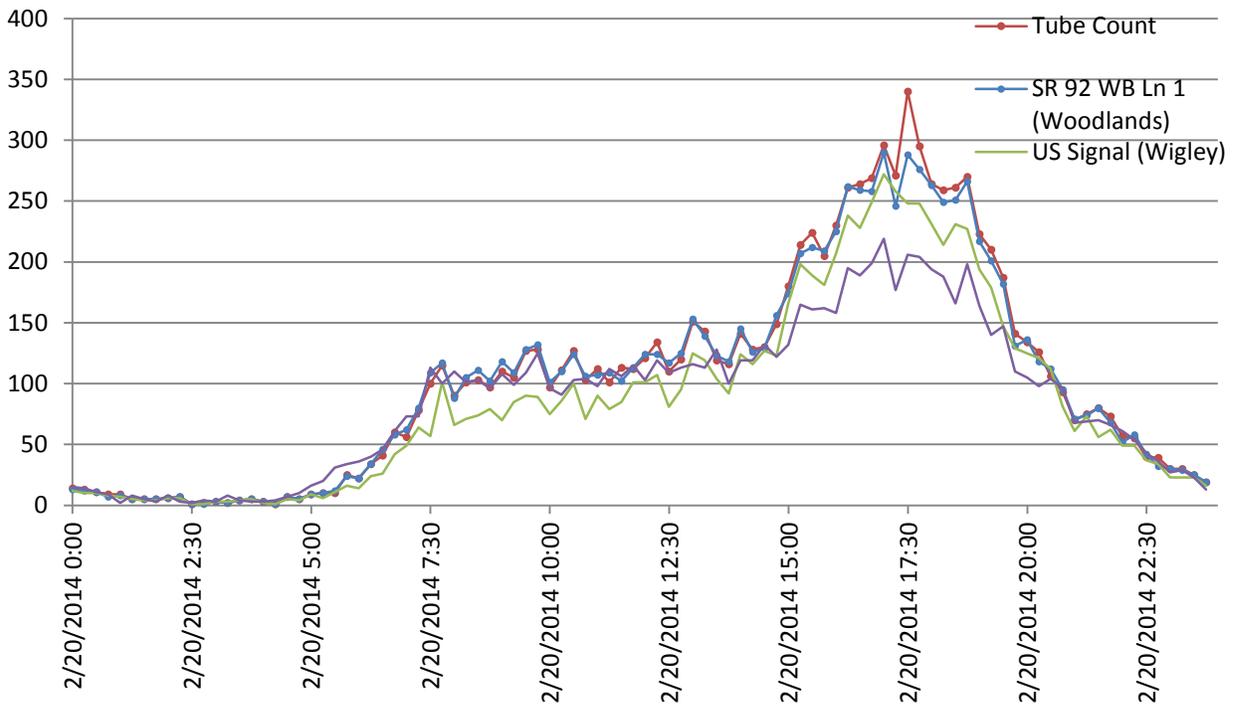


Figure A-58: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Woodlands Parkway for Lane 1

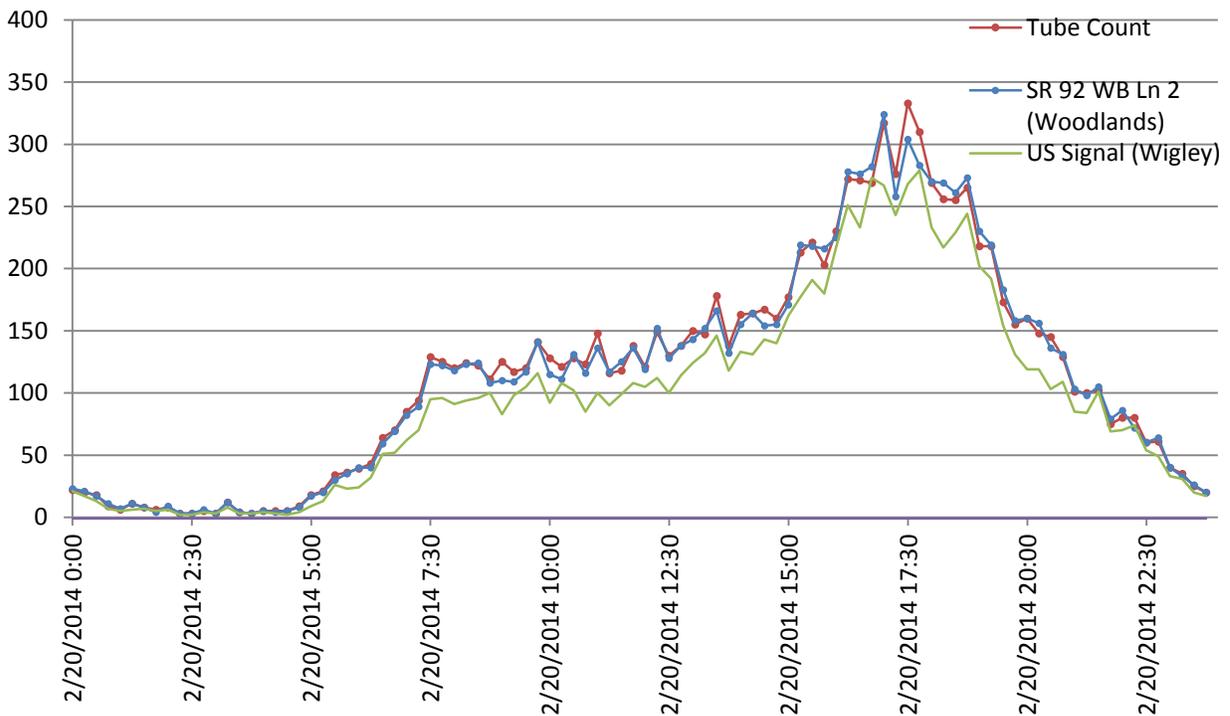


Figure A-59: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Woodlands Parkway for Lane 2

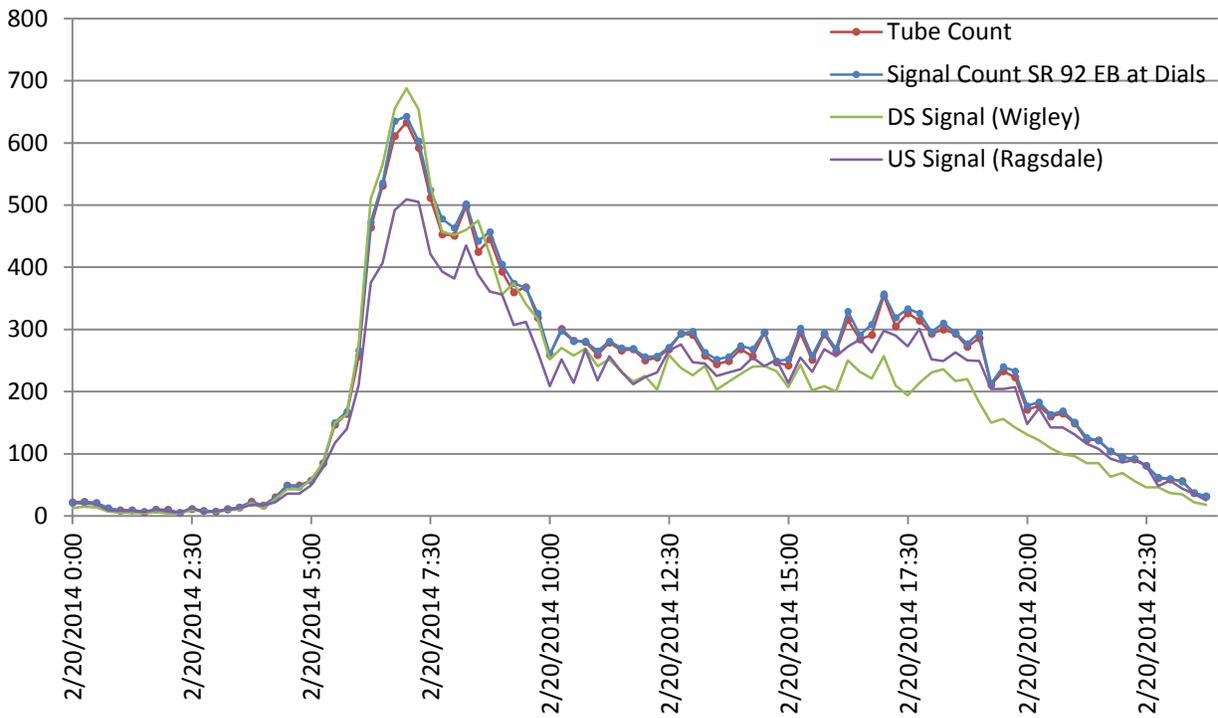


Figure A-60: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 EB and Dials Drive for Aggregates over All Lanes

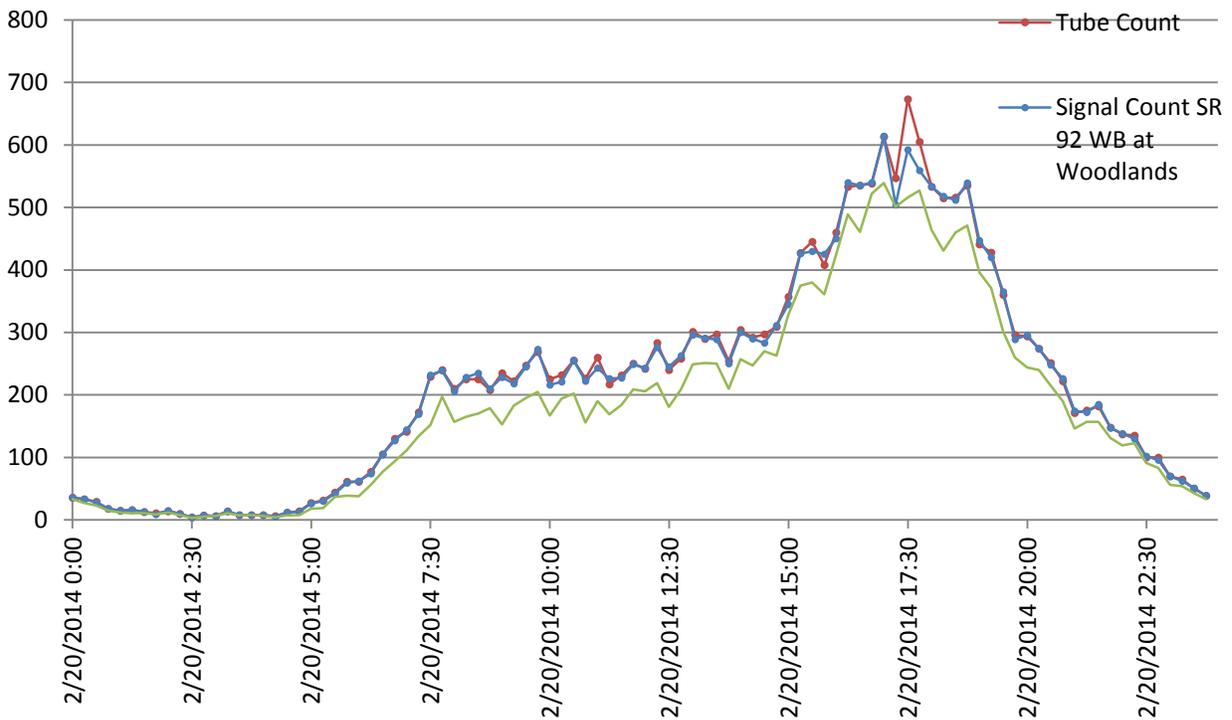


Figure A-61: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Woodland Parkway for Aggregates over All Lanes

7.10 SR 92 at Bowen Road

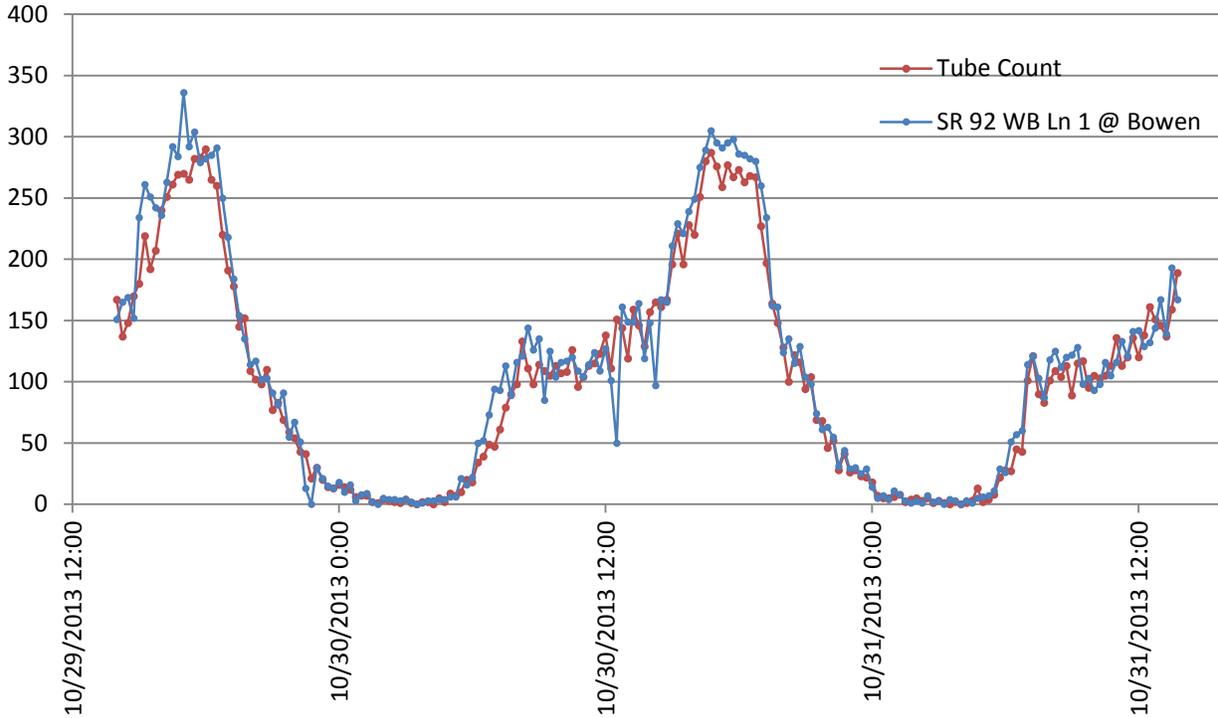


Figure A-62: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Lane 1

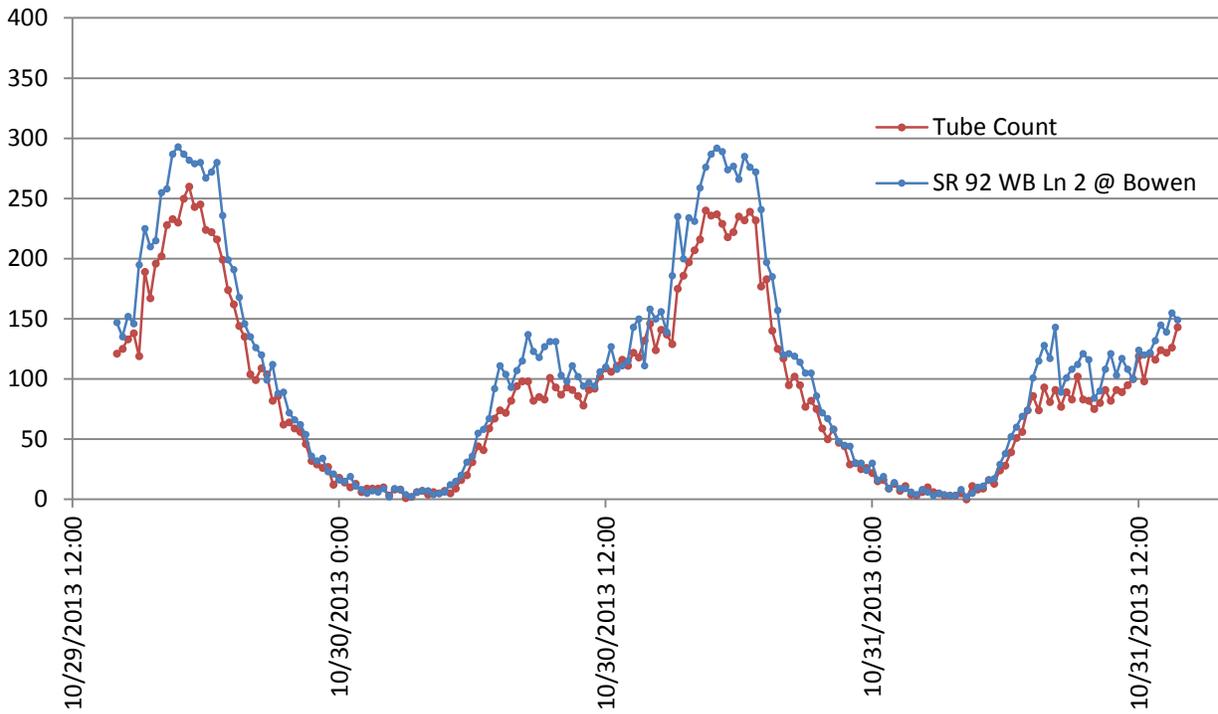


Figure A-63: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Lane 2

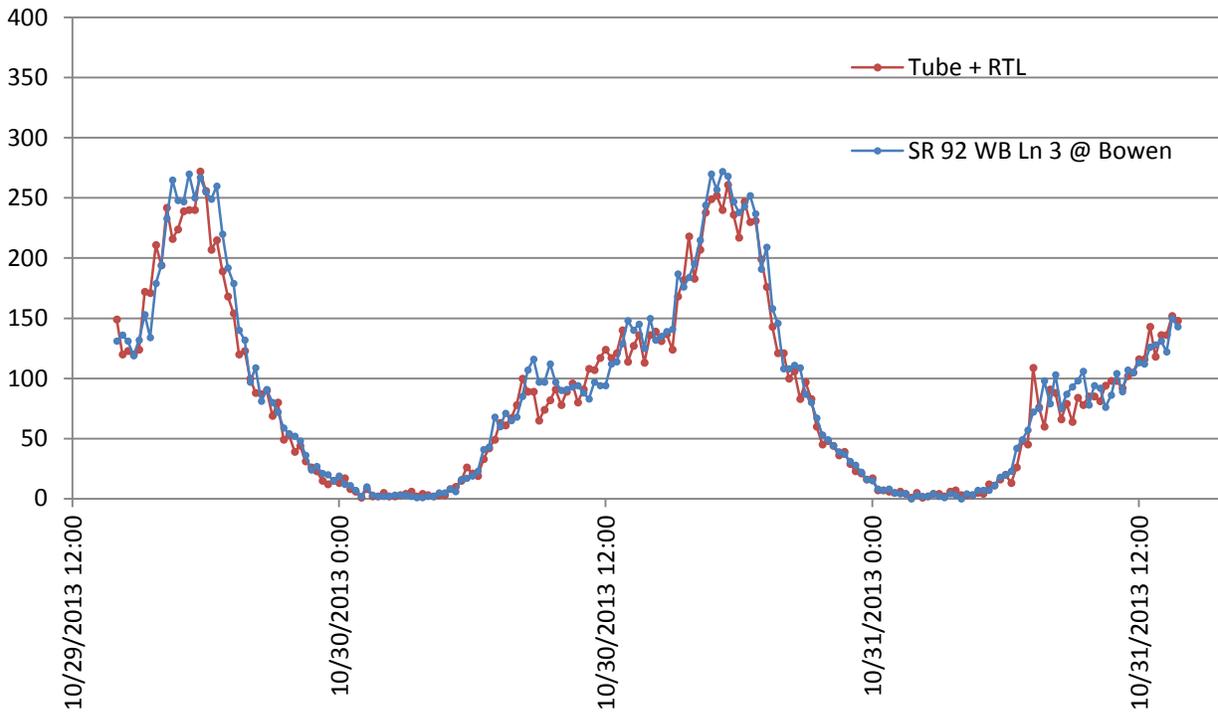


Figure A-64: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Lane 3

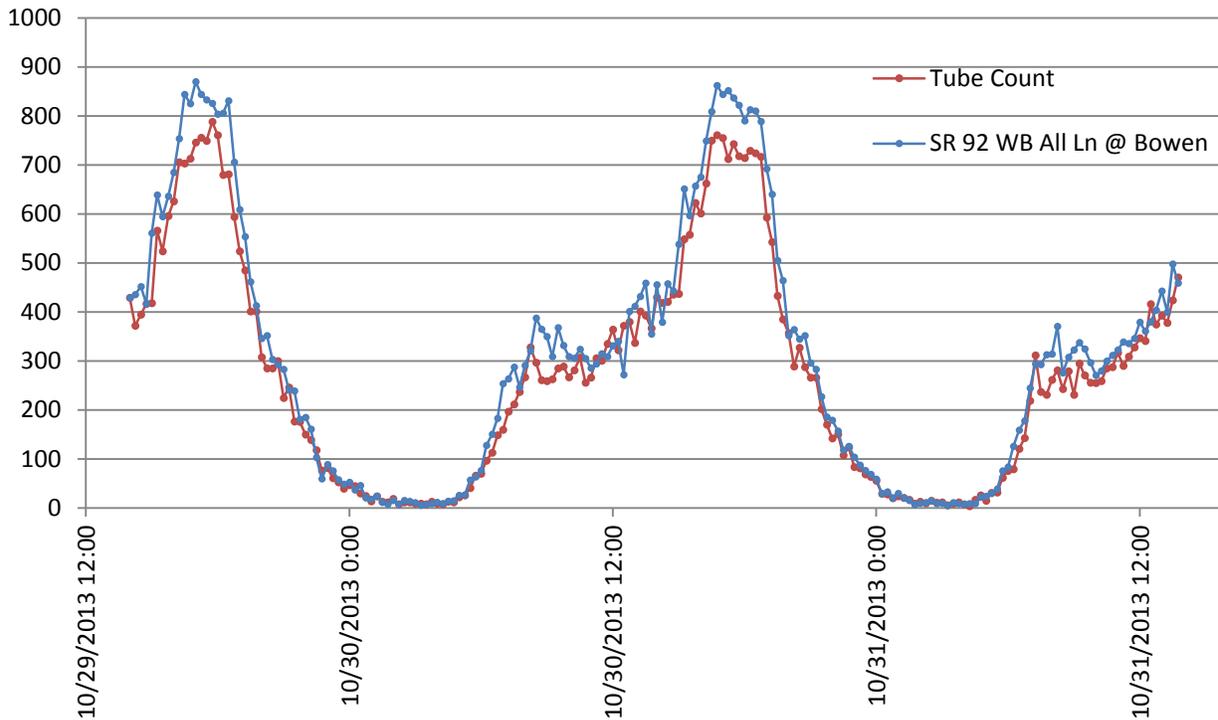


Figure A-65: Time Series Plot for Pneumatic Tube Counts and Signal Detector Counts at Intersection of SR 92 WB and Bowen Road for Aggregates over All Lanes

GEORGIA DOT RESEARCH PROJECT 13-10

FINAL REPORT

**INTEGRATING INTERSECTION TRAFFIC SIGNAL
DATA INTO A TRAFFIC MONITORING PROGRAM**



**OFFICE OF RESEARCH
15 KENNEDY DRIVE
FOREST PARK, GA 30297-2534**