INVESTIGATION OF BICYCLE AND PEDESTRIAN CONTINUOUS AND SHORT DURATION COUNT TECHNOLOGIES IN OREGON

Final Report

SPR 772

RESEARCH

Oregon Department of Transportation

INVESTIGATION OF BICYCLE AND PEDESTRIAN CONTINUOUS AND SHORT DURATION COUNT TECHNOLOGIES IN OREGON

Final Report

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16. Abstract

While motorized traffic counts are systematic and comprehensive, bicycle and pedestrian counts are often unknown or inaccurate. This research presents recommendations to increase bicycle and pedestrian count accuracy while integrating bicycle and pedestrian counting with existing ODOT traffic counting. Three bicycle counting technologies – pneumatic tubes, inductive loops and thermal cameras – were tested in a controlled environment as well as mixed traffic condition. Test results indicate that all bicycle counting technologies are adequate to count bicycles under controlled, favorable conditions. However, in mixed traffic conditions only the pneumatic tubes were able to count bicycles with less than 20% error. Bicycle counts in mixed traffic conditions with pneumatic tubes are more accurate when bicycle-specific vehicle classification schemes are used and when counting bicycle traffic within 10 feet tube length of the counting device. Two pedestrian counting technologies – passive infrared and pedestrian phase actuations – were tested and attained satisfactory results.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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1.0 INTRODUCTION

While motorized traffic counts are systematic and comprehensive, bicycle and pedestrian traffic volumes are often unknown. These data are needed in order to better plan, design and maintain infrastructure and programs for bicycling and walking.

Over the last decade, there has been increased interest in counting pedestrians and bicycles and establishing non-motorized counting programs, as exemplified by inclusion of an entire chapter of the 2013 edition of the Federal Highway Administration (FHWA) Traffic Monitoring Guide (TMG) devoted to bicycle and pedestrian counting methods and technologies (*FHWA 2013*). However, jurisdictions still struggle with how to integrate bicycle and pedestrian counting into standard practice.

The findings of ODOT SPR 754 *(Figliozzi et al. 2014)* "Design and Implementation of Pedestrian and Bicycle-Specific Data Collection Methods in Oregon," indicate that using 2070 signal controllers to record pedestrian signal actuations may be a highly cost-effective way to measure pedestrian activity throughout the state; ODOT SPR 754 indicate that it is very challenging to count bicycles at intersections utilizing inductive loops. ODOT SPR 754 also found that using existing ODOT motorized pneumatic tube counting equipment to count bicyclists was unsuccessful. The success of other jurisdictions (*Lindsey 2013*) and the desire to find a cost effective means of collecting bicycle counts indicates that further investigation of if and how ODOT's existing equipment could be modified to enable bicycle counting is warranted. The goal of this research is to advance the work begun in ODOT SPR 754 by further investigating if and under what conditions existing continuous and short duration, bicycle and pedestrian count technologies are most accurate and how they can be cost effectively integrated into ODOT's current traffic monitoring and signal operations systems.

Every count site faces varying challenges that demand different technological needs. For counting bicycles, in one case, a tube counter may be best choice while in another, inductive loops may be more appropriate. In this study, the authors share findings and recommendations for how to maximize accuracy while integrating bicycle and pedestrian counting with existing systems in order to minimize additional equipment acquisition and staff time, based on tests conducted for and in conjunction with the ODOT.

The objective of this study was to test and evaluate three off-the-shelf bicycle or pedestrian counting technologies for accuracy, cost, and compatibility with ODOT's existing count programs, equipment, and infrastructure. The technologies were to be evaluated for two conditions: short duration counting of bicycles on road or path segments and continuous counting of bicycles and pedestrians at signalized intersections.

Three bicycle technologies were chosen for evaluation: pneumatic tubes, inductive loops and thermal cameras. These technologies were evaluated in a controlled environment as well as mixed traffic condition. The mixed traffic conditions tested included road and sidewalk segments as well as intersection locations.

Three types of pneumatic tube counters for counting bicycles were tested, including equipment from five manufacturers: two bicycle-specific counters, three varieties of motor-vehicle classification counters, and one volume-only motor-vehicle counter. In addition to studying bicycle counting accuracy, this study also examines speed estimates using pneumatic tubes and how bicycle and automobile traffic affect counting accuracy.

Inductive loops and thermal cameras were included because these are existing technologies used for signal detection. If they could be used to not only to detect, but also count bicycles, bicycle counting could potentially be conducted around the state for little additional cost, greatly expanding the state's bicycle traffic monitoring program. Hence, these technologies were evaluated for counting accuracy during mixed traffic conditions in this study.

Though the study focused mainly on bicycle counting, pedestrian travel monitoring devices were also studied. The research team tested and evaluated a passive infrared sensor for counting pedestrians on a sidewalk and pedestrian pushbutton actuations at a signalized intersection for measuring pedestrian activity.

Prior to testing the technologies in field conditions with mixed traffic, the team wanted to understand how well they worked under ideal conditions. This would allow us to identify if any of the technologies were unable to detect cyclists even in ideal conditions before testing them in a more challenging environment. For this reason, these technologies were evaluated for accuracy in a controlled (bicycle-only) environment at ODOT's Traffic Signal Systems Unit (TSSU) parking lot. The pilot test included inductive loops, pneumatic tubes and thermal camera. Following the pilot test, the technologies were further evaluated in mixed traffic settings via a series of two sets. The first test at Columbia River Highway was designed to test pneumatic tubes only. The second test was conducted at the intersection of Hall Blvd. and 99W in Tigard, OR and incorporated pneumatic tubes, inductive loops, thermal camera, passive infrared and pedestrian pushbutton signal actuations.

The remainder of this report is organized as follows. Chapter 2 reviews previous research on counting technologies and provides recommendations on technologies to test. Chapter 3 details the methods followed for testing the selected technologies. Chapters 4 and 5 present the results of the pilot and in-field tests. Chapter 6 outlines the conclusions and recommendations from the study.

2.0 LITERATURE REVIEW

The first task in our research project "Investigation of Bicycle and Pedestrian Continuous and Short Duration Count Technologies in Oregon" was to identify technologies for evaluation. The goal of this section is to briefly summarize the wealth of previous work, document and assess the accuracy of technologies for counting bicycling and walking, and recommend three technologies for testing during this research project. Three technologies are identified in the work plan (pneumatic tubes, inductive loops, and video), but discussion with the TAC at the kickoff meeting revealed that they are open to replacing video with a different technology to test, based on ODOT staff recommendations. Possible technologies for testing are listed in Table 2.1.

Appendix A shows a table summarizing previous research that details the error of each technology. For some technologies, such as inductive loop and passive infrared counters, many research studies are available. For many other technologies such as radar, magnetometers, thermal imaging, etc., little or no testing has been done. This includes many of the intersection counting solutions listed in Table 2.1, which are more often used for signal detection than counting. For these signal detection technologies, counting may be offered as a special feature, but is often not the focus of the product, which often results in less accuracy especially for bicycle and pedestrian counting.

Table 2.1: Potentially applicable technologies by category.

Mode	Time Period	Intersection	Road or Path Segment
Pedestrian	Temporary	Video image processing	Passive or active Infrared Radar Seismic sensor (paths only)
	Permanent	Pedestrian pushbutton	Pressure mat Passive or active Infrared Radar
Bicycle	Temporary	Video image processing	Passive or active infrared Pneumatic tubes
	Permanent	Inductive loops Thermal camera Radar Video Camera Microradar Microwave	Inductive loop Passive or active infrared Magnetometer

The technologies listed in Table 2.1 are ranked in Table 2.2 by the three criteria that were used for judging technologies: effectiveness, cost, and compatibility. Effectiveness is measured in terms of technologies that count bicycles and pedestrians with the least error (or high accuracy). Cost is listed in Table 2.2 in terms of relative cost on a three point scale with one "$" indicating the lowest cost, and "$$$" indicating the highest relative cost per count site. Compatibility is described in terms of how well these technologies integrate with ODOT's existing systems. In the case of intersection counting technologies, compatibility indicates the ease with which these technologies integrate with the existing signal system. In the case of short duration counting technologies for road or path segments, compatibility is described in terms of how well these technologies integrate with ODOT's existing motor vehicle traffic count program.

Table 2.2: Technologies by Criteria.

Technology	Temporary/ Permanent	Manufacturer	Effectiveness (Accuracy)	Cost	Compatibility with existing systems
Pedestrian					
Video image processing	Temporary	Miovision	Miovision clients report low error.	$$$	Not integrated with existing. Special equipment must be set up.
Passive Infrared	Temporary/ Permanent	Eco-Counter, TRAFx	20% error is typical	$ to $$	Not integrated into signal system.
Pedestrian Pushbutton	Permanent	Varies	Measures pedestrian activity, not counts	$	Highly compatible
Pressure Plate	Permanent	Eco-Counter		$$$	Not integrated into signal system.
Bicycle					
Pneumatic tubes	Temporary (Permanent sometimes)	Diamond, Eco-Counter, JAMAR, MetroCount, TimeMark,	Varies: ± 5% to 100% error, depending on make/model, classification system and installation.	$$	Tube counters are standard traffic monitoring equipment.
Video image processing	Temporary	Miovision	Miovision clients report low error.	$$$	Not integrated with existing. Special equipment must be set up.
Inductive Loops	Permanent	Diamond, Eco-Counter, Reno A&E, EDI, JAMAR	Varies: 3% to >100% error.	$ to $$	Can be readily integrated into signal system.
Video Detection	Permanent	Iteris	Significant error for counting	$$$	Existing signal system.
Radar	Temporary/ Permanent	Data Collect	Unknown	$$	Stand-alone system.
Radar	Permanent	Wavetronix	Unknown– but no evidence that it is able to count	$$$	Existing signal system.
Thermal	Permanent	FLIR	Ave. Absolute	$$$	Existing signal

Technology	Temporary/ Permanent	Manufacturer	Effectiveness (Accuracy)	Cost	Compatibility with existing systems
Camera			% Diff. Error 22% - 31%		system.
Microradar	Permanent	Sensys	Varies 0 to 18% error with detection (not counting)	$$$	Can be readily integrated into signal system.
Piezoelectric Strips	Permanent	MetroCount, TDC	Varies	$$	Stand-alone system.

Three technologies were recommended by the research team and approved by the TAC for testing: pneumatic tubes, inductive loops, and thermal camera. In addition to these primary technologies, two additional technologies were also tested - passive infrared and pedestrian pushbuttons. Passive infrared devices can provide overall combined counts of bicyclists and pedestrians. To distinguish between bicyclists and pedestrian infrared counters can be combined with a bicycle specific counting technology. Pedestrian pushbutton actuations cannot provide actual pedestrian counts, instead they serve as a proxy for gauging pedestrian activity at intersections.

2.1 BICYCLE COUNTING TECHNOLOGIES

Technologies that are capable of counting bicycles are continuously evolving. A number of technologies are available commercially that can count bicycles. However, accuracy can vary widely depending on technology and site location. More details can be found in the Appendix A. In this section, the technologies that are of interest – inductive loops, pneumatic tubes, thermal camera, are reviewed.

2.1.1 Inductive Loops

Inductive loops have been used widely used for detecting motor vehicles. Recently many jurisdictions have also shown interest in utilizing the same infrastructure to detect and count bicycles. These loops detect any metallic object that passes over the loop by recording a change in inductance. For loops, the following loop shapes have been shown to be capable of counting bicyclists (Figure 2.1): parallelogram, quadrupole, and diamond.

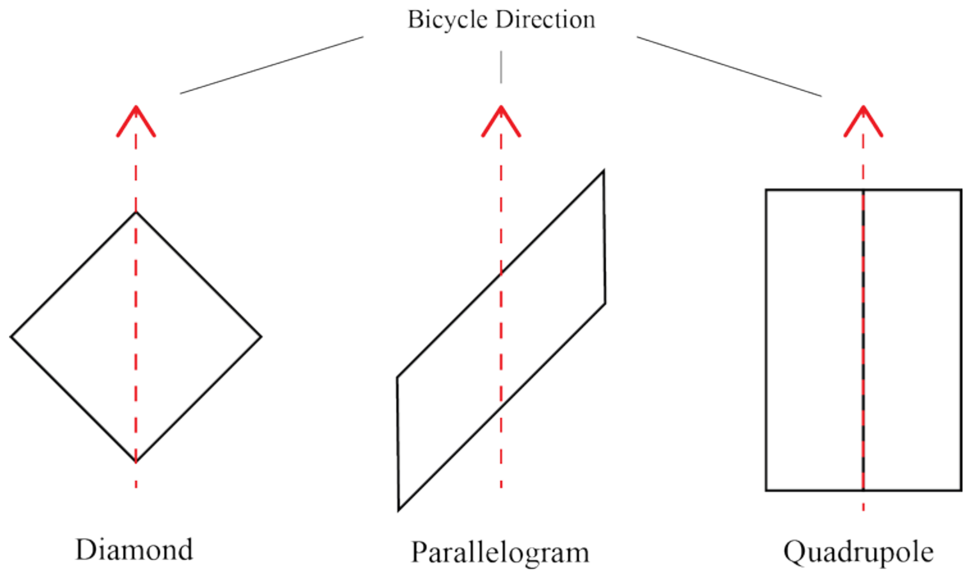


Figure 2.1: Inductive Loop Shapes

At least four manufacturers claim to have products that can be used in conjunction with traffic signal equipment and differentiate between bicycles and motorists: Eco-Counter[1], Reno A&E, Diamond, and JAMAR. Many studies have tested the various loop configurations for their accuracy in counting bicycles (see Appendix A) and have generally report less error in situations where motor vehicles and bicycles are separated (*Nordback et al. 2011*). The Eco-Counter Zelt is the most widely tested inductive loop product for differentiating bicycles from motorists and has been found to have had success at this using diamond-shaped loops (*Nordback et al 2011*). The parallelogram and quadrupole shape loops have been found to be capable of producing accurate counts when motorists do not drive over them (*Nordback et al. 2010; ODOT 2010, and Kothuri et al. 2012*). A previous research study by PSU revealed difficulties in counting bicycles using diamond-shaped inductive loops that are not able to differentiate bicycles from motor vehicles (*Figliozzi et al. 2014*). The TAC and city of Portland have expressed particular interest in testing the parallelogram shape.

2.1.2 Pneumatic Tubes

Pneumatic tubes have been widely used in the past for travel monitoring to gather vehicle counts. Recently there has been a push to adapt the technology to classify and count bicycles in addition to motor vehicles. Pneumatic tube technology consists of a set of two tubes laid across a roadway or path along with a counter. As vehicles or bicycles pass over the tubes, pulses of air travel through the tubes to the counter, which detects them due to change in pressure. These tubes are portable, low cost technology and are typically used for short duration counts. Due to tube durability, they are not usually used for continuous count sites (with the notable exception of the

[1] According to Greg Nowak, Transportation Data Coordinator, the city of Vancouver, British Columbia, has integrated Eco-Counter Zelt diamond-shaped loops into their signal detection system. They use the Zelts for signal detection at one location, which is a separated facility, but mostly they use them only for counting. They prefer installing them on separated facilities, but have 12 with mixed traffic. Because data are highly scrutinized, they validate the Zelts regularly with tube counters. (Greg Nowak, Transportation Data Coordinator, the City of Vancouver, BC, telephone conversation with Krista Nordback November 7, 2014.)

Hawthorne Bridge Bicycle Barometer in Portland, Oregon).Three types of pneumatic tubes are available commercially:

a) Bicycle-specific Counters - These are dual tube configurations, but are specifically designed for bicycle counts. They differentiate between motor vehicles and bicycles but provide bicycle counts only and can be used in a shared lane with mixed traffic.

b) Classification Counters - These are dual tube configurations used for motor vehicle classification counts. Some of the equipment in this category can be used to both classify motor-vehicles and count bicycles in mixed traffic, when adjustments are made and bicycle-specific classification schemes are used.

c) Volume Counters - These are single tube configurations used for motor vehicle traffic volume counts without any classification ability. These can be used to count bicycles if they are laid over a dedicated bicycle lane, but they cannot distinguish between bicycles and vehicles in mixed traffic.

There is limited research regarding the performance of pneumatic tubes to count bicycles. Hyde-Wright et al. evaluated the performance of one type of classification counter and bicycle-specific pneumatic tube counters at various sites in Boulder, Colorado (*Hyde-Wright et al. 2014*). Their results revealed that bicycle-specific counters were more reliable and accurate than the classification counters when counting bicycles; however, they observed a drop in accuracy as the distance from the counter increased. A Norwegian study also tested classification counters and bicycle specific tube counters and found high accuracy for bicycle specific counters (over 95%), but only 70 to 75% for accuracy for the classification counter tested (*Giaever et al. 2008*). A study from New Zealand also examined a bicycle specific tube counter and a classification counter with similar results: nearly 100% of bicycles were counted with the bicycle specific tubes and 85% to 90% with the classification counter (*ViaStrada 2009*). More recently, Brosnan et al. also conducted tests of two classification counters and bicycle-specific tube counters on two different facilities in Minnesota (*Brosnan et al. 2015*). Their results revealed lower error on the lower volume facility. In addition, undercounting was a significant issue, primarily due to occlusion, in which two vehicles simultaneously cross the tubes such that the air pulses from both cannot be differentiated. Both studies found that bicycle-specific counters had higher accuracy than general traffic counters and developed adjustment factors to adjust for the error. NCHRP 797 also included tube counters, but only evaluated bicycle specific tube counters *(Ryus et al. 2015)*. Researchers found that they typically undercount and that some models perform better than others. One product was undercounting with 11% mean percentage error and another with 53% mean percentage error *(Ryus et al. 2015)*.

2.1.3 Thermal Camera

For the non-invasive intersection technology to test, the work plan had originally recommended video technology. A recent paper submitted to TRB by Kading et al. described the city of Portland's experience with bicycle detection using the Iteris SmartCycle video camera product. They found significant errors for counting "related to light, shadows, group riding" *(Kading et al. 2014)*. Based on the city of Portland's experience, the research team decided to test an alternate technology. Research by Kendrick et al. at Portland Bureau of Transportation investigated counting using FLIR brand thermal imaging cameras and while the product tested was not highly accurate, it was recommended as one of the most promising of the non-invasive signal detection technologies *(Kendrick et al. 2015)*. The manufacturer has continued to make upgrades to the product after testing by PBOT, hence this technology was chosen for testing in the non-invasive technology category.

2.2 PEDESTRIAN COUNTING TECHNOLOGIES

Similar to bicycle counting technologies, pedestrian counting technologies are also evolving. However compared to bicycle counting technologies, currently available commercial pedestrian counting technologies are more limited, as counting pedestrians is more challenging. Pedestrians do not travel along fixed paths and also travel in groups, making it difficult for the counter to count them accurately. More details can be found in the Appendix A.

2.2.1 Passive Infrared

Passive infrared devices detect pedestrians and bicyclists by comparing the ambient temperature with the infrared radiation emitted by people passing in front of the sensor *(Ryus et al. 2015)*. These devices cannot distinguish between pedestrians and bicyclists, however they are often used in conjunction with other bicycle counting technologies such as inductive loops or pneumatic tubes to allow for separate counts of bicyclists and pedestrians. In such a case, the pedestrian count is obtained by subtracting the bicycle count from the combined count.

While, positioning the device appropriately is critical for accuracy, occlusion and extreme ambient temperatures can affect device performance *(Ryus et al. 2015)*. Most studies have shown that these devices undercount pedestrians, with an increase in the rate of undercounting as the pedestrian volumes increase *(Schneider et al. 2012, Turner et al. 2013, Ryus et al. 2015)*.

2.2.2 Pedestrian Pushbuttons

The purpose of pushbuttons at intersections is to allow pedestrians to request pedestrian phase to cross an intersection. A few studies have investigated the possibility of using pedestrian pushbutton actuations as a proxy for pedestrian demand at an intersection (*Day et al. 2010, Kothuri et al. 2012, Figliozzi et al. 2014*). While these actuations cannot provide actual counts, they can indicate the level of pedestrian activity at the intersection. Figliozzi et al. computed a ratio between the number of crossing pedestrians and pedestrian phases using pushbutton actuations from one day at an intersection, which could be then be used to estimate pedestrian crossing volume (*Figliozzi et al. 2014*). However, more research is needed to apply it in practice.

2.3 RECOMMENDATIONS

Based on the judging criteria and TAC input, following three bicycle-specific technologies were chosen for testing.

- Inductive loops (Parallelogram and Diamond shapes)
- Pneumatic Tubes

- Thermal Camera (FLIR)

In addition, two pedestrian-specific technologies were also investigated.

- Passive Infrared
- Pedestrian Pushbutton

3.0 EQUIPMENT AND METHODS FOR TESTING

A variety of equipment from different manufacturers was tested during the course of this project for bicycle and pedestrian counting purposes. This chapter describes the equipment tested as well as the methods and metrics that were used during testing.

3.1 EQUIPMENT FOR TESTING

In this study, pneumatic tubes, inductive loops and thermal cameras for gathering bicycle counts and passive infrared and pushbuttons for pedestrian counts were tested. The specific equipment types are further described below.

3.1.1 Pneumatic Tubes

The research team tested three types of off-the-shelf pneumatic tube counters: volume, classification, and bicycle-specific counters. For simplicity, each piece of equipment tested is designated by a letter number combination for reference in this report. The diameters of the tubes themselves varied, but were generally in two categories: standard road tubes (approximately 0.7-inch outside diameter) and mini tubes (approximately 0.4-inch outside diameter). Table 3.1 shows the specific pneumatic tube counters that were tested in this study.

Table 3.1: Types of Pneumatic Tube Counters

Type	Designation	Make	Model
Bicycle-specific	B1	Eco-Counter	Bicycle only TUBES
	B2	Eco-Counter	Bicycle & motor vehicle TUBES
Classification	C1	JAMAR Technologies, Inc.	TRAX Cycles Plus
	C2	Time Mark Corporation	Gamma
	C3	MetroCount	MC5600
Volume	V1	Diamond Traffic Products	TT6

3.1.1.1 JAMAR TRAX Cycles Plus

TRAX Cycles Plus from JAMAR Technologies, Inc. is a pneumatic tube counter that is able to distinguish and count bicycles and motor vehicles in mixed traffic. It was introduced into the market in 2014 and consists of sensitive air switch sensors that are capable of recording the time stamp for each axle hit (*JAMAR Technologies 2015*). The algorithms within JAMAR's TRAXPro software allow the user to view volume, classification, speed and gap from the data collected using TRAX Cycles Plus (*JAMAR Technologies 2015*). During the course of this study bicycle-specific improvements were made to JAMAR’s classification scheme. This revised scheme was used to process data from the pilot study and the intersection site (Hall Blvd.), but not at the Columbia River Highway since these data were available to the manufacturer during the time in which JAMAR developed this new bicycle-specific classification scheme. Figure 3.1 shows a picture of the TRAX Cycles Plus pneumatic tube counter that was tested in this study.

Photo by Authors

Figure 3.1: JAMAR TRAX Cycles Plus Pneumatic Tube Counter

This tube counter was specifically included in this study because ODOT owns a number of these counters and there was specific interest from ODOT in assessing their performance for bicycle counting purposes.

3.1.1.2 Diamond Traffic Tally 6

Diamond Traffic Products Traffic Tally 6 (TT6) is a general purpose counter and cannot distinguish between bicycles and motor vehicles. Installation consists of a single road tube that is laid across the roadway. According to the vendor, the counter is capable of counting 1-4 lanes of traffic simultaneously (*Diamond Traffic Products 2015*). Data is retrieved using Centurion CC software. This pneumatic tube counter is also used by ODOT for vehicle counting and classification. Figure 3.2 shows the Diamond TT6 pneumatic tube counter that was used in this study.

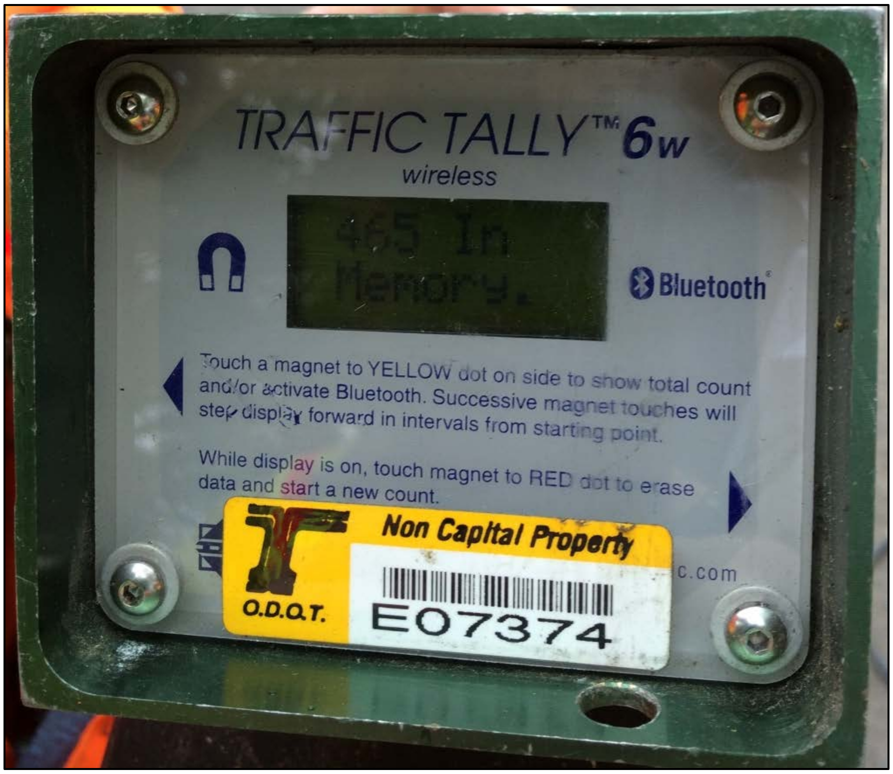


Photo by Authors

Figure 3.2: Diamond Traffic Tally 6 (TT6) Pneumatic Tube Counter

3.1.1.3 TimeMark Gamma

TimeMark's Gamma pneumatic tube counter can record classification, speed and vehicle volume data for one or two lanes of traffic (*TimeMark 2015*). Typical installation consists of two tubes laid across the roadway. This counter is capable of distinguishing bicycles from motor vehicles and is also part of ODOT's inventory for gathering motor vehicle counts. Figure 3.3 shows a picture of the TimeMark Gamma pneumatic tube counter.

Photo by Authors

Figure 3.3: Gamma Pneumatic Tube Counter

3.1.1.4 MetroCount MC 5600

The MC 5600 is a vehicle classifier counter that records every axle that goes over each tube. This counter is capable of providing vehicle volume, speed and classification data and is capable of distinguishing between bicycles and motor vehicles. Two tubes are typically installed in the roadway and attached to the tube counter. The MC 5600 stores all the axle hits and the analysis is performed by using the MetroCount's proprietary software. Figure 3.4 shows a picture of the MC 5600 tube counter.

Photo by Authors

Figure 3.4: MetroCount MC 5600 Pneumatic Tube Counter

The data from MC 5600 is run through the Traffic Executive™ software, where speed, classification and gap of each vehicle can be retrieved. While this counter is a part of Portland State University (PSU's) inventory, it is not a part of ODOT's inventory.

3.1.1.5 Eco-Counter TUBES

Eco-Counter pneumatic tube technology (TUBES) uses two tubes placed on the roadway to count bicyclists only. It can be used on paths or a mixed use facility and is able to distinguish bicycles from motor vehicles. It differs from the other tube technologies in that it provides a count of bicyclists only. Figure 3.5 shows a picture of an Eco-Counter pneumatic tube counter. Eco-Counter provides specific proprietary pneumatic tubes to be used with the unit on roadways with mixed traffic. When used on paths or sidewalks, smaller diameter tubes (mini-tubes) can be used to reduce trip hazard. Eco-Counter recommends using proprietary "filter tubes" between the counter unit and the mini-tubes for higher accuracy.

Source: http://www.eco-compteur.com/en/products/tubes-range

Figure 3.5: Eco-Counter Pneumatic Tube Counter

3.1.2 Inductive Loops

Inductive loops work based on the principle of electromagnetic induction and are typically embedded in the pavement. When a bicycle passes over the loop, it causes a change in inductance that is captured by the inductive loop. They are typically used for permanent counts, because they are embedded in the pavement and as such are not suitable for short duration counts. A variety of loop configurations have been used by different agencies.

Many jurisdictions are starting to use inductive loop technology for bicycle counting (Colorado, Oregon etc.). In Oregon, ODOT typically uses diamond loops to count motor vehicles. A previous research project *(Figliozzi et al. 2014)* evaluated the use of diamond loops for bicycle counting and found that the counts could be subjected to a high degree of inaccuracy based on loop placement, as the loops do not differentiate between bicycles and motor vehicles. Therefore, based on Technical Advisory Committee (TAC) recommendation, the research team decided to test parallelogram and diamond loop configurations in this study.

3.1.2.1 Parallelogram Loop

As the name implies, these loops are shaped as a parallelogram. The biggest advantage of the parallelogram loop over the diamond loop is the availability of a special bicycle detector card from Reno A&E that is capable of distinguishing between bicycles and motor vehicles. Figure 3.6 shows a picture of the parallelogram loop placed in a bike lane at the intersection of Hall Blvd. and 99 W in Tigard, OR Parallelogram loops were tested during the pilot and field tests, described further in Chapters 4 and 5.

Photo by Authors

Figure 3.6: Parallelogram Loop

Two types of bicycle detector cards were tested during this study. One type was Reno A&E's Model C-1101 B, which is designed for the Type 2070 signal controller and is capable of differentiating bicycles from motor vehicles. Additionally, it also offers signal timing engineers with the ability to provide bicycle specific minimum green and extension times. The second type tested was a detector card made by EDI Inc., Model LM222. The EDI card cannot distinguish between motor vehicles and bicycles. The rationale behind testing the EDI card was that it could be potentially used in locations where differentiation is not critical, such as bicycle lanes or trails that have low propensity of motor vehicles passing over the bicycle loop.

Source: www.renoae.com

Figure 3.7: Reno A&E (Model C-1101B) and EDI (Model LM222) Detector Cards

Figure 3.7 shows pictures of the Model C-1101B by Reno A&E and Model LM 222 made by EDI Inc. While both cards were tested during the pilot test, only the Reno A&E card was tested during the field test. In the mixed traffic test Reno's Model C-1100B card was tested with the diamond loop.

3.1.2.2 Diamond Loop

In addition to the parallelogram loops, the diamond loops were also tested in this study. Similar to the parallelogram loops, they were tested during the pilot and field tests. For the pilot test, the diamond shaped loops at TSSU facility were pre-installed. There were two diamond loops that were connected in series, which were being used to operate a garage door. For the field test, the diamond loop was in the bike lane. Figure 3.8 shows the diamond loop in the bike lane at the intersection of Hall Blvd. and 99W in Tigard, OR.

Photo by Authors

Figure 3.8: Diamond Loop

The EDI loop card was used for the diamond loops both during the pilot study as well as during field tests.

3.1.3 Thermal Camera

Thermal cameras detect vehicles and bicycles via body heat. The biggest advantage of thermal cameras over conventional video cameras is the ability to be unaffected by changes in ambient light (*Ryus et al. 2015*). FLIR's Trafisense thermal traffic camera was evaluated during the pilot and field tests. It consists of a thermal camera and detector and is capable of distinguishing between vehicles and bicycles. According to the manufacturer, Trafisense uses the thermal energy emitted by the vehicles and bicycles to differentiate between them (*FLIR 2015*). Figure 3.9 shows a picture of FLIR TrafiSense thermal camera that was tested. This camera was mounted on a pole during the pilot test. For the field test, it was mounted on the luminaire arm at the intersection.

Source: http://www.flir.com/traffic/display/?id=62071

Figure 3.9: FLIR TrafiSense Thermal Camera

3.1.4 Passive Infrared

Passive infrared devices detect the change in ambient temperature from pedestrians and cyclists within the range of the sensor. The Eco-Counter PYRO-Box tested has a range of 15 feet and is designed to detect two or more pedestrians traveling in a slightly staggered formation. The

PYRO-Box reports the direction of travel as either inbound or outbound (*Eco-Counter 2015*). Figure 3.10 shows an Eco-Counter PYRO-Box which can be temporarily affixed to a pole. The PYRO-Box was tested during the intersection field test to count pedestrians on the sidewalk.

Source: http://www.eco-compteur.com/en/products/pyro-range/pyro-boxww.flir.com/traffic/display/?id=62071

Figure 3.10: Eco-Counter PYRO-Box

3.1.5 Pushbutton

Pedestrian pushbuttons are typically provided at signalized intersections as a means to detect pedestrians. A pedestrian phase is provided by the signal controller, when the pedestrians activate the pushbutton requesting service. Figure 3.11 shows a pushbutton at an intersection. While pushbutton actuations cannot provide pedestrian counts directly, logging pedestrian phases at an intersection can provide a general measure of the pedestrian activity at an intersection. These were studied during the intersection field test.

A ratio of crossing pedestrians per phase can be computed and used to estimate pedestrian counts, which is described further in Chapter 5. However more research is needed to generate pedestrian counts using this approach.

Photo by Authors

Figure 3.11: Pedestrian Pushbutton

3.2 EQUIPMENT USED FOR GROUND TRUTH

Video cameras were used during the pilot study as well as field tests for capturing ground truth data. The research team watched the video and recorded bicycle and pedestrian counts as ground truth. These ground truth counts were then compared to counts from the various equipment that was tested.

Two types of video camera were used. ODOT's Aventura CAM 52 IP 10X DN cameras, which were used the Columbia River Highway. Countingcars.com's COUNTcam cameras owned by Portland State University were used at the pilot test and at the intersection test at Hall and 99W. These video cameras were typically installed on a pole, as depicted in Figure 3.12.

Photo by Authors

Figure 3.12: Video Camera Installation on Signal Pole

3.3 METHODS

3.3.1 Site Selection

Selecting an appropriate site is a critical task. Often the selection of site depends on the choice of counting equipment (*Ryus et al. 2015*). In this study, the research team developed a set of criteria to guide the choice of site. These criteria were primarily employed for choosing a site for the intersection field test. These are listed below.

General Criteria

- *Traffic volume* - A high volume and a low volume location were desired, so that the equipment could be tested under a variety of traffic volumes.

- *Availability and location of poles for mounting cameras or infrared (away from sources of heat)* – The poles were required for mounting cameras that were either used for testing or establishing ground truth.

- *Presence of Type 2070 signal controllers* - These newer signal controllers have better functionality and logging capabilities compared to the older Type 170 signal controllers

- *Availability of inputs in controller for adding detection in parallel* - The inputs were required to add required loops (parallelogram and diamond) in parallel, so that they could count bicycles individually.

- *Surrounding land use* – More urban was preferred as volumes of bicyclists and pedestrians would be higher in urban areas.

- *Distance from Portland* – Sites closer to Portland were preferred to reduce travel time for the research team.

- *Already has video camera* – Sites with existing video cameras were preferred.

- *Presence of sidewalks* – Sites with sidewalks were desired because they provided an opportunity to test pedestrian specific counting equipment.

Bicycle Specific Criteria

- *Bicycle volume* - Higher is better (100/day minimum ideally).

- *Volume of right turning traffic* – Lower volumes of right turning traffic were desired as higher volumes of right turning traffic could impact loop counts.

- *Presence of bicycle lane*

- *Possibility of adding loops for counting bicycles*

- *Presence of FLIR camera or possibility of adding one*

Pedestrian Specific Criteria

- Pedestrian volume – Higher is better.

- Presence of bus stops – Pedestrians are likely to be present near bus stops.

- Availability of push buttons – Presence of pushbuttons provided the research team with the ability to log pedestrian phases.

- Crosswalks

A number of candidate sites were considered for testing. These candidate sites were either recommended by the project's TAC or were chosen by the research team if they fit some criteria. A ranking exercise was undertaken using the criteria listed above. The site selection ranking spreadsheet is included in Appendix C. Based on that exercise, the intersection of Hall and 99W in Tigard was chosen for testing inductive loops, pneumatic tubes, thermal camera and infrared sensor. Additionally, a section of Columbia River Highway near Portland's Women's Forum was chosen for testing pneumatic tubes.

3.3.2 Performance Metrics

In order to compare the accuracy of the counters, the following metrics were used: overall error, mean percent error (MPE) and mean absolute percent error (MAPE). These are equivalent to the average percent deviation and average absolute percent deviation metrics used in NCHRP 797. To compute these metrics, the counts from the automated equipment were compared to ground truth counts. The ground truth for the controlled environment and special cases tests was the count collected by manual counters in the field which was later verified by video counts. The ground truth for the mixed traffic test was manually counted video.

Overall error was calculated as the difference between the ground truth and counting equipment count divided by the total ground truth count for the study period as explained in Equation 3.1.

$$\text{Overall Error} = \frac{c-m}{m} \tag{3.1}$$

where

m = ground truth count for study period

c = tube count for study period

While overall error gives a big picture view of the error, it does not reveal the likelihood of a false negative when a cyclist was not counted or of a false positive when a count is recorded when no cyclist is present. If each counter provided time stamps for each event, these false positives and false negatives could be counted. Unfortunately, since some of the equipment binned their data in 1-minute (C2) and 15-minute (B1 and B2), it was not possible to compute the true number of false positives and negatives across all equipment types. However, by binning the data, it is possible to compute the error per bin, or count interval and observe over and undercounts per count interval. The count intervals varied by equipment for the controlled environment and special cases test, ranging from five minutes to 15 minutes. The count interval for the mixed traffic test was one hour for all equipment types.

$$\boldsymbol{e_i = \frac{c_i-m_i}{m_i}} \tag{3.2}$$

e_i = interval error = error for the count interval i

m_i = ground truth count for count interval i

c_i = tube count for count interval i

Mean Percent Error (MPE) was calculated by averaging the errors for each count interval for the entire study period.

$$MPE = \frac{1}{h}\sum_{i=1}^{h} e_i \qquad \textbf{(3.3)}$$

where

h = the total number of count intervals counted in the study period

Similarly, the MAPE was calculated by averaging the absolute value of the errors for each count interval for the entire study period.

$$MAPE = \frac{1}{h}\sum_{i=1}^{h} |e_i| \qquad \textbf{(3.4)}$$

Another type of analysis conducted examined individual events, such as a bicyclist being counted. False positives were recorded when the ground truth video data did not show a bicycle but the tube counters falsely recorded a bicycle. False negatives were recorded when the tube counter failed to count the bicycle that was present in the ground truth video. These false positive and false negative counts apply to individual count events, whereas the terms overcounting and undercounting apply to counts over a given time period, such as an hour or the entire study period.

4.0 PILOT TEST

4.1 PURPOSE

The purposes of the pilot test were to:

a) Understand the limitations of the equipment in the situations most advantageous for accurate counts,

b) Study the ability of each counter to correctly count bicycles in especially challenging cases, and

c) Potentially eliminate some counting technologies from the mixed traffic test based on their performance.

This test was also an opportunity for the ODOT crew and PSU research team to gain further understanding of the equipment set up. This chapter describes the technologies tested, methodology and results obtained during the pilot test.

4.2 TECHNOLOGIES

For the pilot test, the research team tested the following technologies for bicycle counting: pneumatic tubes, inductive loops and thermal camera. The choice of these technologies was based on guidance from the TAC. Table 4.1 shows the specific pneumatic tube counting equipment that was tested during the pilot test.

Table 4.1: Tube Technologies Tested During the Pilot Test

Type	Designation	Make	Model	Tubes	Comments
Bicycle-specific	B1	Eco-Counter	Bicycle only TUBES	0.3 in. ID 0.6 in. OD	Vendor specific tubes
	B2	Eco-Counter	Bicycle and motor vehicle TUBES	0.3 in. ID 0.6 in. OD	Vendor specific tubes
Classification	C1	JAMAR Technologies, Inc.	TRAX Cycles Plus	0.2 in. ID 0.4 in. OD	Also estimates speeds
	C2	Time Mark Corporation	Gamma	0.3 in. ID 0.7 in. OD	Also estimates speeds
	C3	MetroCount	MC5600	0.2 in. ID 0.4 in. OD	Natural rubber tubes
Volume	V1	Diamond Traffic Products	TT6	0.3 in. ID 0.7 in. OD	Single tube

Other technologies that were tested during the pilot test are shown in Table 4.2.

Table 4.2: Other Technologies Tested During the Pilot Test

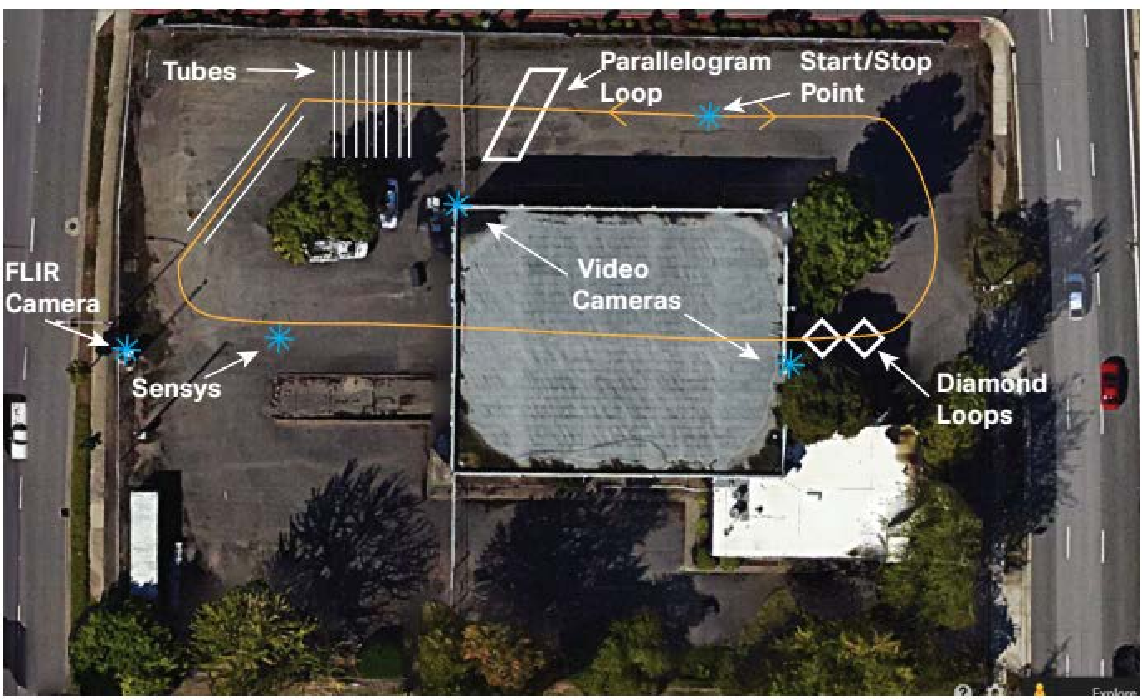
Type	Make	Model	Comments
Inductive Loop Detector Cards	Reno A&E	C-1101B	Designed to differentiate between motor vehicles and bicycles. Tested with the parallelogram shaped loop.
	EDI	LM222	Not designed to differentiate between motor vehicles and bicycles. Tested with both diamond and parallelogram shaped loops.
Thermal Camera	FLIR	TrafiSense	Designed to differentiate between motor vehicles and bicycles.

4.3 METHODOLOGY

4.3.1 Site Layout

The test was conducted at ODOT's Traffic Systems Services Unit (TSSU) parking lot in Salem, OR on Monday, February 23rd, 2015. The weather was mild and sunny with a high temperature of 60 degrees Fahrenheit. The TSSU test facility is laid out such that it was quite easy to test all of the technologies in sequence.

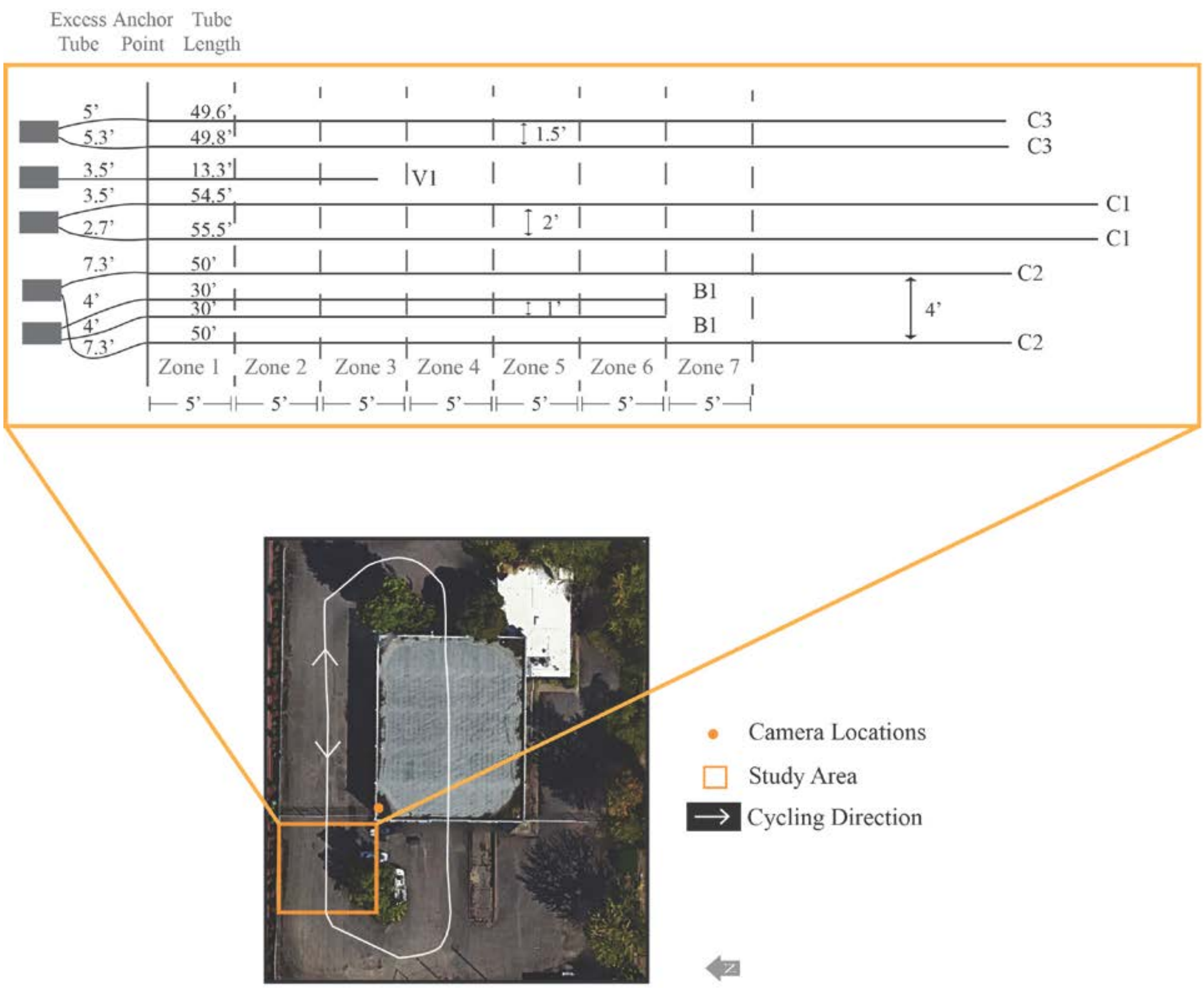
Figure 4.1 shows the layout of the parking lot at TSSU, where the equipment was set up. There is a garage area that cuts through the center of the building, so bicyclists could ride around the parking lot and through the building in a loop as indicated in Figure 4.1.



Source: Google Maps, 2016

Figure 4.1: Pilot Test Location at ODOT TSSU

Figure 4.2 shows the setup of the pneumatic tubes that were tested, including their length and distance between tubes. The excess tube length shown in Figure 4.2 is the length of tube between the anchor point (nail) and the counting device (box). For example, for V1 tubes, the distance between the anchor point and the counting device is 3.5 feet. B2 was not tested in this first test, as it was not available at the time of testing. Video cameras recorded the test in order to count bicycles for ground truth.



Source: Google Maps, 2016

Figure 4.2: Tube Layout at TSSU

The parallelogram, and diamond zones were divided in thirds because of their smaller detection ranges. Diagrams of these zones are shown in Figure 4.3 and Figure 4.4 below.

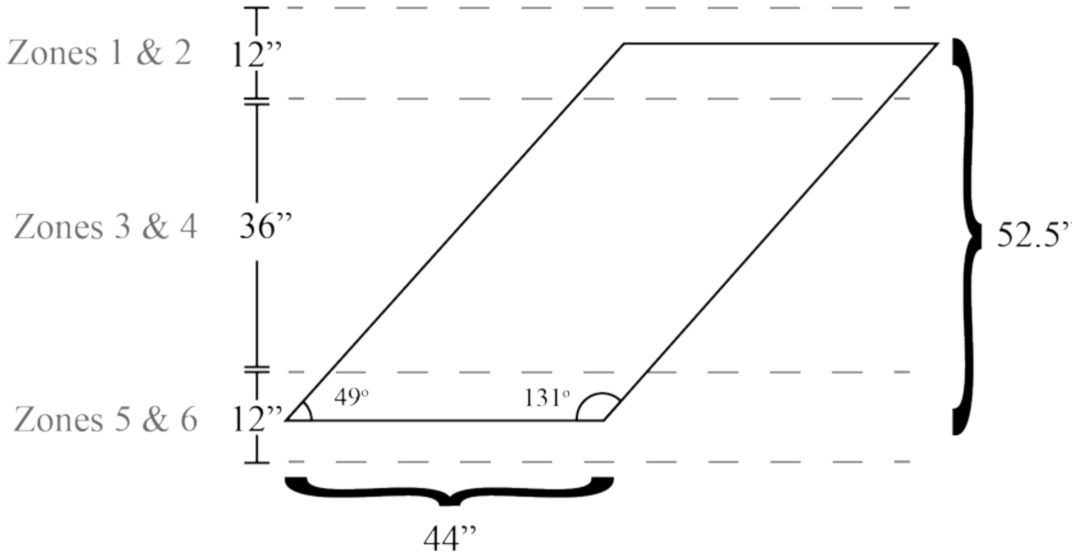


Figure 4.3: Dimensions of Parallelogram Loop

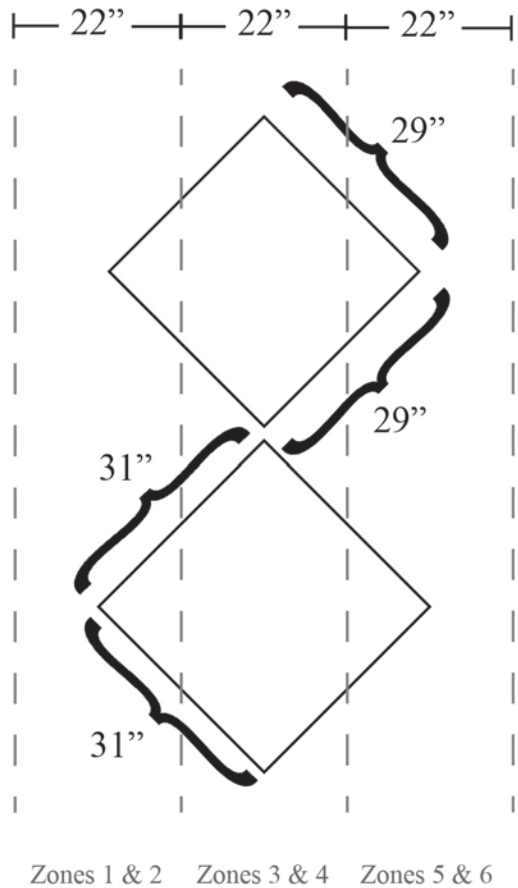


Figure 4.4: Dimensions of Diamond Loop

The research team met with vendors of the various equipment at the test site to ensure that the equipment was set up and calibrated properly. Prior to the commencement of tests, the clocks for the counting equipment were synced. The syncing of the clocks was performed to enable time based comparison of counts from the tubes, loops and thermal camera to the counts from the video, which were considered as ground truth. Table 4.3 shows the schedule and details of the pilot test. The testing was divided into morning and afternoon (AM and PM) time periods. Eight volunteer riders were recruited for the tests. The volunteer riders were provided instructions on where and how to ride prior to the commencement of testing. The start of the testing was indicated to the participants by blowing a whistle. The whistle was also blown each time the riders had to move to the next zone along with verbal instructions. The riders were asked to listen for the sound of the whistle along with the verbal cues to determine where they should be riding. Riders rode in a loop either in clockwise or counterclockwise direction as shown in Figure 4.1.

For the first portion of the test in the a.m. time period, standard bicycles were tested. Bicyclists were asked to ride in each of the 6 zones for 5 minutes before moving on to the next zone in a particular direction. The standard bikes testing lasted for 30 minutes in one direction. The whole process was then repeated in the opposite direction. Thus, the ability of the technologies to detect and count bicycles in both directions and at various distances from the counting device was tested. Bicyclists were then asked to ride in Zone 7 (C1, C2 and C3 tubes only) for a 10-minute period, with 5 minutes in each direction. Following the standard bikes test, testing of special cases was undertaken.

The purpose of the special cases testing was to understand how well the technologies are able to count special cases of bicycles that are encountered less frequently in the field such as tandems, bikes with trailers, carbon fiber bikes, cargo bicycles, and bicyclists riding one behind the other and side by side. Special bicycles used for the special-cases testing are shown in Figure 4.5. For the special cases tests, bicyclists were asked to ride in Zone 1 for the tubes at all times. The afternoon test was a repeat of the morning test and included standard bikes testing for one hour followed by testing of special cases for six zones but did not include Zone 7.

Due to time constraints, the carbon fiber and cargo bicycles were tested in the same time five-minute time period and the tandem and bicycle with trailer were tested in the same time five-minute period. Ideally, sufficient volunteers would have been available to monitor if each bicycle was correctly counted in real time. Unfortunately, on the day of the test, there were not sufficient computers or volunteers to perform this task, except for one of the devices (the Eco-Counter which had 15-minute bins). For this reason, the results are presented for each five-minute test, instead of for each special case tested.

Tandem Bike

Cargo Bicycle

Carbon Fiber Bike

Bike with Trailer

Photos by Authors

Figure 4.5: Special Bikes Tested

Table 4.3: Pilot Test Details

Start Time	End Time	Bicycle Type	Direction	Zone
10:00 AM	10:05 AM	Standard	Counterclockwise	1
10:05 AM	10:10 AM	Standard	Counterclockwise	2
10:10 AM	10:15 AM	Standard	Counterclockwise	3
10:15 AM	10:20 AM	Standard	Counterclockwise	4
10:20 AM	10:25 AM	Standard	Counterclockwise	5
10:25 AM	10:30 AM	Standard	Counterclockwise	6
10:30 AM	10:35 AM	Standard	Clockwise	1
10:35 AM	10:40 AM	Standard	Clockwise	2
10:40 AM	10:45 AM	Standard	Clockwise	3
10:45 AM	10:50 AM	Standard	Clockwise	4
10:50 AM	10:55 AM	Standard	Clockwise	5
10:55 AM	11:00 AM	Standard	Clockwise	6
11:05 AM	11:10 AM	Standard	Counterclockwise	7
11:10 AM	11:15 AM	Standard	Clockwise	7
11:30 AM	11:35 AM	Tandem, Bike with Trailer	Counterclockwise	1
11:35 AM	11:40 AM	Tandem, Bike with Trailer	Clockwise	1
11:40 AM	11:45AM	Carbon Fiber, Cargo Bicycle	Counterclockwise	1
11:45 AM	11:50 AM	Carbon Fiber, Cargo Bicycle	Clockwise	1
11:50 AM	11:55 AM	One behind the other	Counterclockwise	1
11:55 AM	12:00 PM	One behind the other	Clockwise	1
12:00 PM	12:05 PM	Side by side	Counterclockwise	1
12:05 PM	12:10 PM	Side by side	Clockwise	1
1:15 PM	1:20 PM	Standard	Counterclockwise	1
1:20 PM	1:25 PM	Standard	Counterclockwise	2
1:25 PM	1:30 PM	Standard	Counterclockwise	3
1:30 PM	1:35 PM	Standard	Counterclockwise	4
1:35 PM	1:40 PM	Standard	Counterclockwise	5
1:40 PM	1:45 PM	Standard	Counterclockwise	6
1:45 PM	1:50 PM	Standard	Clockwise	1
1:50 PM	1:55 PM	Standard	Clockwise	2
1:55 PM	2:00 PM	Standard	Clockwise	3
2:00 PM	2:05 PM	Standard	Clockwise	4
2:05 PM	2:10 PM	Standard	Clockwise	5
2:10 PM	2:15 PM	Standard	Clockwise	6
2:30 PM	2:35 PM	Tandem, Bike with Trailer	Counterclockwise	1
2:35 PM	2:40 PM	Tandem, Bike with Trailer	Clockwise	1
2:40 PM	2:45 PM	Carbon Fiber, Cargo Bicycle	Counterclockwise	1
2:45 PM	2:50 PM	Carbon Fiber, Cargo Bicycle	Clockwise	1
2:50 PM	2:55 PM	One behind the other	Counterclockwise	1
2:55 PM	3:00 PM	One behind the other	Clockwise	1
3:00 PM	3:05 PM	Side by side	Counterclockwise	1
3:05 PM	3:10 PM	Side by side	Clockwise	1

4.4 RESULTS

This section presents the results of the data analysis for the pilot study. The results from the pneumatic tube counters are presented first, followed by inductive loops and FLIR thermal camera. As mentioned previously, manual counts from the video were considered as ground truth data. The counts from each technology were compared to video counts to assess accuracy.

4.4.1 Pneumatic Tubes

This section details results from each of the five brands of pneumatic tube counters tested. Overall error is referred to and graphed as percent error in this section. Additional error plots for the morning and afternoon (AM and PM) tests by direction for both the standard bikes test as well as the special cases test are presented in the appendix.

4.4.1.1 JAMAR TRAX Cycles Plus

JAMAR TRAX Cycles Plus tube counter had seven zones that were tested during the pilot test. The results indicated that the tube counter was very accurate at counting bicycles in Zones 1-3 during the standard bikes test. However as the distance from the tube counter increased, the error increased for Zones 4-6 as seen in Figure 4.6, which shows the overall accuracy across Zones 1-7 irrespective of direction. The MPE for the standard bikes tests was -17% and MAPE was 19%. For Zones 4-7, JAMAR TRAX Cycles Plus bicycle tube counter undercounted bicycles. It is unclear why the error for Zone 7 was lower than the error for Zones 5 and 6.

Figure 4.7 shows the results of the special cases test using the JAMAR TRAX Cycles Plus tube counter. Undercounting was observed for tandems and bikes with trailers (50% error), carbon fiber and cargo bicycles (49% error) as wells as bicyclists riding side by side (27% error). The error obtained when counting bicycles riding one behind the other was 75%.

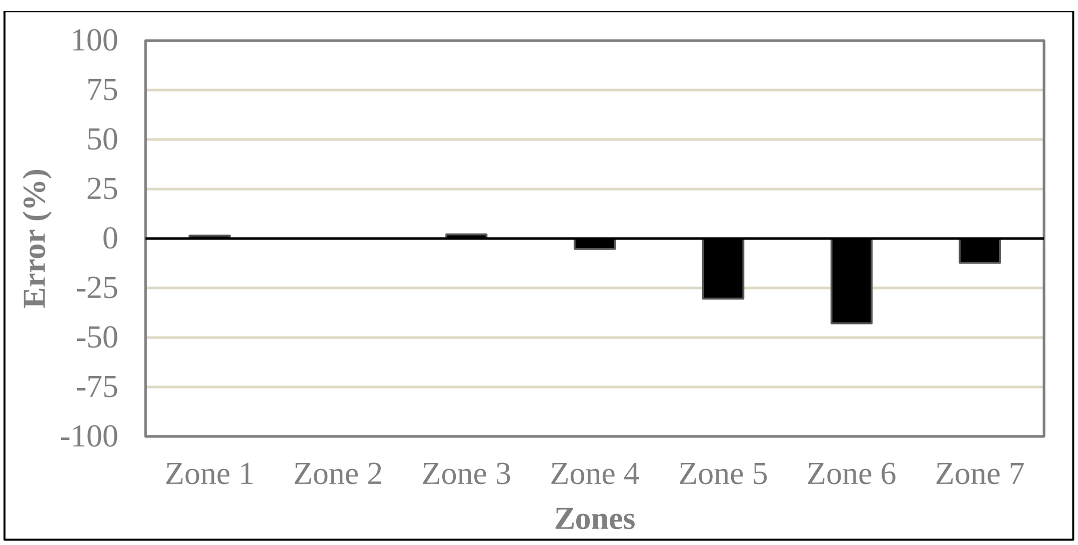


Figure 4.6: JAMAR TRAX Cycles Plus Standard Bikes Test

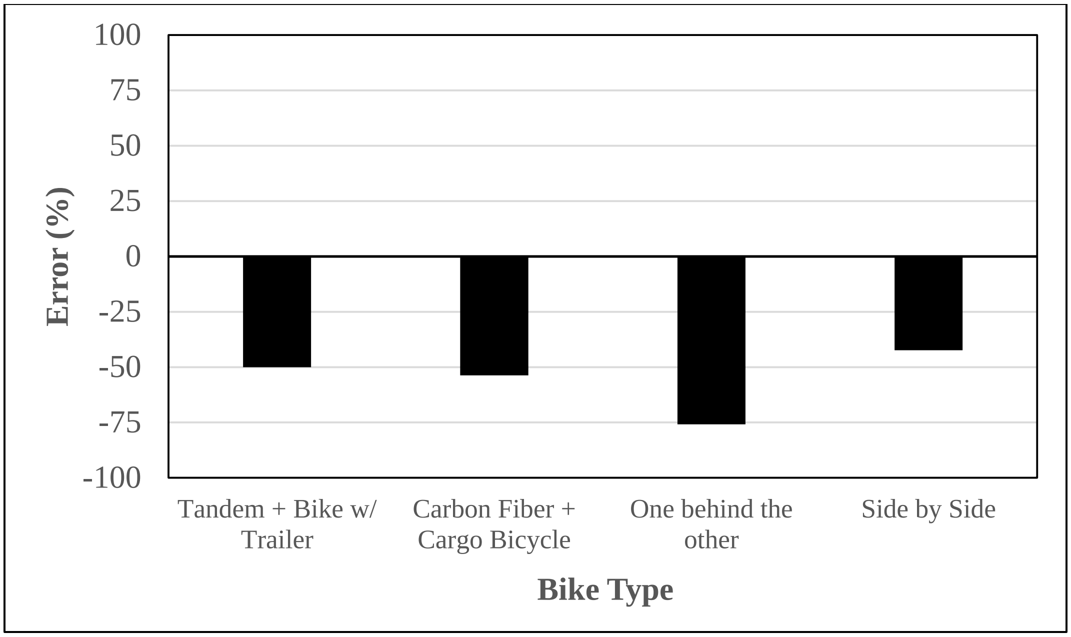


Figure 4.7: JAMAR TRAX Cycles Plus Special Bikes Test

4.4.1.2 Diamond Traffic Tally 6 (TT6)

The Diamond tube was shorter in length and therefore only Zones 1, 2, and 3 were analyzed. The MPE for the standard bikes test was -7%, while MAPE was 10%. Interestingly, the Diamond TT6 tube counter was more accurate in counting bicycles as the distance from the counter increased, during the standard bikes test as seen in Figure 4.8. With the special cases test, the results were mixed as seen in Figure 4.9. The Diamond TT6 tube counter slightly overcounted tandems and bikes with trailers, while undercounting carbon fiber bikes, cargo bicycles, bicyclists riding one behind the other and those riding side by side. The undercounting was particularly pronounced for bicyclists riding side by side (36% error).

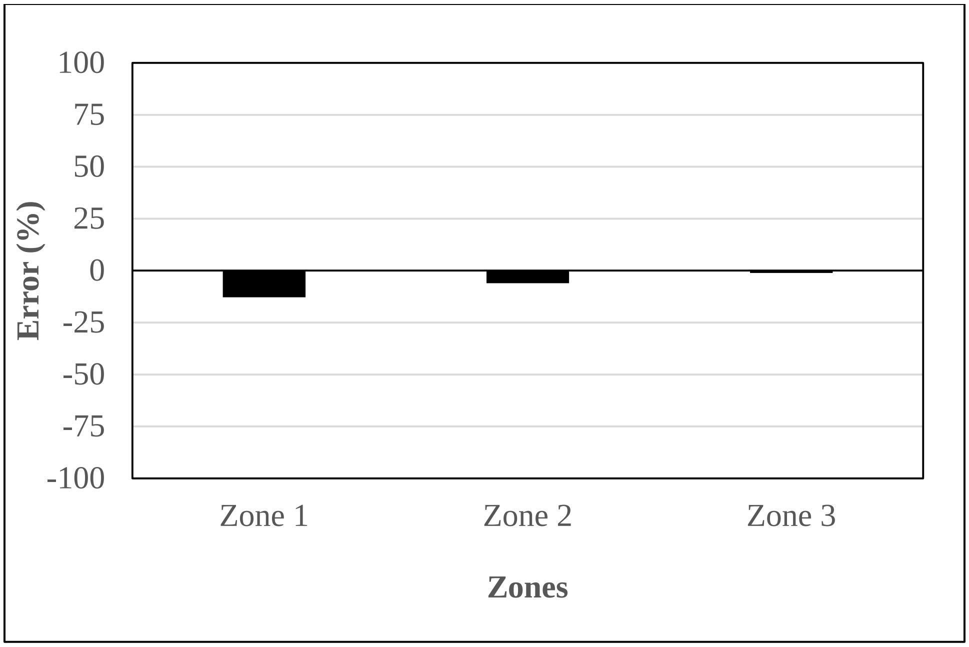


Figure 4.8: Diamond TT6 Standard Bikes Test

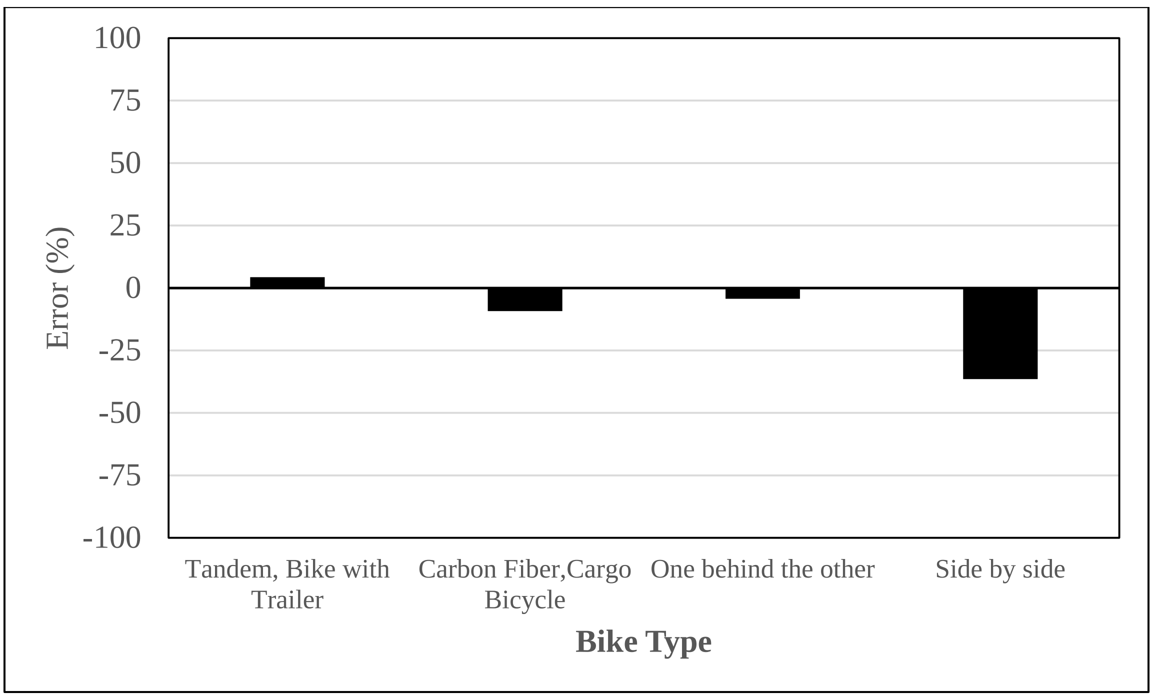


Figure 4.9: Diamond TT6 Special Cases Test

4.4.1.3 TimeMark Gamma

Seven zones were tested with the TimeMark Gamma tube counter during the pilot test. Overall across seven zones, MPE was -19% and MAPE was 20%. TimeMark tube counter was fairly accurate in Zones 1-4, however errors sharply increased for Zones 5-7 for the standard bikes test, with the errors increasing as the distance from the tube counter increased. Figure 4.10 shows the plot of errors across Zones 1-7 for the TimeMark Gamma tube counter. With the special cases test, while the counter showed low errors when counting tandems, bikes with trailers, carbon fiber bikes and cargo bicycles (errors less than 10%), it severely undercounted bicyclists riding one behind the other (64%) and those riding side by side (38%) as seen in Figure 4.11.

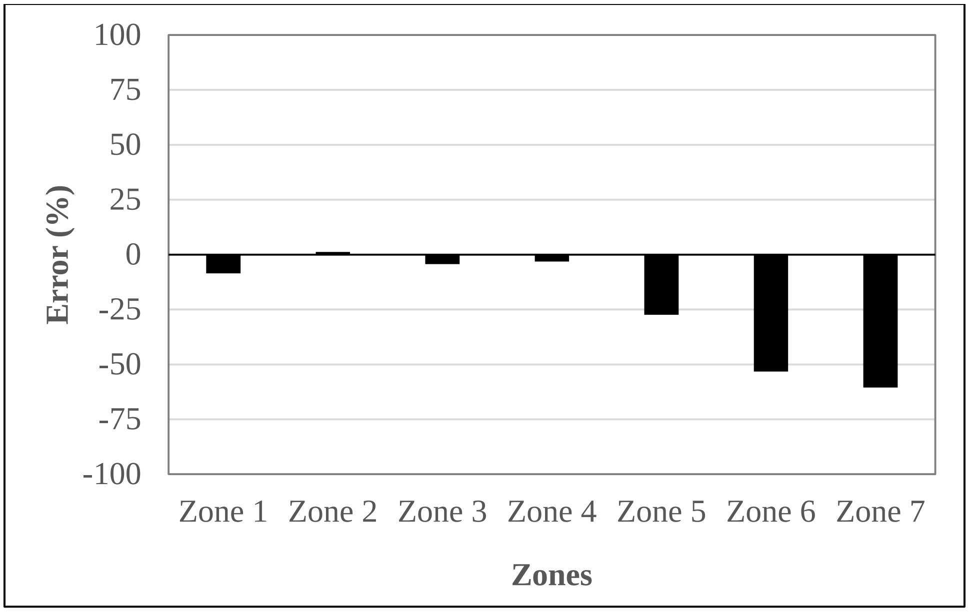


Figure 4.10: TimeMark Gamma Standard Bikes Test

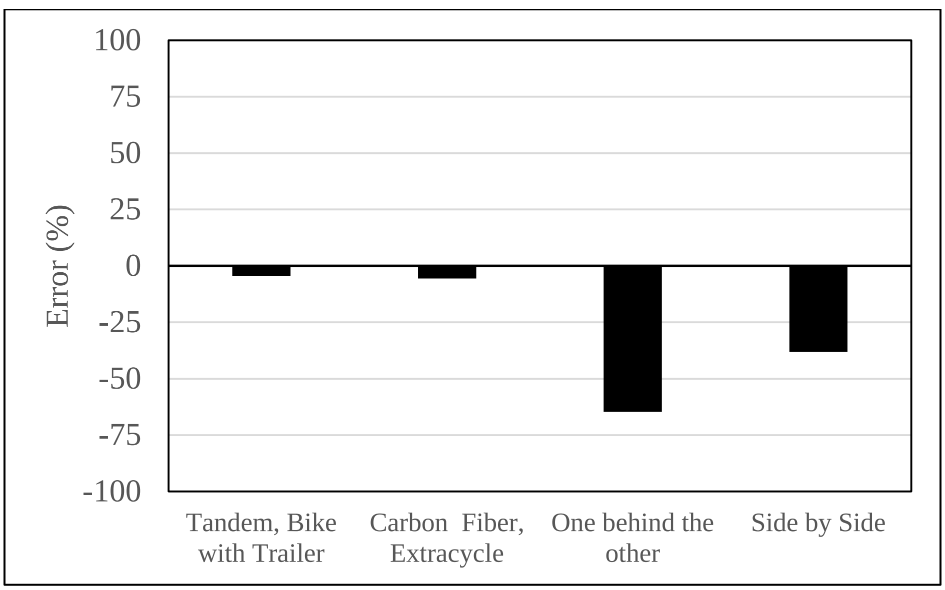


Figure 4.11: TimeMark Gamma Special Cases Test

4.4.1.4 MetroCount MC5600

MetroCount MC5600, using ARX Cycle scheme, undercounted bicycles across most zones during the standard bike test. MPE and MAPE were -36 and 36 respectively. As

Figure 4.12 shows, the undercounting was more pronounced in Zones 5, 6 and 7 with 63%, 64% and 98% undercounting error respectively. During the special cases test, MC 5600 tube counter performed poorly across all categories. Undercounting was more pronounced when counting tandems and bikes with trailers (95% error) as well as bicyclists riding one behind the other (94% error) as seen in Figure 4.13.

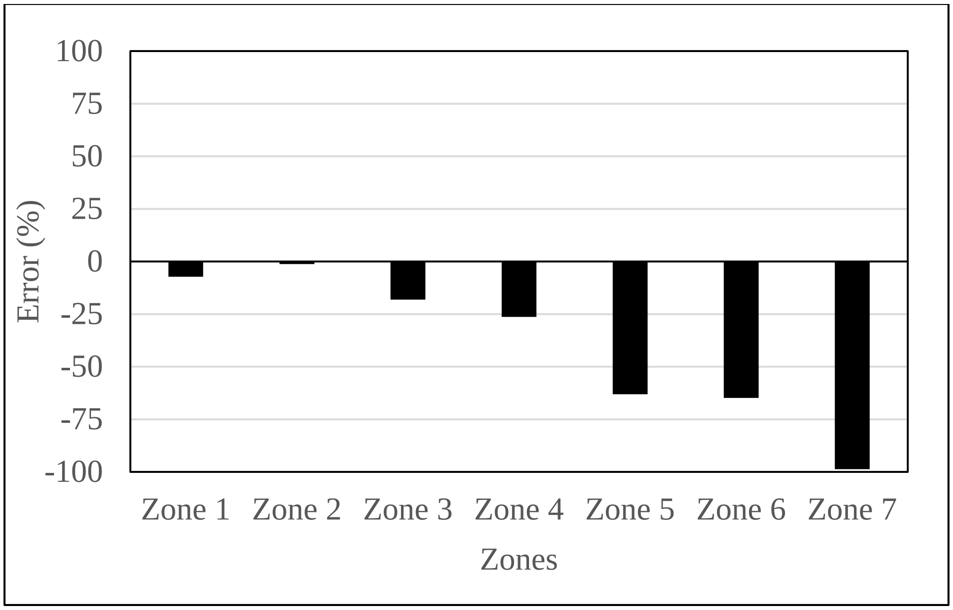


Figure 4.12: MetroCount 5600 Standard Bikes Test

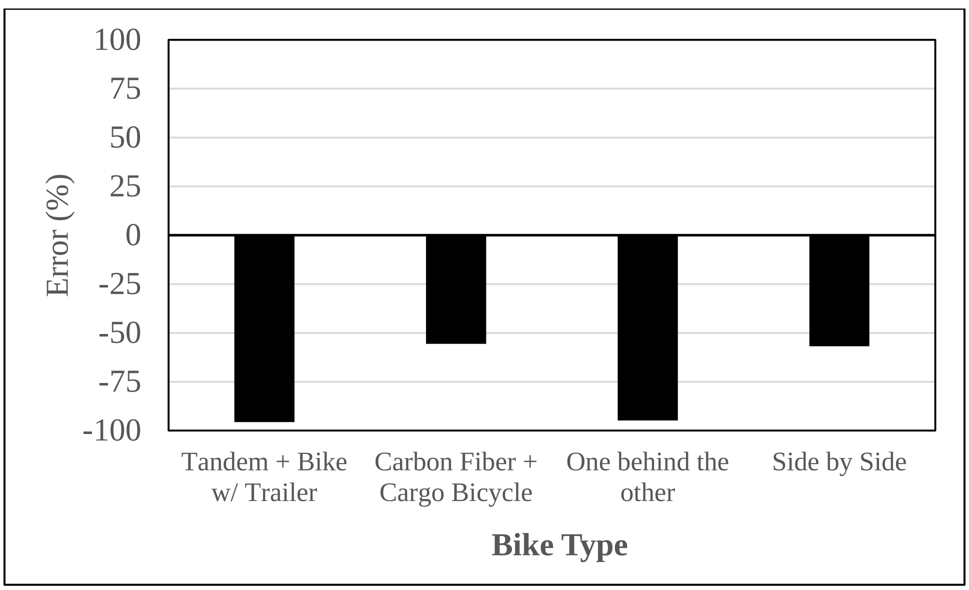


Figure 4.13: MetroCount 5600 Special Cases Test

4.4.1.5 Eco-Counter TUBES

The Eco-Counter pneumatic tube counter performed very well in the standard bikes tests. As stated earlier, this is a bicycle specific counter and is able to differentiate between bicycles and motor vehicles. For the standard bikes test, MPE was obtained as -0.6% and MAPE was 1.7%. As seen in Figure 4.14, no error was seen for Zones 1-3 and slight undercounting was seen for zones 4-6 (1.6%). Zones 1-3 and 4-6 were analyzed together as the lowest time period resolution available for the data was 15 minutes.

Figure 4.15 shows the errors obtained from the special cases test. Because a person was available to see the reading on the Eco-Counter TUBE counter device to see if each individual bicycle was or was not counted, results in the figure are reported in terms of the bicycle type. This was necessary for the Eco-Counter because it has 15-minute bins which would have grouped most of the special bicycles into one group. The Eco-Counter undercounted tandems (50% error) and bikes with trailers (100% error). It was very accurate in counting carbon fiber bikes (0% error) and slightly undercounted cargo bicycles (8% error). However, it severely undercounted bicycles riding one behind the other (73% error) and those riding side by side (58% error).

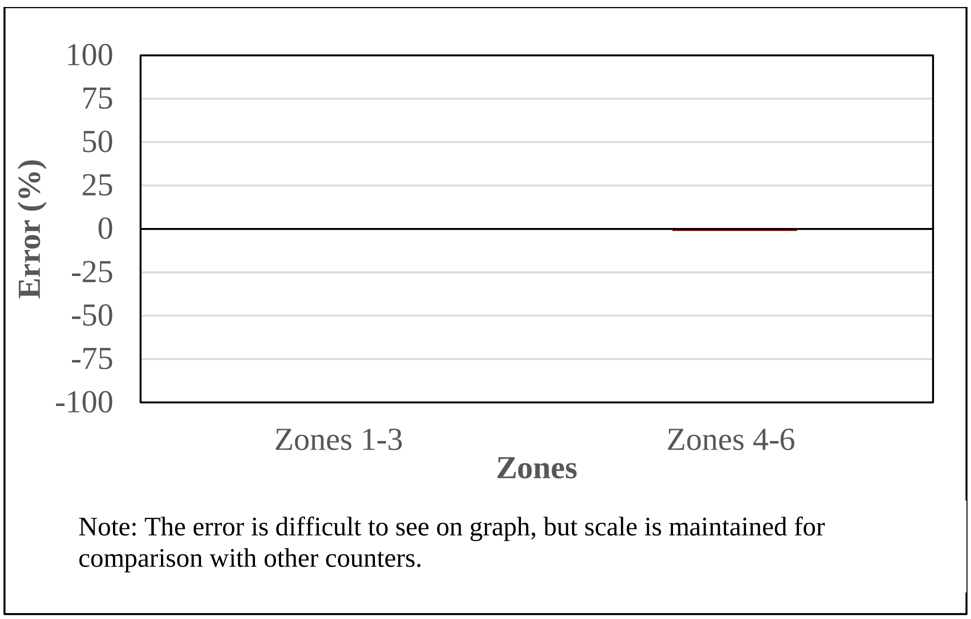


Figure 4.14: Eco-Counter Standard Tubes Test

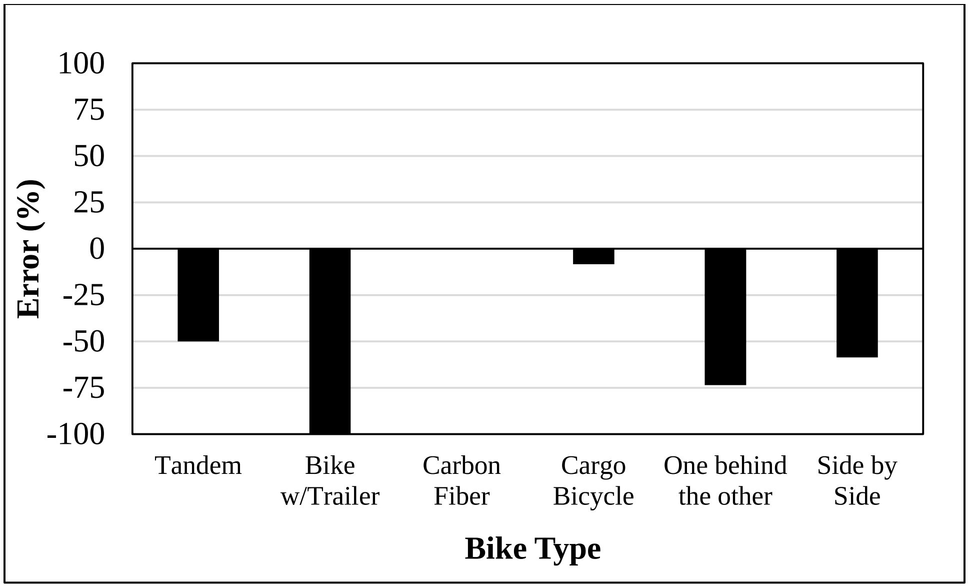


Figure 4.15: Eco-Counter Special Bikes Test

Table 4.4 shows the errors across zones for all tube counters that were tested. All of the tube counters undercounted bicycles compared to actual counts. In Zones 1-3, most of the tube counters were fairly accurate. As the distance from the counter increased, all three classification counters showed higher errors. Of all the counters tested, for standard bicycles, B1 was the most accurate with MPE of -0.6%, indicating a slight undercount. The number of cyclists for each zone (*n*) was the same for all the equipment types, but varied by zone and averaged 85 cyclists per zone.

Cyclist speeds for this test were relatively slow, averaging eight miles per hour based on speeds reported by C1. This was due to sharp turns adjacent to the tube layout. Speeds were especially slow for Zones 4 through 7 which averaged only seven miles per hour. Figure 4.16 shows the error as a function of distance. For C1, C2 and C3 as the distance from the counter increases, error also increases.

Table 4.4: Error by Distance from Counter for Standard Bicycles

Type	Percent Overall Error by Zone (%)							MPE (%)	MAPE (%)
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**		
n	69	85	92	95	93	90	73		
B1*		0			-1		N/A	-1	2
C1	2	0	0.0	-11	-38	-50	-26	-16	17
C2	-7	0	-5	-6	-25	-54	-82	-16	17
C3	-7	-1	-18	-26	-63	-65	-99	-31	31
V1	-12	6	3	N/A	N/A	N/A	N/A	-8	10

* B1 counters provided data in 15 minute bins, so zones had to be grouped.
Note: N/A indicates that the tubes were not long enough to reach these zones.

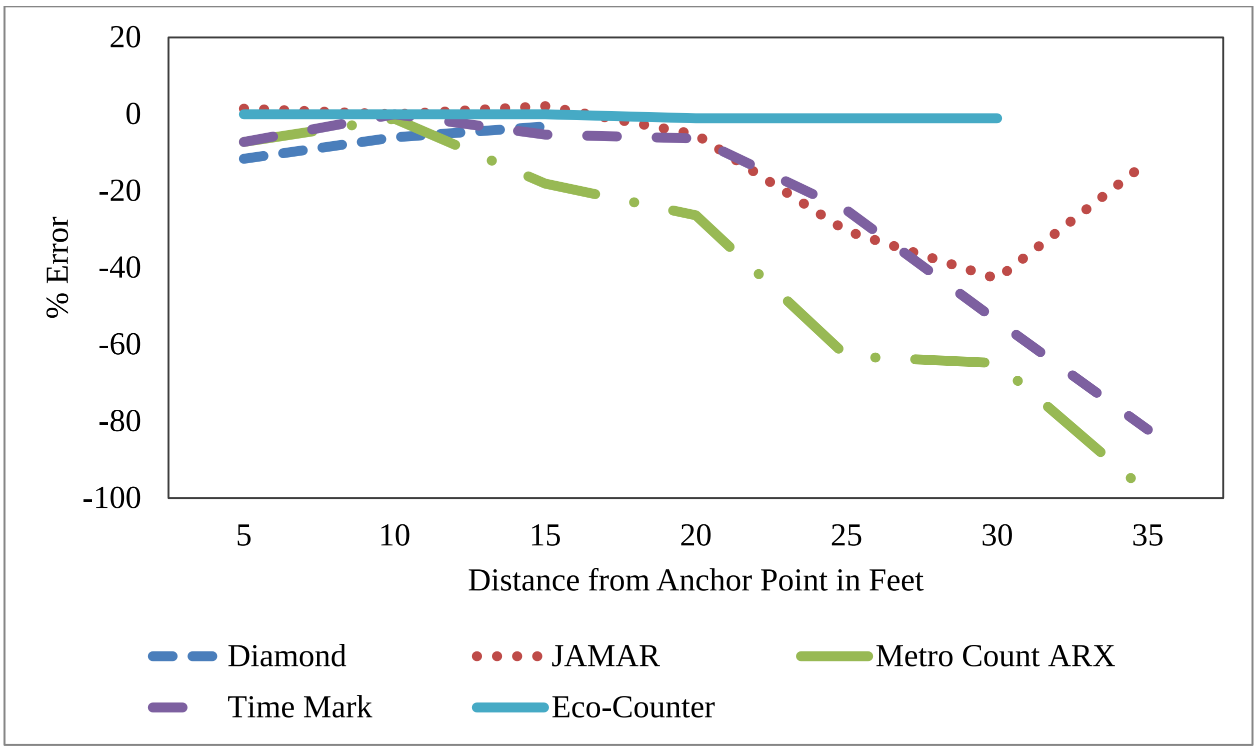


Figure 4.16: Error by Distance for Tubes Tested in Pilot Study

The results indicate that all of the equipment studied are viable technologies for counting bicycles within 0-10 ft. from the tube counter, approximately up to the width of one general traffic lane. Also, only one counter, B1, is a viable technology to count in the range of 0-30 ft. – approximately up to two general traffic lanes. These results agree with findings from a prior research study, where researchers also reported drop in accuracy beyond 27 ft. for both bicycle specific and general purpose tube counters (*Hyde-Wright et al. 2014*).

Table 4.5 shows the accuracy of the pneumatic tube counters during the special cases test. In the tandems and bikes with trailer category, both V1 and C2 counters showed the lowest error, with V1 overcounting by 4% and C2 undercounting by 4%. In the carbon fiber, cargo bicycle category, B1 was most accurate with undercounting errors of 4%. Both C1 and B1 were fairly accurate when counting bicycles riding one behind the other. All the tube counters showed high errors when counting bicycles riding side by side, indicating the limitation of pneumatic tube counting technology.

Table 4.5: Error with Pneumatic Tube Counters During the Special Cases Test

Tube Counter	**Tandem, Bicycle with Trailer**		**Carbon Fiber, Cargo Bicycle**		**Standard Bicycles: One Behind the Other**		**Standard Bicycles: Side by Side**	
	n	Overall Error (%)	*n*	Overall Error (%)	*n*	Overall Error (%)	*n*	Overall Error (%)
B1	24	-75	24	-4	68	-74	70	-59
C1	46	-50	54	-50	116	-2	118	-46
C2	46	-4	54	-6	116	-65	118	-38
C3	46	-96	54	-56	116	-95	118	-57
V1	46	4	54	-9	116	-4	118	-36

4.4.2 Inductive Loops

4.4.2.1 Diamond Loops

Although data from the diamond loops was collected, it was not analyzed for a number of reasons:

1. The loop was not connected to a signal controller and therefore no logs were available with the count data.

2. While an experimental card that could record bicycle signatures was connected to read the loop output, the time stamps on the bicycle signature file were considerably different than the time stamps on the video data and there was no accurate record of the difference between the two time stamps.

3. The vendor was on site and made some real time changes to the recording, while the test was being conducted and therefore the integrity of the data could not be guaranteed.

Hence, the research team decided not to analyze the current data. Instead the research team decided to test the diamond loop configuration during the intersection field tests, which are described in Chapter 5.

4.4.2.2 Parallelogram Loops

With the parallelogram loops, two loop detector cards were tested as outlined earlier. The Reno A&E Model C 1101-B was used in the morning test to count standard bikes as well as special cases. Figure 4.17 shows the plot of errors across zones when counting bicycles using the Reno A&E card. The card severely undercounted bicycles in Zones 1-2, 5-6 as evidenced by the high errors respectively (93%, 97%) in Figure 4.17. However, the card was very accurate in counting bicycles riding over the center of the loop in Zones 3-4 (1% error). After talking to Reno A&E, the research team found out that their detector card Model C 1101-B was designed to not detect any bicycles that are riding within 1 foot from the edge of the loop, as was encountered in this study for Zones 1-2 and 5-6.

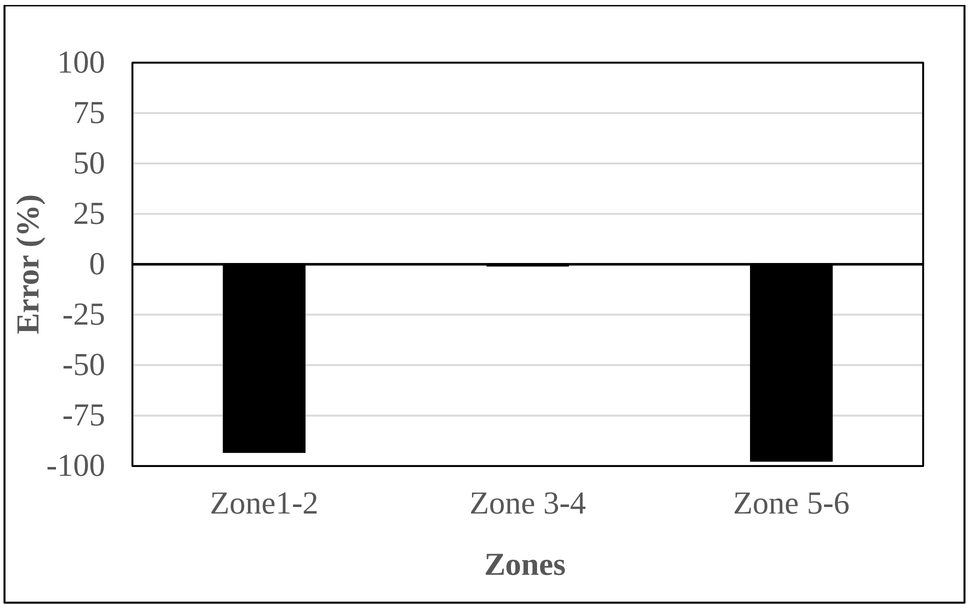


Figure 4.17: Parallelogram Loop Standard Bikes Test with Reno A&E Detector Card

The EDI Model LM 222 card was also used to count bicycles during the afternoon test. Figure 4.18 shows the plot of errors across zones with the EDI detector card. Unlike the Reno A& E card, the EDI card counted bikes accurately along the edge of the loop in Zones 1-2 and 5-6 (2%, 2% error respectively). However, it significantly overcounted bicycles riding over the center of the loop in Zones 3-4 leading to a 64% error.

The overcounts may have been due to the sensitivity being set too high. The sensitivity settings were not adjusted during testing, but might result in different findings. Previous work demonstrates the error variation with sensitivity settings (*Figliozzi et al. 2014*).

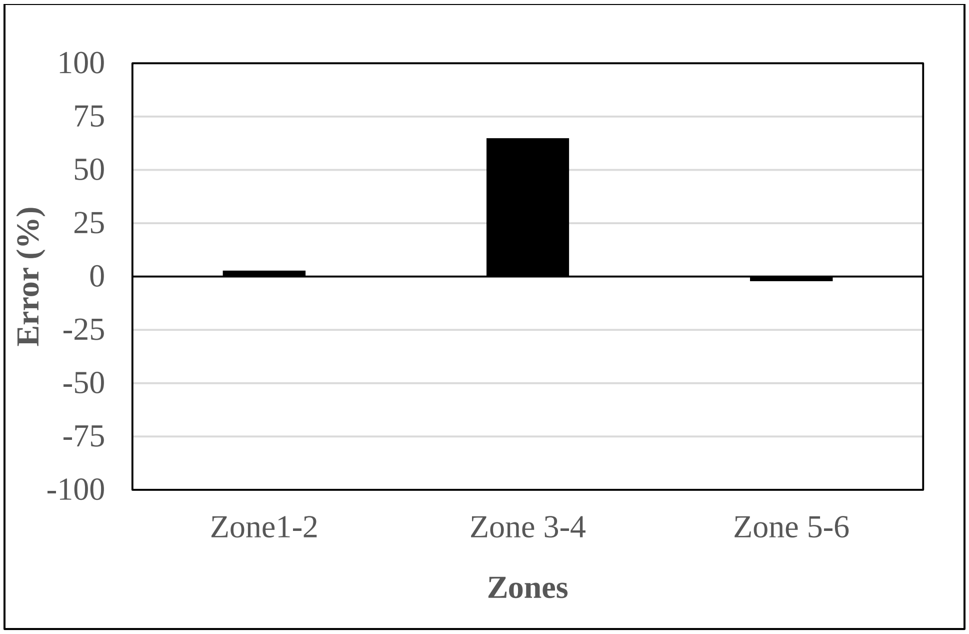


Figure 4.18: Parallelogram Loop Standard Bikes Test with EDI Detector Card

Figure 4.19 shows the results of the special cases test on the parallelogram loop using Reno A&E card. While undercounting was seen for all bike types, the detector card had trouble accurately counting bicycles that were riding one behind the other (48% error) as well as bicycles riding side by side (100% error). The high error for the bicycles riding side by side was due to the riders riding on the outer Zones 1-2 and 5-6 to maintain some degree of separation for safety purposes. However, as the standard bikes test showed, the Reno A&E card is designed to not count any bicycles 1 foot from the edge of the parallelogram.

Figure 4.20 shows the results of the special cases test on the parallelogram loop using the EDI detector card. The results were a mixed bag. While the carbon fiber and cargo bicycle were counted accurately (0% error), undercounting was seen with tandems and bikes with trailers (22%) and bicyclists riding side by side (43%). On the other hand, bikes riding one behind the other were overcounted (18%).

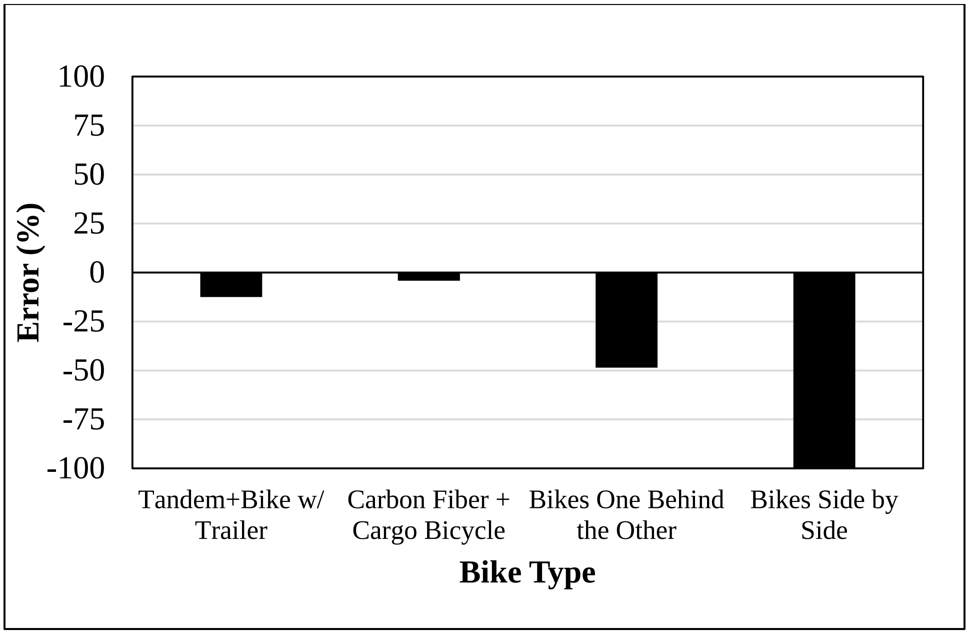


Figure 4.19: Parallelogram Loop Special Cases Test with Reno A&E Detector Card

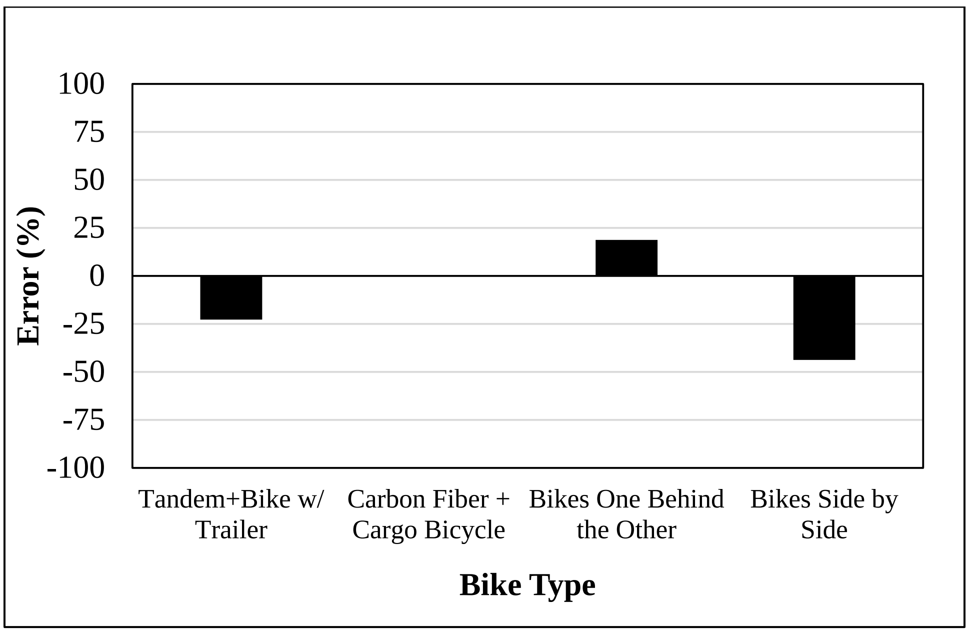


Figure 4.20: Parallelogram Loop Special Cases Test with EDI Detector Card

4.5 FLIR THERMAL CAMERA

The FLIR thermal camera detects body heat in a set zone, counting each warm body as it enters and exits the zone. Zones can be drawn in any shape using FLIR's camera and software on a computer. For the pilot test, a rectangular zone was created and taped off. Cyclists were directed to ride within the zone, which resembled a short bike lane. Only cyclists riding toward the camera were designed to be counted, so only such cyclists were included in the computation of error.

During the standard bicycle test, the FLIR had less than 1% error in both the morning and afternoon tests. There were several cases where cyclists did not obey instructions and rode well outside the zone, but those few cases were removed from the analysis. In a real world situation, however, it is possible that cyclists may ride outside of the bike lane. Therefore, the research team decided to further evaluate FLIR in the field.

Figure 4.21 below displays error for the special cases tests. Error was low or zero for the tandems, bikes with trailers, carbon fiber, and cargo bicycles. For the one behind the other and side by side cyclists, however, error hovered just below 20%. This is another condition that is often seen in the real world. Multiple cyclists might stop in a line at a red light or be riding very close to one another – another reason that this technology was chosen for further testing at a different location.

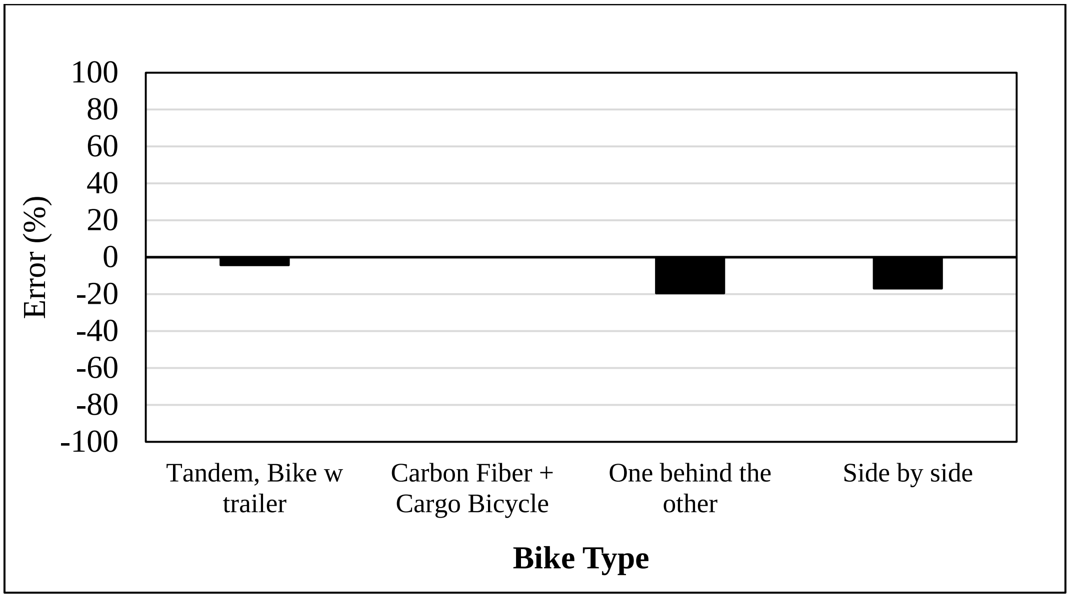


Figure 4.21: FLIR Special Cases Test

4.6 SUMMARY

The purpose of the pilot test was to evaluate the accuracy of various count technologies in a controlled setting. Inductive loops, pneumatic tubes and thermal camera were evaluated for their ability to count both standard bicycles as well as special cases such as tandems, bikes with trailers, carbon fiber bicycles, cargo bicycles, bicyclists riding one behind the other and those riding side by side. While the parallelogram loop with the Reno A&E card was very accurate in counting bicycles riding in the center of the loop, it failed to detect and count bicycles riding along the edges of the loop. The EDI card was very accurate in counting bicyclists that were riding along the edges of the loop, but showed high overcounting of bicyclists that were riding in the center of the loop.

Findings for pneumatic tubes revealed that all of the equipment tested were capable of counting standard bicycles with less than 10% error within 10 to 15 feet of the count equipment, when bicycles are the only vehicle to be counted and the bicyclists ride as individuals, not in groups. The results from the special cases test showed that bicycles riding side-by-side, one-behind-the-other, bicycles with trailers, and long wheel-base bicycles are particularly difficult to count using pneumatic tubes.

The FLIR thermal camera was very accurate in counting bicycles during the standard bicycle test but showed greater errors counting bicyclists riding one behind the other and those riding side by side.

Based on the results obtained, all the equipment tested during the pilot test was considered sufficiently accurate to warrant further evaluation during the field tests, which are described in the next chapter.

5.0 FIELD TESTS

Following the pilot test, two field tests were conducted in a real world traffic environment. The purpose of the field tests was to test the equipment in mixed traffic, i.e. in the conditions where ODOT staff typically measure bicycle volumes. The first test was along a section of the Columbia River Highway; only pneumatic tubes were tested. The second field test was conducted at the intersection of 99W and Hall Blvd. and included pneumatic tubes, inductive loops and FLIR thermal camera as well as two pedestrian traffic monitoring technologies – passive infrared and pedestrian push-button phase actuations.

5.1 COLUMBIA RIVER HIGHWAY TEST

5.1.1 Purpose

In order to evaluate the performance of the counting equipment in a real-world scenario, the pneumatic tube counters were tested on a state highway with relatively high bicycle volumes. To minimize tube displacement due to turning, accelerating or decelerating vehicles, the team sought a relatively flat and straight section of roadway in a rural setting. Other criteria for selecting a site included proximity to Portland to minimize travel time, moderate to high bicycle traffic volume, and a cross-section representative of ODOT highways. The highway section selected was a two-lane section with four to five-foot shoulders on the historic Columbia River Highway, a road used by tourist traffic and cyclists to access a scenic portion of the Columbia River Gorge east of Corbett, Oregon. The slight grade provided the opportunity to study one direction with higher bicycle speeds (15-30 mph) and the other with slower bicycles (5-15 mph). The roadway width, 32.5-feet from pavement edge to pavement edge, provided adequate width to test the condition of how well one counter could count cyclists on both shoulders.

5.1.2 Technologies

Since preliminary results for all the equipment tested were sufficiently accurate, the same equipment that was used in the pilot test was tested in the mixed traffic test, with the addition of B2, which was not available previously. Table 5.1 lists the various pneumatic tube counters that were tested.

Table 5.1: Technologies Tested at Columbia River Highway

Type	Designation	Make	Model	Tube Spacing
Bicycle-specific	B1	Eco-Counter	Bicycle-only TUBES	1 ft.
	B2	Eco-Counter	Bicycle & Motor Vehicle TUBES	1 ft.
Classification	C1	JAMAR Technologies, Inc.	TRAX Cycles Plus	2 ft.
	C2	TimeMark Corporation	Gamma	10 ft. and 16 ft.
	C3	MetroCount	MC5600	1.5 ft.
Volume	V1	Diamond Traffic Products	TT6	N/A

5.1.3 Methodology

It was important to study actual traffic, not traffic generated by volunteer riders, since actual bicycle traffic may behave differently than recruited riders. For this reason, a three-day holiday weekend with high bicycle volumes was selected for the test; Memorial Day weekend, Friday, May 22, 2015 through Monday, May 25, 2015. Daily high temperatures ranged from 60 on Friday to 67 degrees Fahrenheit on Monday with less than a tenth of an inch of rain on Friday and Saturday and no rain with partly cloudy skies Sunday and Monday. A total of 576 cyclists, 300 eastbound (EB) and 276 westbound (WB) were observed during daylight hours (8:00 AM to 8:00 PM) from the manually counted video during the four days (46 hours) studied. Two hours on Sunday were lost due to camera downtime while switching data storage cards.

In order to ensure that our "ground truth" video counts were accurate, 3 researchers watched the same one hour of video from the Sunday test during the hour from 10:00 a.m. to 11:00 a.m. While counts between researchers were slightly different when classifying motor vehicles, they all counted the same number of bicycles during that hour, which is the important factor for this study. Table 5.2 shows the results of the inter-rater reliability test that was conducted between the three researchers, while they watched the same 1 hour of video.

Table 5.2: Inter-Rater Reliability

	Motor Bikes	Cars & Trailers	Trucks/Vans	Buses	2 Axle 6 Tire	Bikes	Total
Researcher 1	9	248	29	0	2	32	320
Researcher 2	9	234	43	0	3	32	321
Researcher 3	9	255	23	1	0	32	320

5.1.3.1 Site Layout

As shown on Figure 5.1, tubes were laid out on both the north and south side of the roadway. This tested the hypothesis that counts closer to the detector would be more accurate based on previous studies and findings from the pilot test. Thus, an effort was made to repeat the tube set up on each side of the roadway. ODOT transportation monitoring staff set up all of the tubes and the V1 and C2 data loggers. For the C2 equipment in the eastbound direction, ODOT staff set up two identical sets of equipment, one with a spacing of 10 feet and another with a 16-foot spacing between tubes, in order to test both their standard setup for motor vehicle classification counts (16-foot spacing) and a spacing recommended by the manufacturer for the case when both bicyclists and motor vehicles are to be counted (10-feet), respectively. The C1, C3, B1 and B2 data loggers were set up by the Portland State University research team.

The volume tubes, V1, were only set up on the shoulder since they cannot differentiate between motorists and bicyclists. The reason for including them at all was to study whether this simplistic approach could be used in this type of cross section or whether bicyclists would avoid the tubes and motorists drive over them. To test whether cyclists avoided the tubes, these were set up in front of the other tubes so that cyclists could avoid them, though they could not avoid the other tubes.

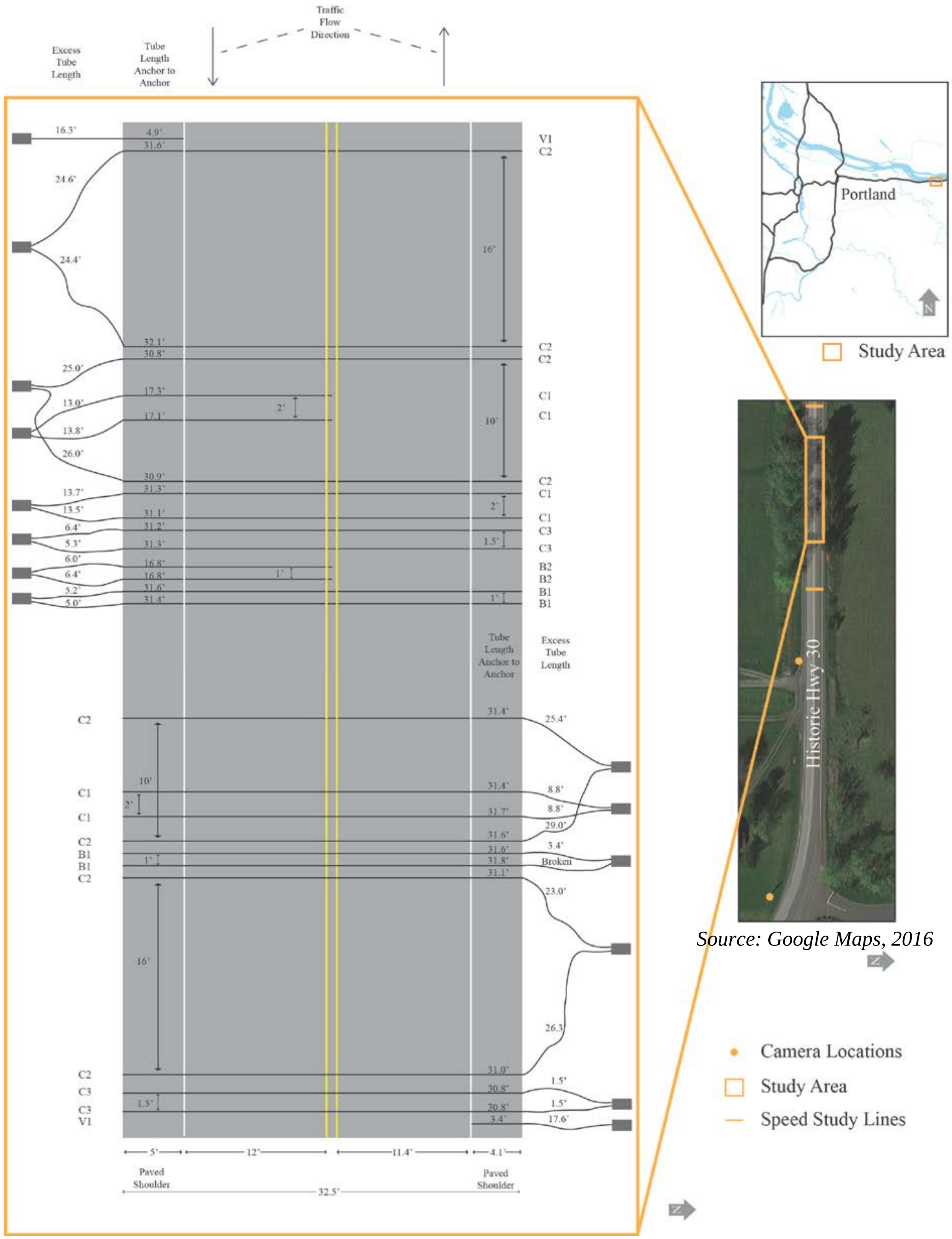


Figure 5.1: Layout of Pneumatic Tube Counters for Mixed Traffic Test

5.1.4 Results

5.1.4.1 Count Accuracy

Error attributed to each counter varied substantially during the mixed traffic test as shown in Table 5.3. Undercounting was encountered with all tested counters, and error for all counting equipment was high, above 10% MPE. The bicycle specific counters had relatively low error (20% to 23% undercount MPE). The classification counters varied widely with the C1 equipment being most accurate of all the equipment tested (13% to 22% undercount MPE) and C2 being the least accurate of all equipment tested (44% to 73% undercount MPE). The volume only counter performed unexpectedly well with only 20% undercount MPE.

Table 5.3: Tube Accuracy at Columbia River Highway

Counter Name	*n*	Bicycles Counted	Overall Error (%)	MPE (%)	MAPE (%)	Total Hourly Overcounts
B1, Eco Counter, North Side	576	361	-37	-23	26	2
B1, Eco Counter, South Side	576	378	-34	-20	23	3
B2, Bike & Motor Vehicle Eco Counter, South Side (half road)	300	183	-39	-20	26	2
C1, JAMAR, North Side	576	409	-29	-18	22	9
C1, JAMAR, South Side	576	400	-31	-13	31	15
C1, JAMAR, South Side (half road)	300	185	-38	-23	24	1
C2, Time Mark, North Side (10ft)	576	170	-70	-50	55	3
C2, Time Mark, North Side (16ft)	576	200	-65	-44	50	12
C2, Time Mark, South Side (10ft)	576	142	-75	-60	60	1
C2, Time Mark, South Side (16ft)	576	79	-86	-73	73	3
C3, Metro Count, North Side	576	236	-59	-43	43	0
C3, Metro Count, South Side	576	288	-50	-32	32	0
C3, Metro Count, North Side BOCO	576	380	-34	-28	29	1
C3, Metro Count, South Side BOCO	576	495	-14	-10	10	1
V1, Diamond, South and North Sides	576	425	-26	-20	27	20

Another metric of interest is the number of overcounts in a given hour bin. These overcounts for each technology are shown in the last column in Table 5.3. These are especially obvious for hours in which no cyclists were observed in the video, but "phantom cyclists" were detected by some counters. Such overcounts are especially concerning if they are caused by misidentified motor vehicles, as this can cause the counters to report biased data with incorrect traffic patterns for bicycles. Such errors can be especially problematic for roads with low bicycle counts, a condition prevalent on state highways in the U.S. While B1 and C3 show relatively few overcounts, C1, C2, and V1 show more.

Based on the results from the controlled environment study, the research team expected to find less error in counting bicyclists closer to the counting equipment than farther away from it (bicyclists riding on the opposite side of the road). With this in mind, the error of the counting equipment was divided into near and far categories. Figure 5.2 shows the error obtained from each of the pneumatic tube counters by distance from the counter. Generally, accuracy is higher for bicyclists closer to the counter as shown in Figure 5.2 below.

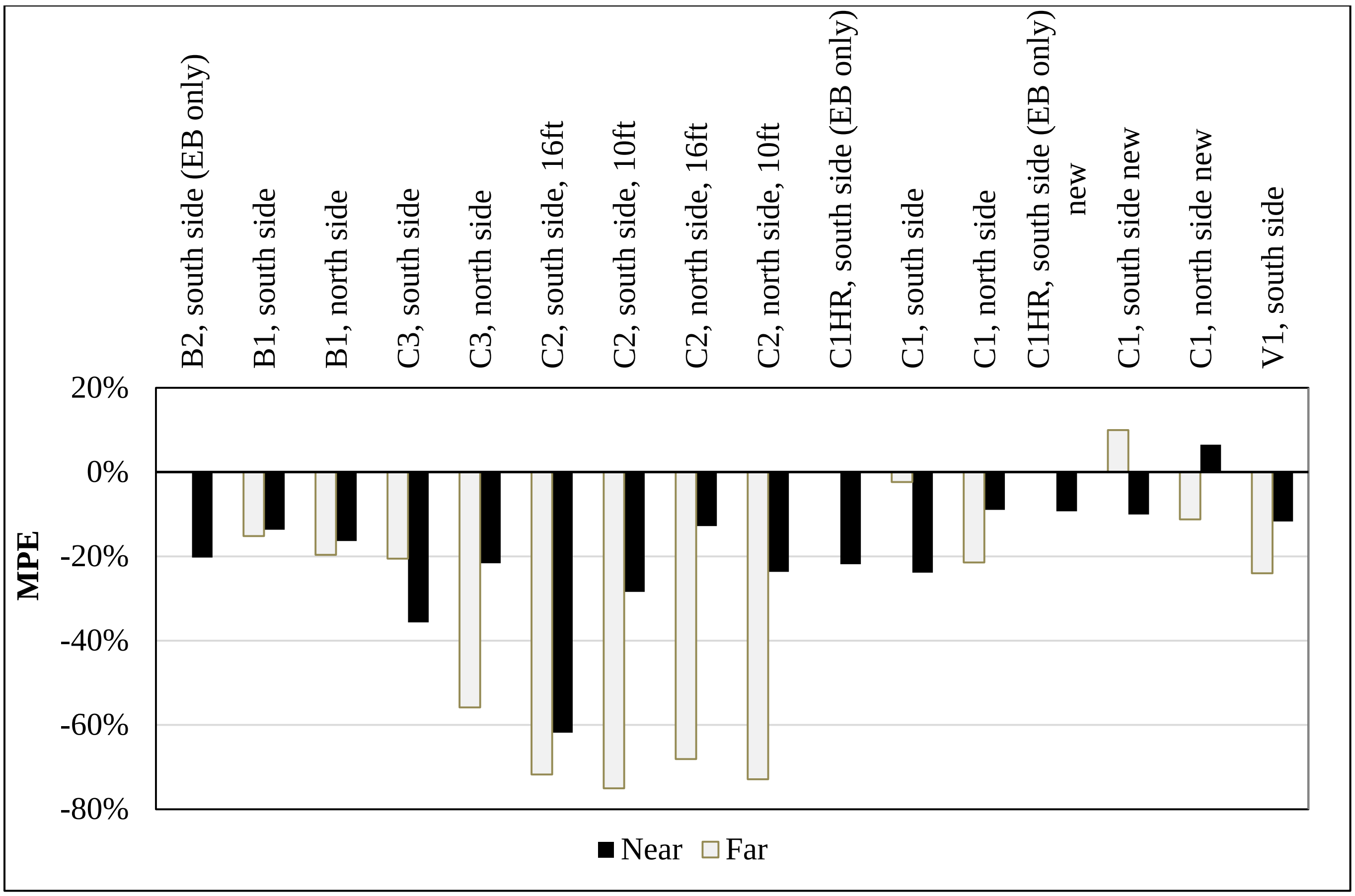


Figure 5.2: MPE by Distance from Counter

In addition, error seemed to vary by direction as shown in Figure 5.3, which shows generally higher error for eastbound (EB) than for westbound (WB) equipment. Perhaps this is due to higher error for lower speed bicycles, since bicycle speeds were higher in the westbound (downhill) direction. However, analysis of error with speed did not show a clear relationship between bicyclist speed and accuracy.

Another question of interest is whether shorter tubes that only covered one vehicle lane and the shoulder (half road) would yield more accurate results than longer tubes that covered the entire road. However, the error for the two half road cases (B2 and C1 half road) do not show substantially lower error than comparable equipment (B1 and C1).

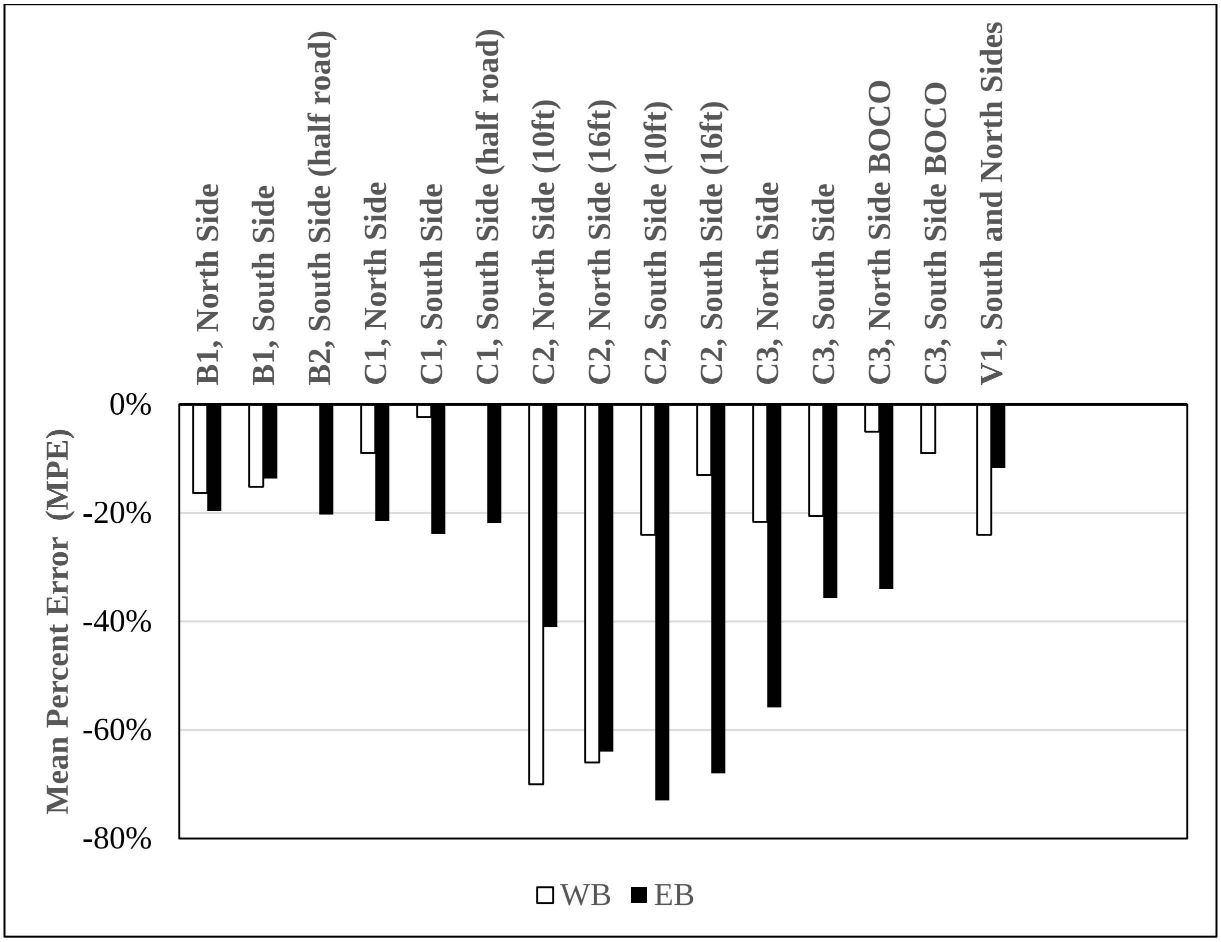


Figure 5.3: MPE by Direction of Traffic

What is causing the error? Figure 5.4 and Figure 5.5 examine error per count interval with bicycle and motor vehicle traffic volumes. According to Figure 5.4 and Figure 5.5, error appears to increase with increasing bicycle traffic volumes and to a lesser extent with increasing vehicle volumes. These results are intuitive since passing vehicles cause occlusion. Occlusion takes place when motor vehicles and bicyclists pass over the tubes simultaneously, or in a very short time interval, such that the pulse of air from the bicycle is not recognized by the classification algorithm.

Bicycles traveling in groups are similarly difficult to count as shown in the earlier results from the controlled environment special cases tests (bicyclists riding side by side and one behind the other). Some of the equipment tested is better than others at separating out these cases.

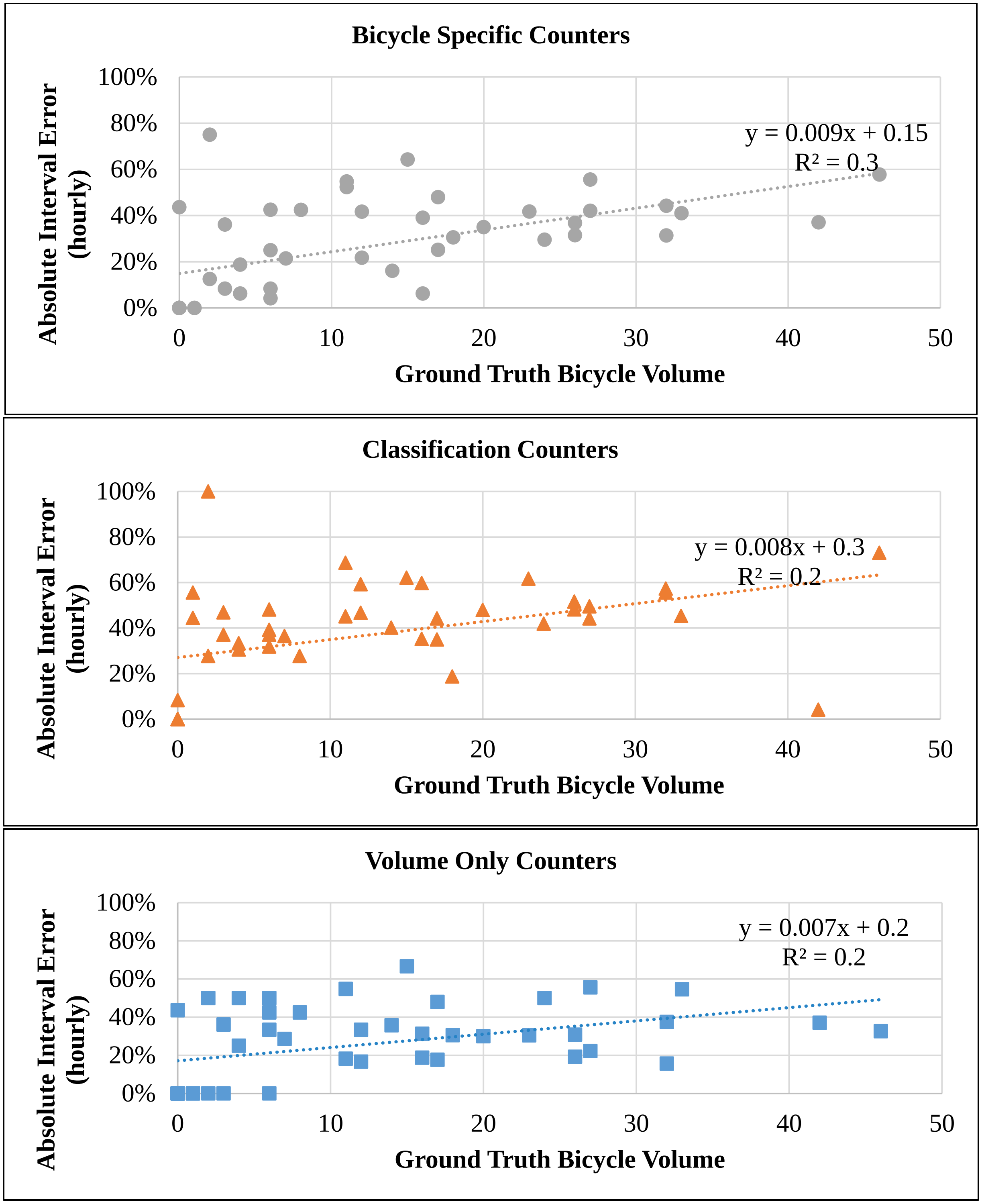


Figure 5.4: Absolute Interval Error as a Function of Bicycle Volume

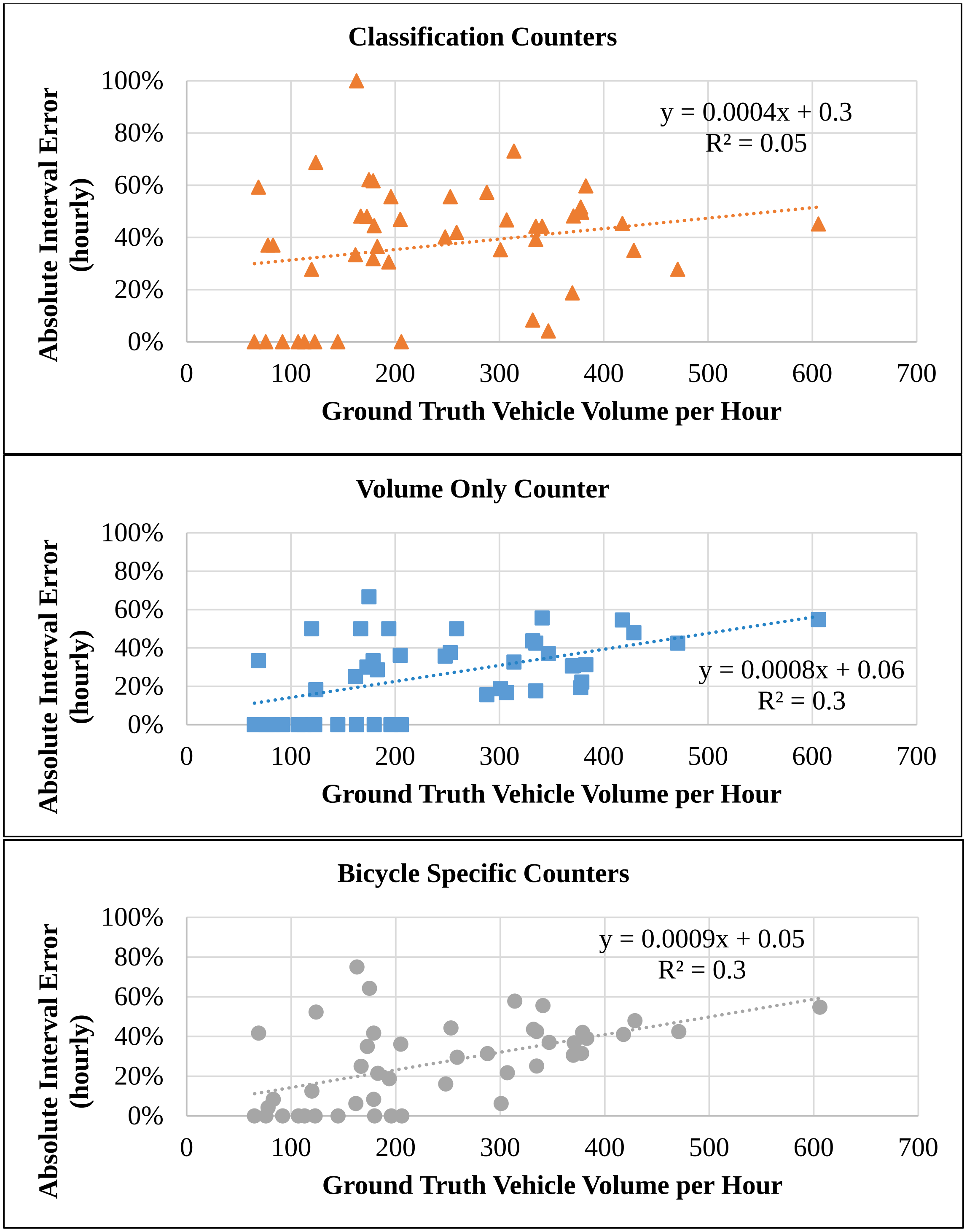


Figure 5.5: Absolute Interval Error as a Function of Motor Vehicle Volume

Does tube diameter impact error? This study did not identify a clear link between error and tube diameter. The large diameter tubes used with the C2 equipment did yield high errors, but the same tubes were used with the V1 equipment and did not result in high error.

5.1.4.2 Speed Study

In addition to examining count accuracy, the research team also compared the speeds recorded by various devices compared to that measured by observing when each bicyclist passed a set of points during the mixed traffic test. The two points are shown in Figure 5.1. This comparison of average speeds by equipment and direction for the study period is shown in Table 5.4 below. These results show that on average, the speed estimates of most of the equipment agreed both with each other and with the manually computed speed. The bicycle speed for both directions combined averaged 17 to 19 miles per hour with an average of 12 to 13 miles per hour in the eastbound (uphill) direction and an average of 20 to 22 miles per hour in the westbound (downhill) direction.

As expected, westbound speeds were higher than the averages computed for the eastbound direction. This result is explained by the slope of the study location. Potentially contributing to the variation in average speeds are differences in classification accuracy. For the C2 equipment particularly, the lane farthest from the counter recorded fewer bikes and also exhibited larger deviations from the all counter average than C1 and C3.

Table 5.4: Comparison of Bicyclist Speed Estimates

Equipment	Average Bicycle Speed (mph)		
	Eastbound	Westbound	Combined
C1, south side, (total)	13.3	20.3	17.0
C1, north side, (total)	12.5	20.5	16.8
C1HR, south side, near (EB)	12.1	n/a	n/a
C2, south side, 16ft, (total)	13.8	12.7	13.3
C2, north side, 16ft, (total)	13.2	19.2	18.2
C2, south side, 10ft, (total)	12.6	17.7	13.2
C2, north side, 10ft, (total)	13.2	20.9	20.0
C3, south side BOCO, (total)	13.0	21.6	17.6
C3, north side BOCO, (total)	13.4	21.8	18.7
All Counter Average	12.9	19.4	16.4
Manual (Video)	12.1	21.6	16.7

5.1.4.3 Bike by Bike Comparison

What causes counting equipment to miss or misclassify bicycles? To address this question the study team performed a more detailed analysis by directly comparing ground truth-confirmed bicycle counts with the time-stamped events from the counting equipment. These comparisons were conducted on a 3-hour period (8am -11am) on Monday, May 25th, 2015, the time period for which vehicle time stamps were collected from video. The counters included were C1, C2 (10ft and 16ft tube spacing), and C3 (vendor and BOCO schemes). Since the tube locations differed along the roadway and there were varying delays associated with each counter, the timestamps did not often line up exactly with the times recorded from the video. However, the time differences were consistent enough to determine, with acceptable certainty, which events matched each other.

Researchers examined the video data and counts from the tube counters to determine the number of matched bicycles, false positives and false negatives. False positives were recorded when the ground truth video data did not show a bicycle but the tube counters falsely recorded a bicycle. False negatives were recorded when the tube counter failed to count the bicycle that was present in the ground truth video.

Bicyclists riding in groups caused problems for counters. False negatives were much more common than false positives. When bicyclists were riding side by side while crossing the tubes, the counters were unable to detect both, resulting in an undercount. For groups of bicycles larger than 2, the counters tended to either interpret the group as a 2+ axle motor vehicle or only detect one or two of the bicycles, missing the others all together. One other scenario that often led to miscounting or misclassification is when motor vehicles and bicycles crossed a tube simultaneously or in very close succession. Often, when a car crossed the tubes at the same time as a bike, the car would be counted, but not the bike.

Table 5.5 shows the types of errors encountered for the various pneumatic tube counters. Of the counters included in the comparison analysis, C1 had the highest number of correct matches and fewest false negatives, followed by C3, and C2. C1 showed relatively few false positives, most of which occurred close in time to a motor vehicle passage over the tubes, thus contributing to the likely cause of the miscount. Interestingly, the BOCO scheme seemed to only improve the accuracy of C3 placed on the south side of the highway. The same effect can be seen in C2 where the shorter tube spacing showed increased accuracy on the south side, but not on the north. For C1 and C3 the explanation of the false positives was easier to ascertain while C2 undercounts were much more difficult to decipher.

However, C1 also had the highest number of vehicle-caused false positives, which could lead to misleading interpretation of the traffic pattern especially in cases where bicycle volumes are low and the motor vehicle false positives dominate the data. In such cases, the counter would report a motor vehicle traffic count as a bicycle count and it would be difficult to develop a correction factor to account for this error.

Table 5.5: Types of Errors

Equipment	Bike Matches	False Negatives	False Positives	False Positives (vehicle caused)
C1, north side, (total)	43	15	0	0
C1, south side, (total)	41	16	0	3
C1HR, south side, near (EB)	31	13	0	1
C2, north side, 16ft, (total)	12	46	0	2
C2, north side, 10ft, (total)	12	46	0	0
C2, south side, 16ft, (total)	5	53	0	0
C2, south side, 10ft, (total)	19	38	0	0
C3, north side, (total)	22	36	0	0
C3, south side, (total)	32	26	0	0
C3, south side BOCO, (total)	44	14	1	0
C3, north side BOCO, (total)	32	26	0	0

5.1.5 Summary

Counting bicycles in mixed traffic can be challenging. Occlusion can prevent bicycles from being counted. Weaker air pulses in the pneumatic tubes from bicycles can be harder to detect. Some bicycles have longer than normal wheel bases or additional wheels which can confuse the counter, and cyclists that ride side-by-side or in platoons are harder to count. Despite these obstacles, jurisdictions would like to be able to count bicycles using the equipment they already have in their inventory - an array of motor vehicle counting equipment.

Three types of pneumatic tube counting equipment: bicycle-specific, classification, and volume only counters were tested during the mixed traffic field test along Columbia River Highway. All three types are capable of counting bicycles, but each presents situations where they are more or less appropriate. Bicycle-specific counters have been shown in previous tests to accurately count bicycles *(Macbeth 2002; Hyde-Wright et al. 2014; Brosnan et al. 2015)*. Bicycle-specific and classification counters are able to distinguish between bicycles and motor vehicles. Classification and volume only counters are commonly available to those who monitor motor vehicle traffic. Bicycle specific counters have been found to be accurate and can be used in mixed traffic, but do not provide speed or classify motor vehicles. Classification counters offer the opportunity to both count bicycles and classify motor vehicles as well as provide speed data, but accuracies vary widely from accurate to unacceptable.

Findings from the mixed traffic test are listed below.

- Undercounting was encountered with all equipment in the two-lane highway condition tested, with MPE varying from -13% (V1) to -73% (C2).

- Generally higher bicycle and motor vehicle traffic lead to more undercounts, likely due to occlusion, especially for classification counters.

- Bicyclist speed estimates from C1 and C3 are reasonably consistent with each other and with observed speeds from video.

- A clear correspondence between error and bicyclist speed was not observed.

- Some equipment was more likely to count cyclists when none were present (C1, C2 and V1).

The phenomenon of counting vehicles as bicycles can be worse than undercounting if it is used to study of bicycle travel patterns because the motor vehicle detection could overwhelm the bicycle detections and indicate an incorrect travel pattern.

When standard motor vehicle counting equipment is used to count bicycles as part of a classification count, the error in counting bicycles can be high as seen in this study, but some equipment is more accurate than others. Bicycle specific counters and some classification counters have lower error. Unexpectedly, in this test, simply using single-tube volume counters in the shoulder had similar error as the bicycle specific and the best classification counter. However, this approach should only be used in bicycle-only environments, such as separated bicycle lanes or, as seen in this study, where bicycles travel predictably in the shoulder, motor vehicles avoid the shoulder, bicycle volumes are similar or greater than those observed in this study, and motor vehicle volumes are less than 1,000 Annual Average Daily Traffic (AADT).

Regardless of what equipment is used, verification testing should be conducted and care should be taken in setting up the equipment and processing the data. Bicycle counting using pneumatic tubes is a more challenging task than counting motor vehicles and should be approached with attention to detail.

5.2 HALL BLVD. & 99W TEST

5.2.1 Purpose

The purpose of this test was to evaluate bicycle and pedestrian counting technologies at a signalized intersection. Existing detection equipment for pedestrians and bicyclists at signalized intersections could be leveraged for counting purposes. However, there is a tradeoff in this dual purpose: for detection it may be better to slightly over detect (it might be better to detect a vehicle as a bicycle than to not detect the bicycle, for example.). For counting purposes it is better to slightly undercount (counting vehicles as bicycles can lead to potentially significant overcounts which could obscure bicyclist travel patterns, for example). If the slight undercounts are systematically related to bicycle volume, the counts can be adjusted as shown in NCHRP 797, but erroneous counts related to counting motor vehicles are very difficult to adjust for. However if undercounts lead to hours or days with zero counts, it is also difficult to adjust for these errors. In either case, substantial over or undercounts are to be avoided.

Utilizing signal detection technology for counting is challenging, however, it is appealing due to the potential to economically gather bicycle and pedestrian data at signalized intersections around the state.

5.2.2 Technologies

Table 5.6 shows the specifics of the inductive loops, thermal camera, pushbuttons and passive infrared devices tested at the intersection of Hall Blvd. & 99 W.

Table 5.6: Non-Tube Technologies Tested at Hall & 99W

Type	Make	Model	Comments
Inductive Loop Detector Cards	Reno A&E	C-1101B	Designed to differentiate between motor vehicles and bicycles. Tested with the parallelogram-shaped loops.
	Reno A&E	C-1100B	Designed to differentiate between motor vehicles and bicycles. Tested with the diamond-shaped loops.
Thermal Camera	FLIR	TrafiSense	Designed to differentiate between motor vehicles and bicycles.
Push Button	N/A	N/A	Pedestrian phase calls provide a measure of pedestrian activity at the intersection.
Passive Infrared	Eco-Counter	PYRO-Box	Not designed to differentiate between bicycles and pedestrians.

Table 5.7 shows the details for the pneumatic tube counters tested at the same location.

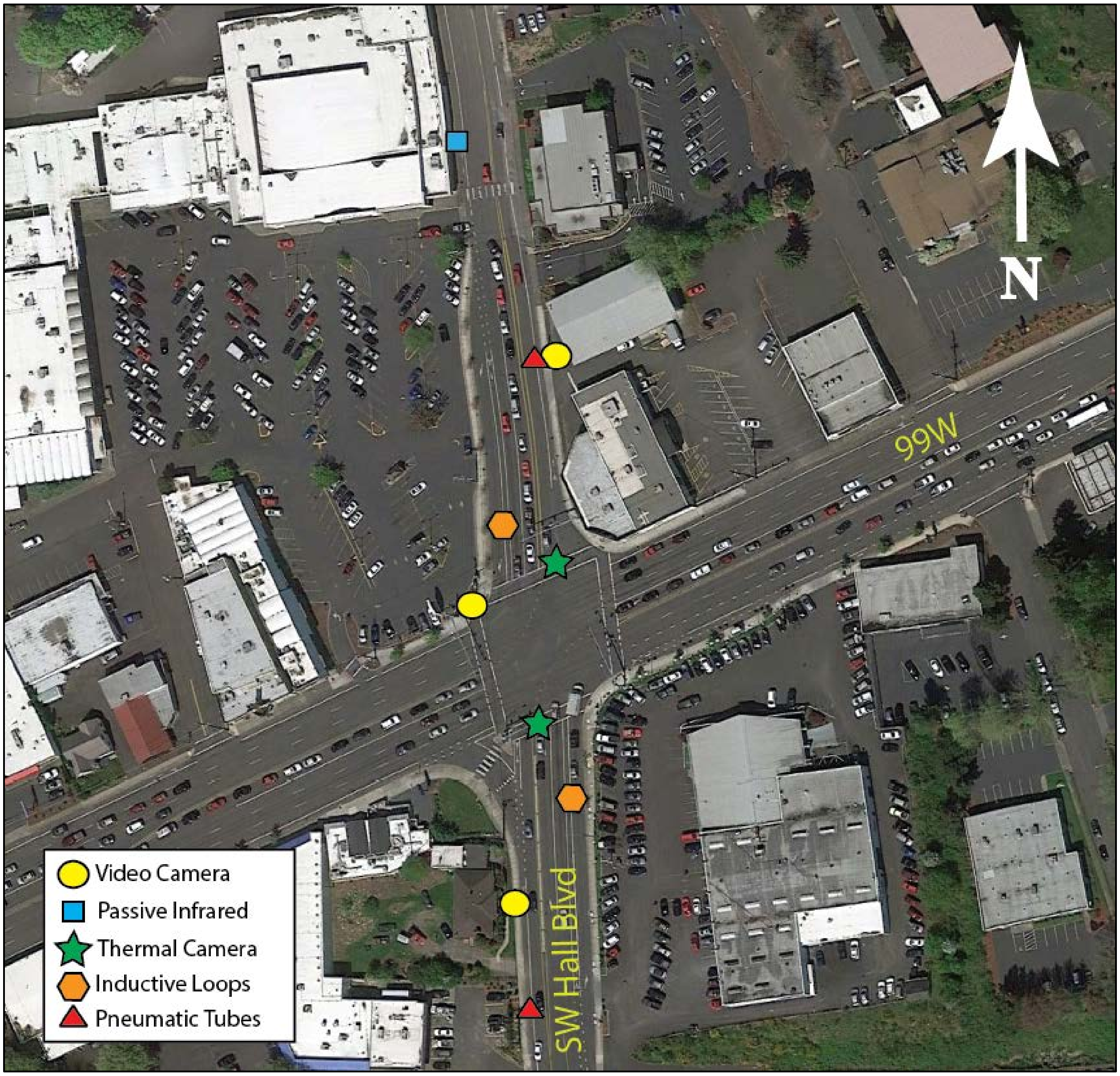
Table 5.7: Pneumatic Tube Counters Tested at Hall & 99W

Type	Designation	Make	Model	Tube Spacing
Bicycle-specific	B1	Eco-Counter	Bicycle only TUBES	1 foot
Classification	C1	JAMAR Technologies, Inc.	TRAX Cycles Plus	2 feet
	C2	TimeMark Corporation	Gamma	6 feet
	C3	MetroCount	MC5600	1.5 feet
Volume	V1	Diamond Traffic Products	TT6	N/A

5.2.3 Methodology

5.2.3.1 Site Layout

This test was conducted at the intersection of Hall Boulevard and 99 West in Tigard, Oregon from September 8, 2015 to September 11, 2015. Figure 5.6 shows the intersection layout as well as locations of the cameras, inductive loops, tubes and passive infrared. Three cameras mounted on poles were used to record video that was later used to obtain ground truth counts. The first set of cameras was strapped to a utility pole on north Hall Boulevard. One of these cameras was pointed at the Eco-Counter infrared counter across the street, another was pointed downward at the northbound tubes, and the other was pointed directly across 99 W at the northbound loops. The second set of cameras was positioned on the traffic signal just above the street sign on the northwest corner of Hall and 99W. One camera was pointed directly downward to view pedestrians using the crosswalk push button, and the other was pointed at the north Hall loops and FLIR zones. The third set of cameras viewed the tubes on the south side of Hall Boulevard.



Source: Google Earth, 2016

Figure 5.6: Equipment Locations at Hall & 99W

For this test, researchers decided to install pneumatic tubes across only the bike lane and sidewalk to count bicycle traffic. The sidewalk was included because a previous study conducted at the same intersection found that 50% of the bicyclists rode on the sidewalk (*Figliozzi et al. 2014*). Figure 5.7 and Figure 5.8 show the tube setup for the northbound and southbound directions on Hall Boulevard. The photo in Figure 5.9 shows how the tubes were taped and anchored on both sides of the sidewalk and both sides of the bike lane.

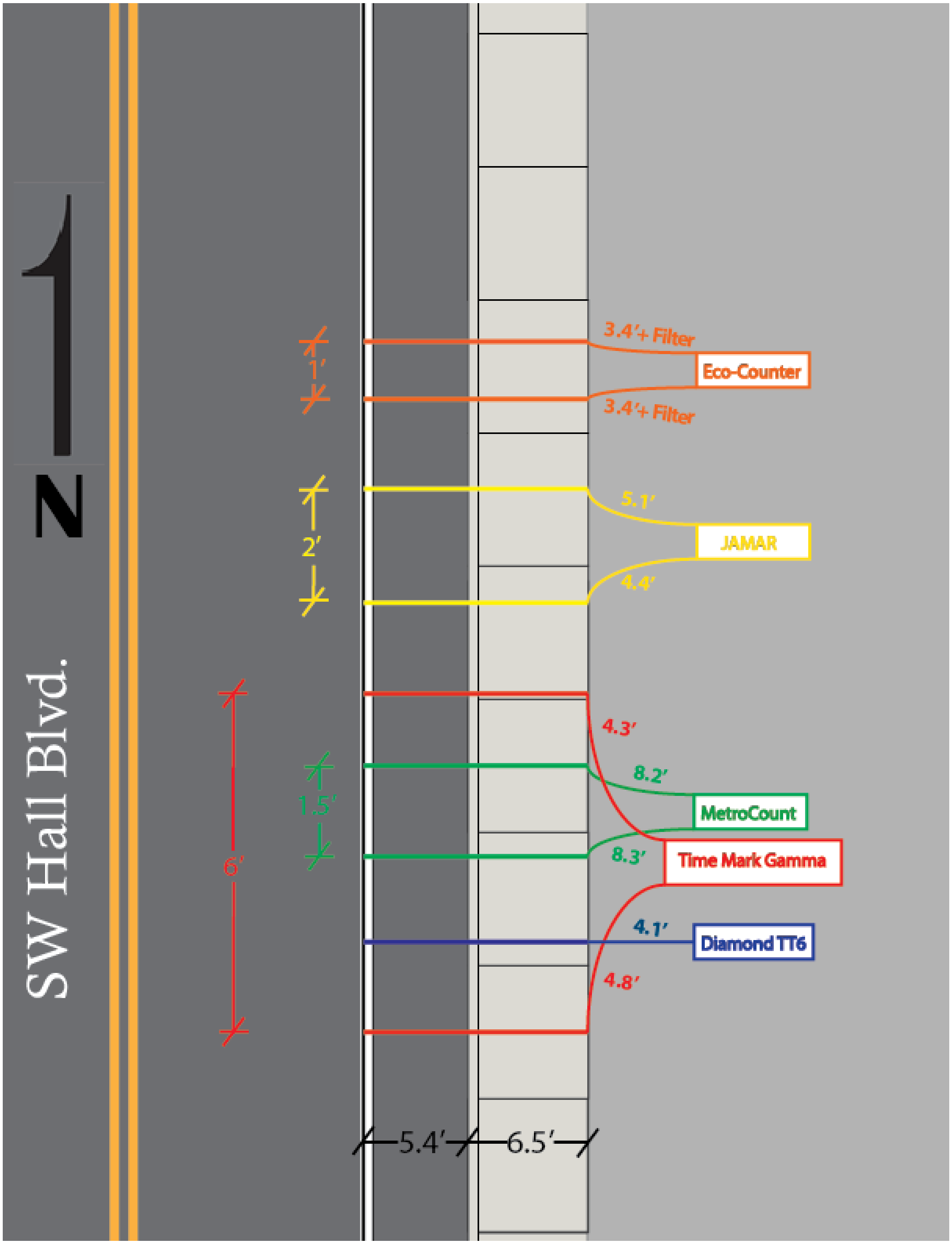


Figure 5.7: Tube Setup for Northbound Bicycle Traffic on the North Side of 99W

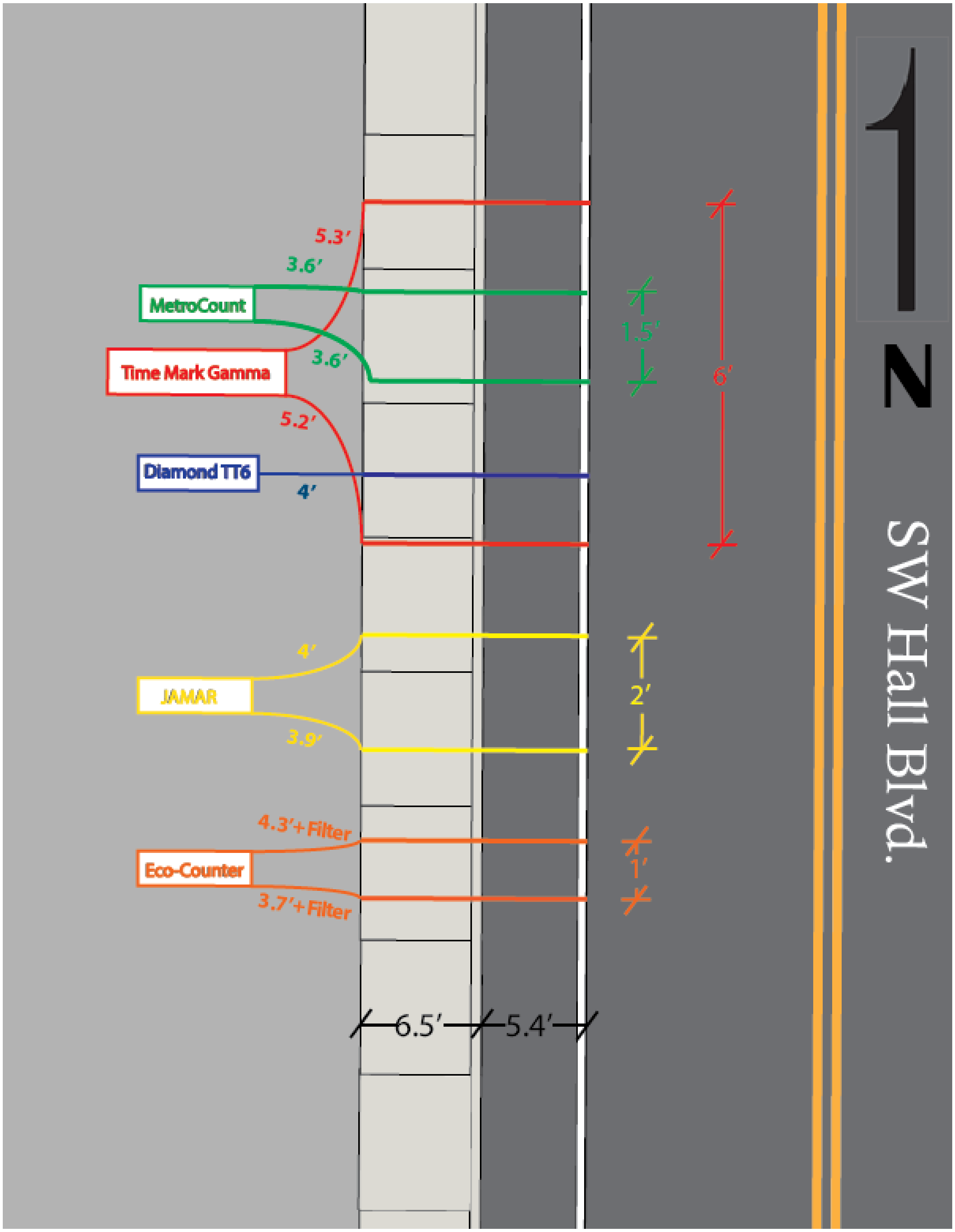


Figure 5.8: Tube Setup for Southbound Bicycle Traffic on the South Side of 99W

Photo by Authors
Figure 5.9: Tube Installation on Hall Blvd. North of 99W Looking North

The research team hypothesized that longer tube lengths contributed largely to the higher errors obtained during testing at Columbia River Highway site. Therefore, for this test, tube lengths were kept as short as possible (10 to 15 feet). In addition, small diameter tubes (mini-tubes) were used for all of the tube counters. Others have found smaller tubes associated with higher accuracy (*Brosnan et al. 2015*), but the main reason for this change was to reduce the potential for pedestrians, rollerbladers, and skateboarders to trip on the tubes.

Photo by Authors
Figure 5.10: Parallelogram and Diamond Loops

Parallelogram and diamond loops were installed in succession in the bike lane in order to ensure that both counters were counting the same bicyclists. Figure 5.10 shows the installation in the field. The dimensions of the north and south loops are detailed in Figure 5.11 and Figure 5.12.

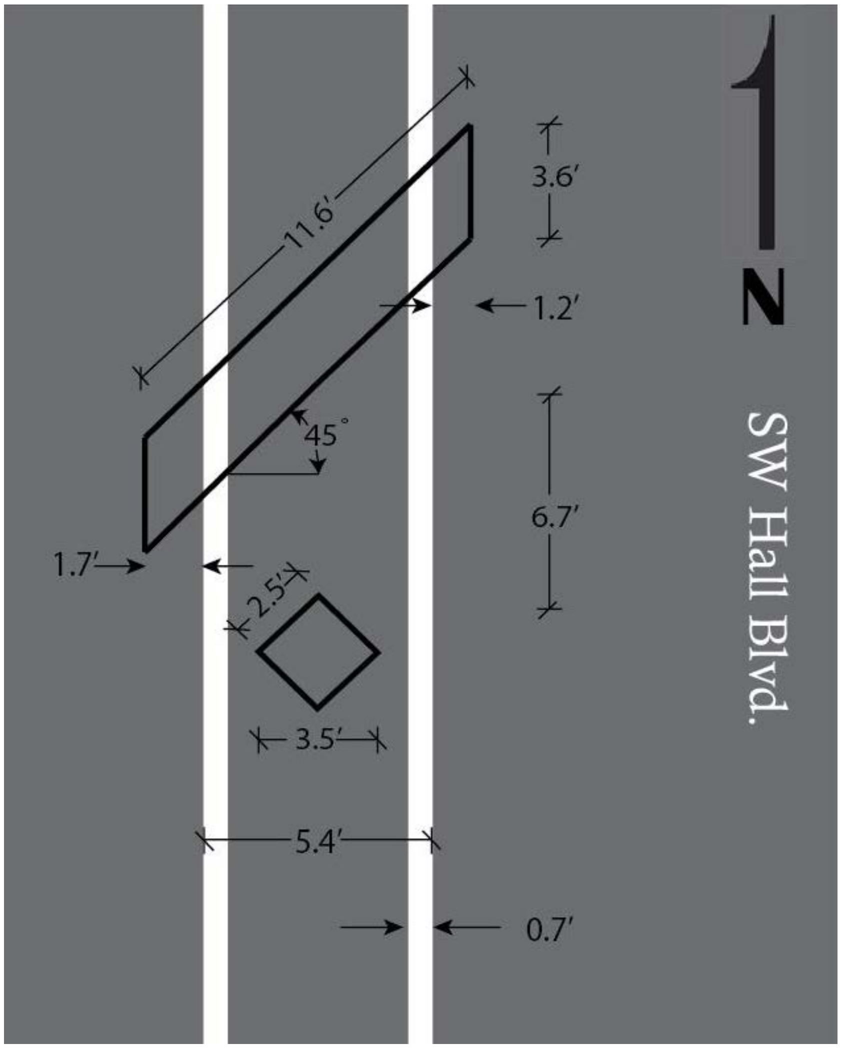


Figure 5.11: Parallelogram and Diamond Loops on the North Side of 99W

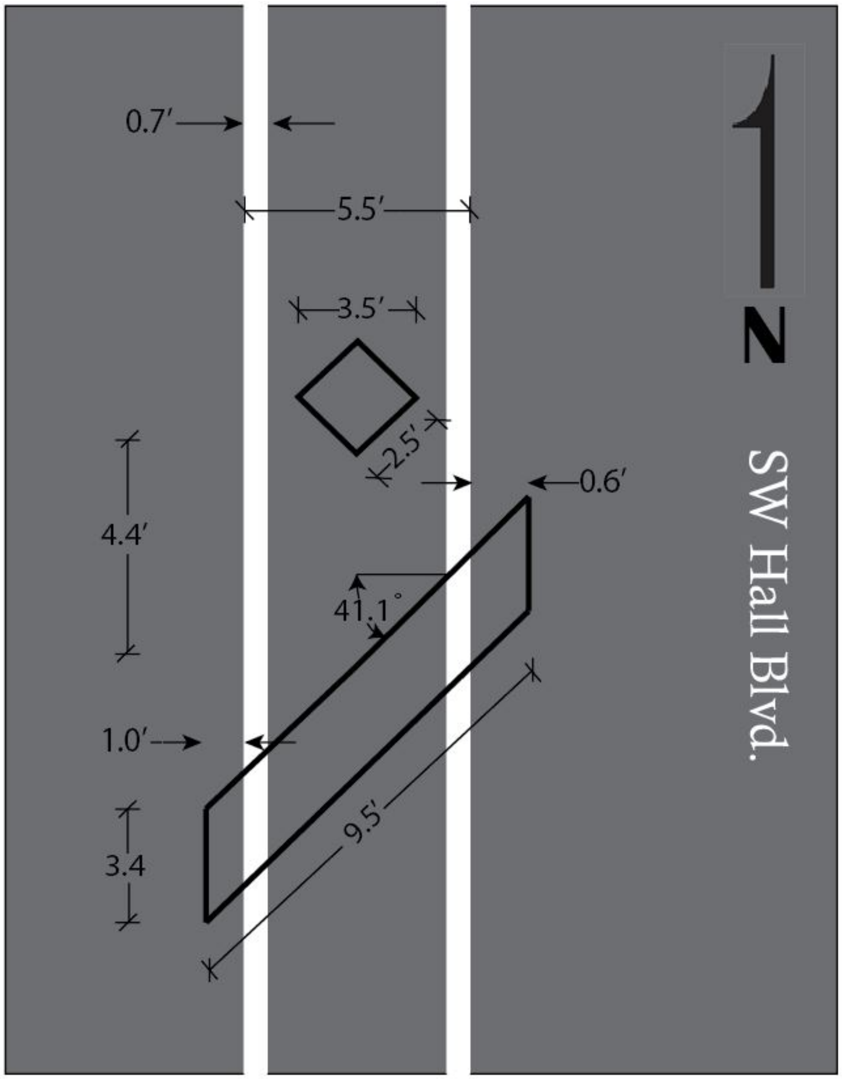


Figure 5.12: Parallelogram and Diamond Loops on the South Side of 99W

A passive infrared counter, an Eco-Counter PYRO-Box, was installed on a signpost according to manufacturer's specifications in order to detect pedestrians and cyclists traveling along a sidewalk near a commercial shopping center. The box was mounted such that the infrared sensor was 27 inches above the sidewalk. The sensor was positioned pointing directly toward the brick wall of a commercial building. The distance between the counter and the wall was 4.7 feet. Figure 5.13 shows the setup configuration. Although the sidewalk is adjacent to a southbound bicycle lane, pedestrians and cyclists on the sidewalk were observed traveling in both directions.

Photo by Authors

Figure 5.13: Eco Counter PYRO Box Setup

The FLIR TrafiSense thermal camera was installed on luminaire arms for the northbound and southbound approaches on SW Hall Blvd in order to detect bicycles and pedestrians in the left and right turn lanes, bicycle lane, and the adjacent sidewalk. Figure 5.14 shows the location of the FLIR TrafiSense.

Photo by Authors

Figure 5.14: FLIR Trafisense Thermal Camera Placement

5.2.4 Results

5.2.4.1 Pneumatic Tubes

Overall, the accuracy of the tube counters improved in relation to the results obtained at the Columbia River Highway site, as seen in Table 5.8. Although V1 overcounted bicycles significantly in both directions (120%, 165% MPE), the other counters generally undercounted bicycles. C1 counter on the north side counted bicycles with perfect accuracy (0% MPE). While the bicycle-specific counter B1 on the north side of the street performed well with 2% MPE, however, its counterpart on the south side showed high error (-32% MPE). Researchers hypothesized that the higher error could have resulted from faulty equipment setup or some other extraneous factor. C2 tube counters specifically showed great improvement with shorter tube length and spacing than previous tests.

Table 5.8: Tube Counter Errors at Hall Blvd. and 99W

Counter	Ground Truth	Tube Counter Bicycle Count	MPE (%)	MAPE (%)	Error (%)
B1 North of 99W	85	87	2	2	2
B1 South of 99W	91	62	-29	32	-32
C1 North of 99W	85	85	0	0	0
C1 South of 99W	91	97	8	13	7
C2 North of 99W	85	75	-13	13	-12
C2 South of 99W	91	84	-6	12	-8
C3 North of 99W (BOCO)	85	83	-4	4	-2
C3 South of 99W (BOCO)	91	86	-5	5	-5
V1 North of 99W	85	164	120	120	93
V1 South of 99W	91	146	165	187	60

An in-depth analysis was undertaken on the time-stamped data provided by three counters C1, C2 and C3 to determine the causes of error. Each overcount and undercount was identified on the video. Figure 5.15 and Figure 5.16 identify the causes for overcounting and undercounting respectively. For overcounts, C1 tube counter showed a greater tendency to overcount compared to the other tube counter. Factors linked to overcounting include a motor vehicles swerving into the bike lane, pedestrians stepping on the tubes and skateboards and strollers being incorrectly classified as bicycles. C2 tube counter showed the highest propensity to undercount. The highest undercounts were due to cyclists riding one behind the other, resulting in the C2 tube counter counting only one bicyclist instead of two. Another factor associated to undercounting includes cyclists swerving out of the bike lane to avoid the tubes and stopping on the tubes. There were 12 instances of bicycles not being counted for no apparent reason.

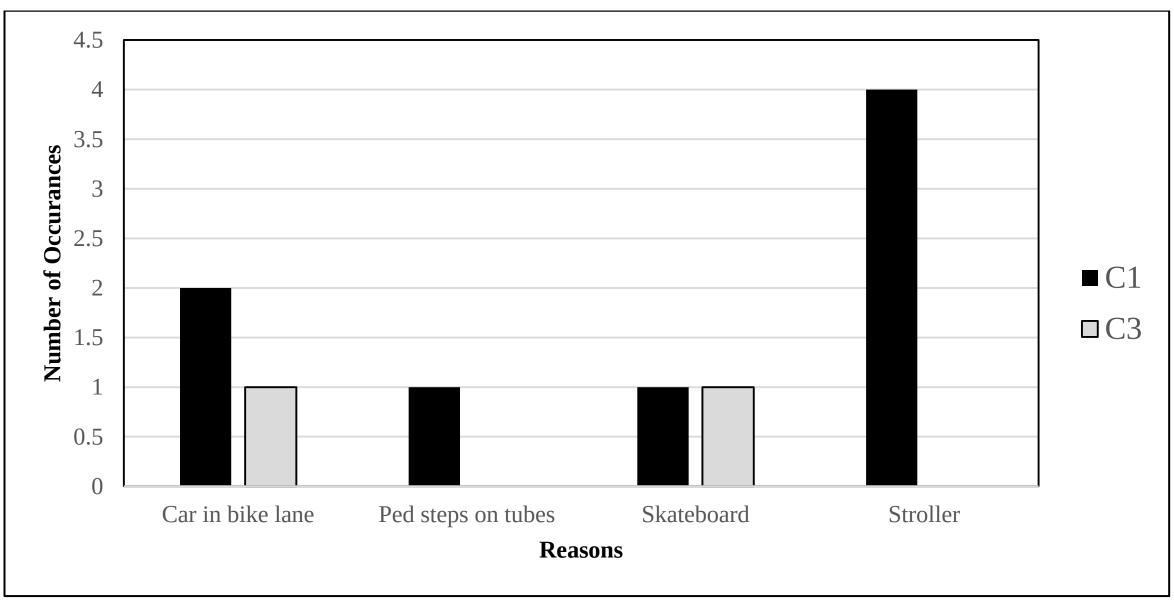


Figure 5.15: Causes for Overcounting

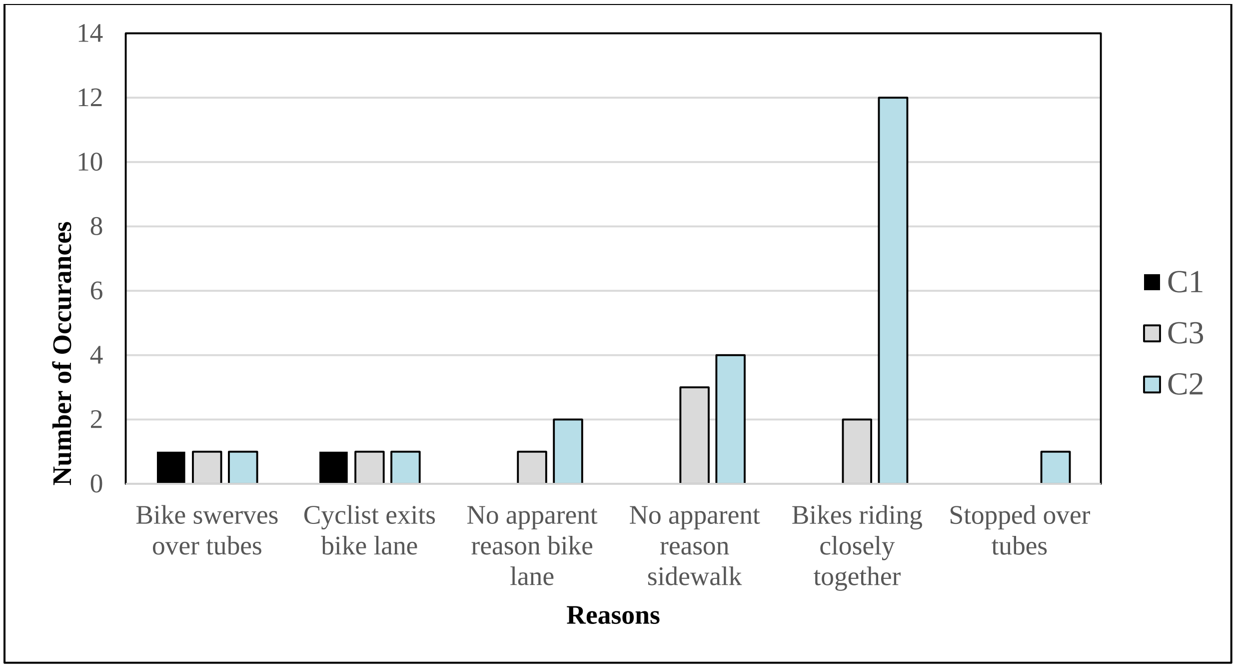


Figure 5.16: Causes for Undercounting

5.2.4.2 Inductive Loops

The bicycle counts recorded by the diamond and parallelogram loops were compared to those obtained from video for the northbound and southbound approaches of Hall Blvd in the bike lane only. This means that bicyclists riding on the sidewalk were not counted. In locations where bicycles are often riding on the sidewalk, such as this site, additional loops could be installed in the sidewalks to capture this volume. That was not tested here since counting bicycles in non-motorized facilities has already been tested and found to be accurate when properly installed (*Ryus et al. 2015, Nordback et al. 2011*). Instead this study focuses on the more challenging task of counting bicycles with loops in mixed traffic.

The comparisons of ground truth to inductive loop counts were made for data starting at 11 AM on September 8, 2015 and ending at 7:30 AM on September 11, 2015. Also, since the video data was only available from 6:30 AM to 7:30 PM each day, the comparisons on September 9th and 10th were limited to those time periods. For both approaches, the diamond loops were equipped with the EDI detector cards which were not capable of distinguishing between motor vehicles and bicycles, whereas the parallelogram loops were equipped with Reno A&E cards that were capable of distinguishing between bicycles and motor vehicles. Table 5.9 shows the results of the comparisons between loop counts and ground truth counts from the video. Both loop configurations produced overcounts as indicated by the errors. While the diamond loops on both approaches and the parallelogram on the northbound approach had high percent errors (> 400%), the parallelogram loop on the southbound approach had lower percent error (162%). The research team hypothesized that the lower error could be related to fewer vehicles passing over the loop.

Table 5.9: Diamond and Parallelogram Loop Errors

	Count			% Error	
Approach	**Ground Truth**	**Diamond**	**Parallelogram**	**Diamond**	**Parallelogram**
NB	108	706	566	553	424
SB	105	668	276	536	162

5.2.4.3 Thermal Camera

The FLIR thermal camera was set up to count bicycles (and pedestrians in one zone) in four zones on the north and southbound approaches of Hall Blvd. The zones were designated as follows: Zone 1 – Sidewalk, Zone 2 – Right turn lane, Zone 3 – Bike lane, and Zone 4 – Left turn lane. The bicycle counts obtained from the thermal camera for each of these zones was compared to the ground truth counts obtained from the video data as seen in Table 5.10. For Zone 1, the manufacturer indicated that the thermal camera is designed to count all bicycles and pedestrians coming toward the camera. For this reason, the ground truth included all bicyclists and pedestrians coming toward the camera in Zone 1, but only bicycles in the other zones. However, cyclists represent 13% of sidewalk use in all directions during the period observed.

For Zones 1, 2 and 4, thermal camera counts are higher than the ground truth for both approaches, indicating that the thermal camera was classifying motor vehicles as bicycles in these zones. The overcounting is especially pronounced for the right turn lane in the northbound approach and for the left turn lane in the southbound approach. However, for Zone 3 i.e. the bike lane, the thermal camera undercounted bicycles compared to the ground truth counts.

Table 5.10: Comparison of Thermal Camera Counts and Ground Truth

		NB			SB		
Zone	**Facility**	**Ground Truth**	**Thermal Camera Count**	**% Error**	**Ground Truth**	**Thermal Camera Count**	**% Error**
1	Sidewalk*	65	20	-69	122	34	-72
2	RT	5	207	4040	9	57	533
3	Bike Lane	104	63	-39	113	59	-48
4	LT	3	14	367	1	22	2100

*Ground truth for the sidewalk includes the number of both bicyclists and pedestrians coming toward the camera. For all other zones, ground truth is bicycles only.

Further analysis explored the differences between thermal camera counts and ground truth counts in the bike lane (Zone 3). The time stamp of each bicycle count recorded by the thermal camera was used to identify whether a corresponding count was recorded in the ground truth data. False positives are defined as counts that were recorded by the thermal camera but were not present in the ground truth data. False negatives are defined as counts that were not recorded by the thermal camera but were present in the ground truth data. The number of occurrences of false positives and false negatives were recorded for the bike lane (Zone 3) and are shown in Table 5.11.

Table 5.11: Thermal Camera False Positives and Negatives in Bike Lane (Zone 3)

		NB		**SB**	
		Number	**%**	**Number**	**%**
False Positives		6	6	4	4
False Negatives		50	49	55	49

Both the north and southbound approaches showed higher incidence of undercounts (49%) than overcounts. The false negatives explain the undercounting phenomenon for bike lane counts (Zone 3) as seen in Table 5.10. Additionally, a number of false negatives occurred during the late afternoon/early evening hours indicating a potential impact of temperature on count accuracy. However, more research is needed to fully understand the impacts.

Supplemental Thermal Camera Analysis

Since the video captured by the thermal camera during the actual testing was unavailable, 4 hours of supplemental thermal camera video for the southbound approach was analyzed from the same intersection on September 3, 2015 from 1:00 PM to 5:00 PM. The average temperature was 61 degrees Fahrenheit during this period. Table 5.12 shows the comparison between thermal camera counts and ground truth video counts obtained using the thermal camera images.

While, the thermal camera detected 100% of the cyclists traveling in the bicycle lane, it undercounted bicycles and pedestrians traveling on the sidewalk, and overcounted in the right turn and left turn lanes. The false positives comprised of cars, vans, trucks, and motorcyclists which represented 50%, 18%, 27%, and 5% respectively.

Table 5.12: Thermal Camera Counts vs. Ground Truth

		SB		
Zone	**Facility**	**Ground Truth**	**Thermal Camera Count**	**Difference**
1	Sidewalk	11	3	-8
2	RT	0	21	21
3	Bike Lane	8	8	0
4	LT	0	1	1

Many vehicles, with irregular shapes and sizes such as trucks with protruding equipment and cars with roof attachments appear to be common sources of false positives as shown in Figure 5.17.

Source: FLIR, 2016

Figure 5.17: FLIR False Positives – Southbound Right Turn Lane Hall & 99W

The thermal camera detected 27% (3) of the pedestrians traveling on the sidewalk. The remaining 73% (8) of pedestrians were observed traveling along the outer boundary of the thermal camera detection area as shown in Figure 5.18. This suggests that bypass errors may result if the zones are not set up correctly to capture the entire area.

<u>US 20 and Robal Rd.</u>

Additionally, 231 hours of video captured by the thermal camera at the intersection of US 20 and Robal Rd. from September 10 to October 16, 2015 was collected for a concurrent ODOT research project *(ODOT SPR 781)*. The average temperature at the time of the detections was 75.6 degrees Fahrenheit . The thermal camera was found to have overcounted by 89%. The thermal camera detected 7 cyclists and 2 pedestrians out of a total of 17 detections. The remaining 8 detections were classified as false positives caused by vehicles traveling in the adjacent lane.

Source: FLIR, 2016

Figure 5.18: Thermal Camera False Negative – Sidewalk SB Hall & 99W

5.2.4.4 Passive Infrared

The Eco-Counter PYRO-Box was mounted on a pole and recorded pedestrians on the sidewalk beginning September 9, 2015 to September 11, 2015.

Table 5.13 shows the comparison between PYRO-Box counts and video counts for the 12 complete hours of counts. Only morning hours could be included because shadows obscured the sidewalk at other times, such that researchers could not identify pedestrians in the video. Counts from the PYRO-Box were compared with the ground truth counts obtained from video. In the 12 hour period, 78 pedestrians and 12 bicyclists were observed on the sidewalk. The overall error for the time period was a 4% overcount. The MPE was a 5% overcount and the MAPE was 11%.

Table 5.13: Eco-Counter PYRO-Box Counts vs. Ground Truth Counts

Date	Time	Ground Truth	PYRO-Box	% Error
9/9/2015	7:00AM	3	3	0
	8:00 AM	11	11	0
	9:00 AM	7	6	-14
	10:00 AM	6	8	33
9/10/2015	7:00 AM	6	5	-16
	8:00 AM	7	7	0
	9:00 AM	10	10	0
	10:00 AM	9	11	22
	11:00 AM	11	10	-9
9/11/2015	7:00 AM	6	7	16
	8:00 AM	8	10	25
	9:00 AM	6	6	0
Total		90	94	4

Figure 5.19 shows the relationship between PYRO-Box counts and the video counts (ground truth). The solid diagonal line indicates a perfect match between PYRO-Box counts and the video counts. More points in the plot are above the solid line than below it, indicating that the PYRO-box is overcounting in more cases, than undercounting compared to video counts.

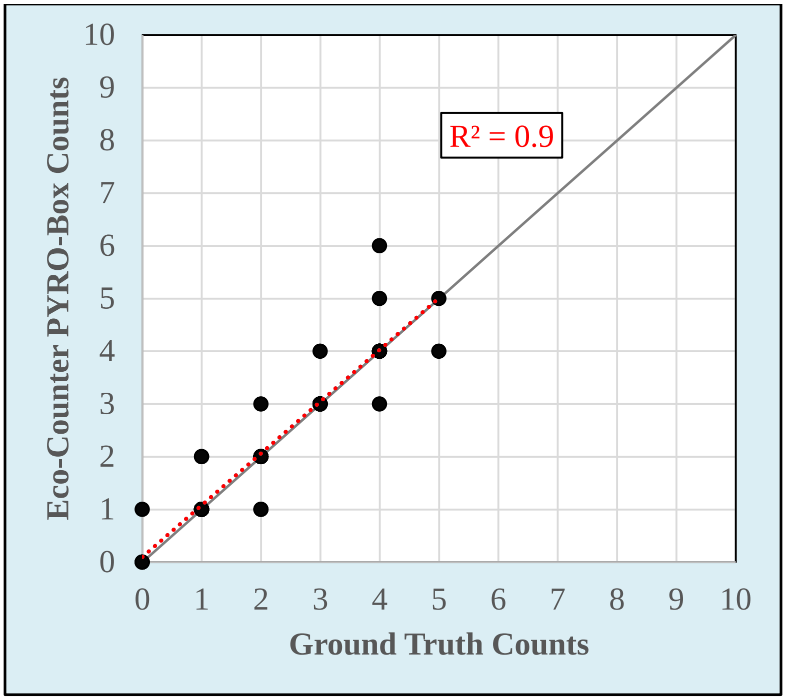


Figure 5.19: PYRO-Box Counts vs. Ground Truth

Figure 5.20 shows no significant correlation between hourly volume and percent error. However, greater error (false negatives and false positives) was observed in the southbound direction of travel as shown in Figure 5.21. Although the exact cause of the false negatives is unknown, as many as 4 detections, or 80% of false positives in the southbound direction may have been potentially caused by cyclists, who were assumed to be traveling in the adjacent bicycle lane but were otherwise indistinguishable in the video from cyclists on the sidewalk.

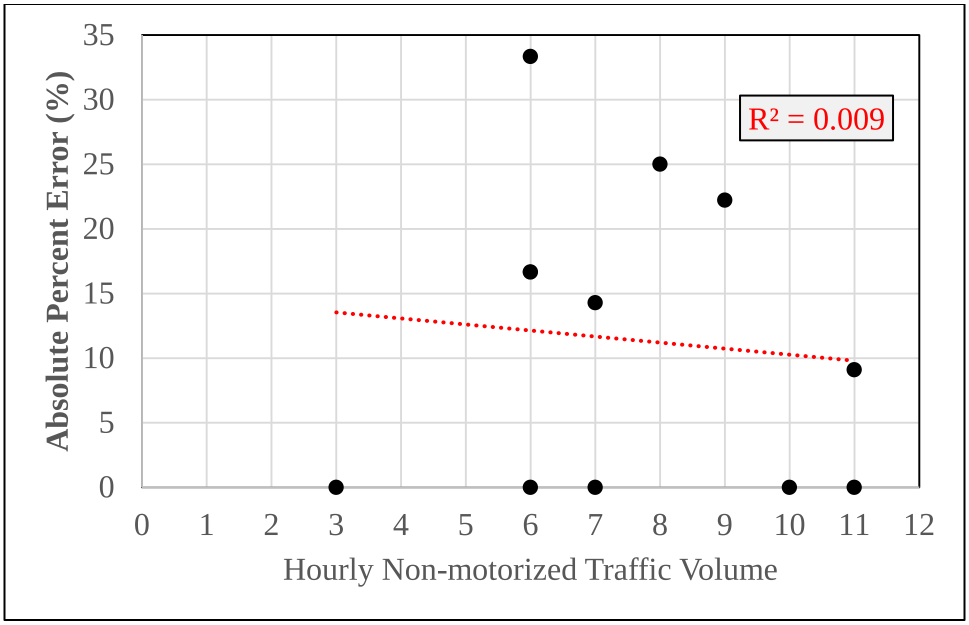


Figure 5.20: PYRO-Box Volume vs. Error (%)

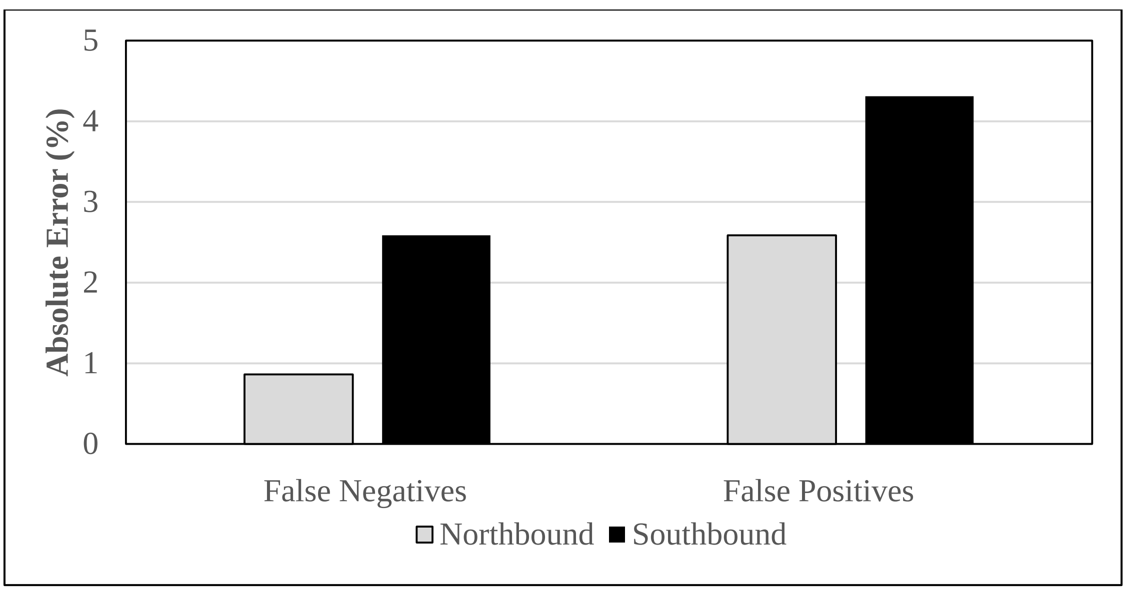


Figure 5.21: PYRO-Box Error by Direction

5.2.4.5 Pedestrian Pushbutton

The pedestrian crossings classified as ground truth were observed from the video recording beginning September 8, 2015 at 3:00 PM to September 11, 2015 at 9:00 AM from 7:00 PM to 6:00 PM daily. These counts were compared to the pedestrian phases logged by the signal controller. The phase data was obtained from the Measures of Effectiveness or MOE logs from the signal controller. The hourly pedestrian volumes location of crosswalk are presented in Figure 5.22. Each pedestrian represents a single movement. Therefore, if a pedestrian crossed in more than one crosswalk, two pedestrian movements were counted.

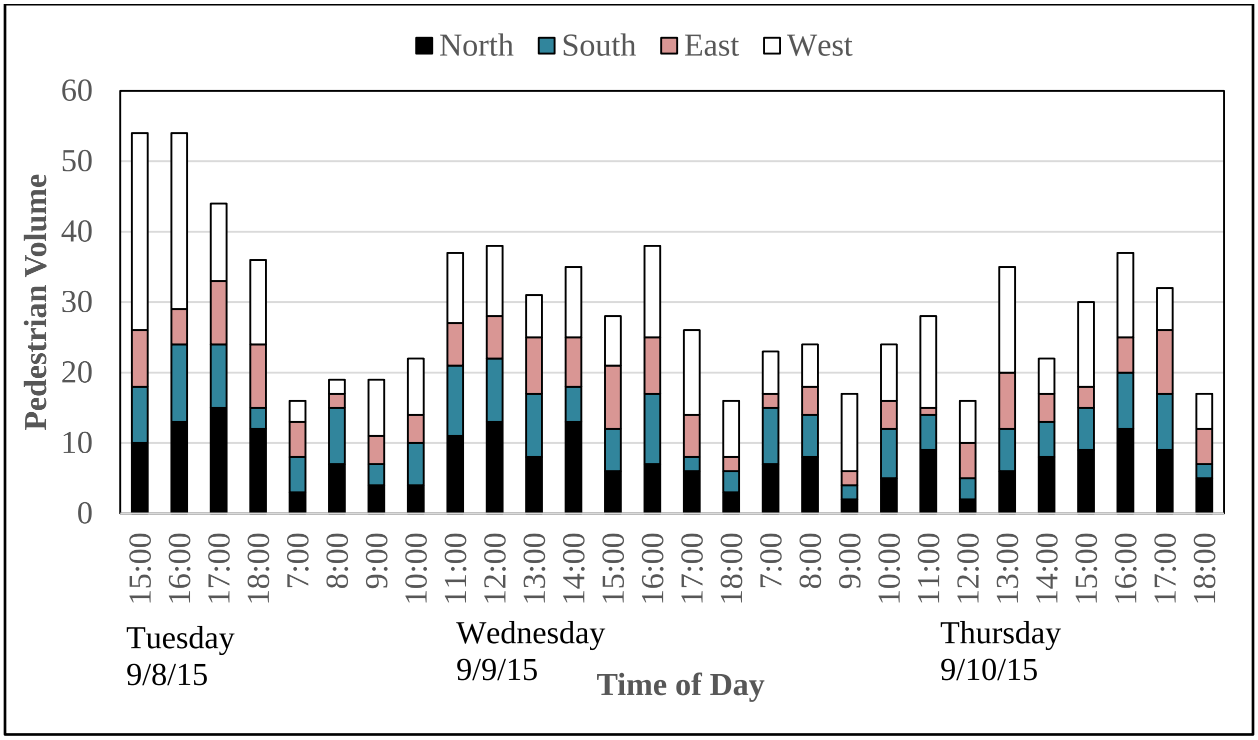


Figure 5.22: Pedestrian Volume by Time of Day

Figure 5.23 presents the size of pedestrian groups by crosswalk. Group size refers to the number of pedestrians crossing a single direction during a pedestrian phase. At all crosswalks, majority of the pedestrians crossed by themselves (group size of 1). Other group sizes were also observed but were less frequent. Overall, there were 818 pedestrian crossings and 759 groups, indicating a group size of 1.07 pedestrians per group.

Table 5.14 presents the pedestrian counts and pedestrian phases from the signal controller logs by location of crosswalk with respect to the intersection. A ratio of pedestrian volume to pedestrian phases is also estimated and presented in Table 5.14. These ratios can be used as adjustment factors to estimate pedestrian volume, if pedestrian phase information is known. The north, south and west crosswalks had ratios greater than 1 indicating higher numbers of crossing pedestrians than pedestrian phases, which in turn implied that more than one pedestrian was crossing per phase at these crosswalks. Conversely, the east crosswalk had a ratio of less than 1.

Scatterplots showing the relationship between pedestrian phases and pedestrian volumes by each crosswalk per hour are shown in Figure 5.24. At all four crosswalks, there is evidence of a linear relationship between pedestrian volumes and pedestrian phases as indicated by R^2 values.

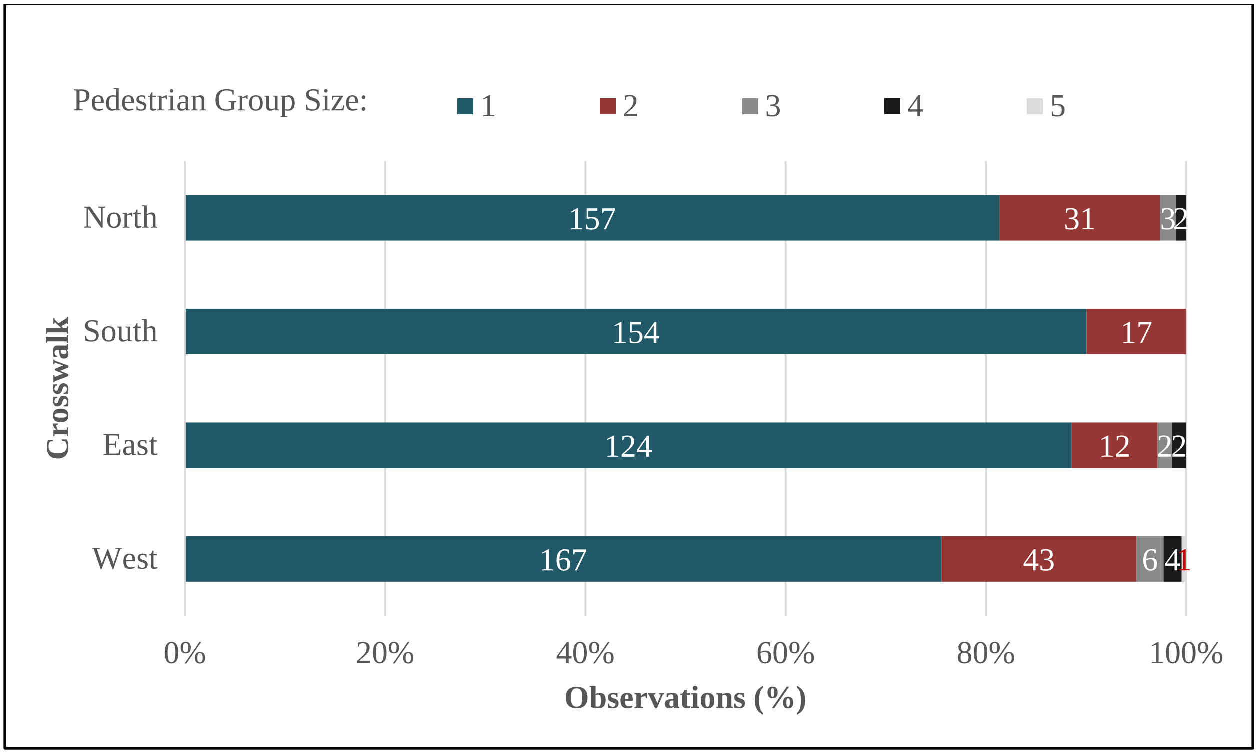


Figure 5.23: Pedestrian group size proportions by crosswalk

Table 5.14: Video Counts vs. Pedestrian Phase Counts Summary

Parameter	North	South	East	West	Total
Pedestrian Volume (Video Counts)	217	173	150	278	818
Pedestrian Phases (2070 Data)	190	145	158	230	723
Ratio (Pedestrians/Phase)	1.14	1.19	0.95	1.21	1.13

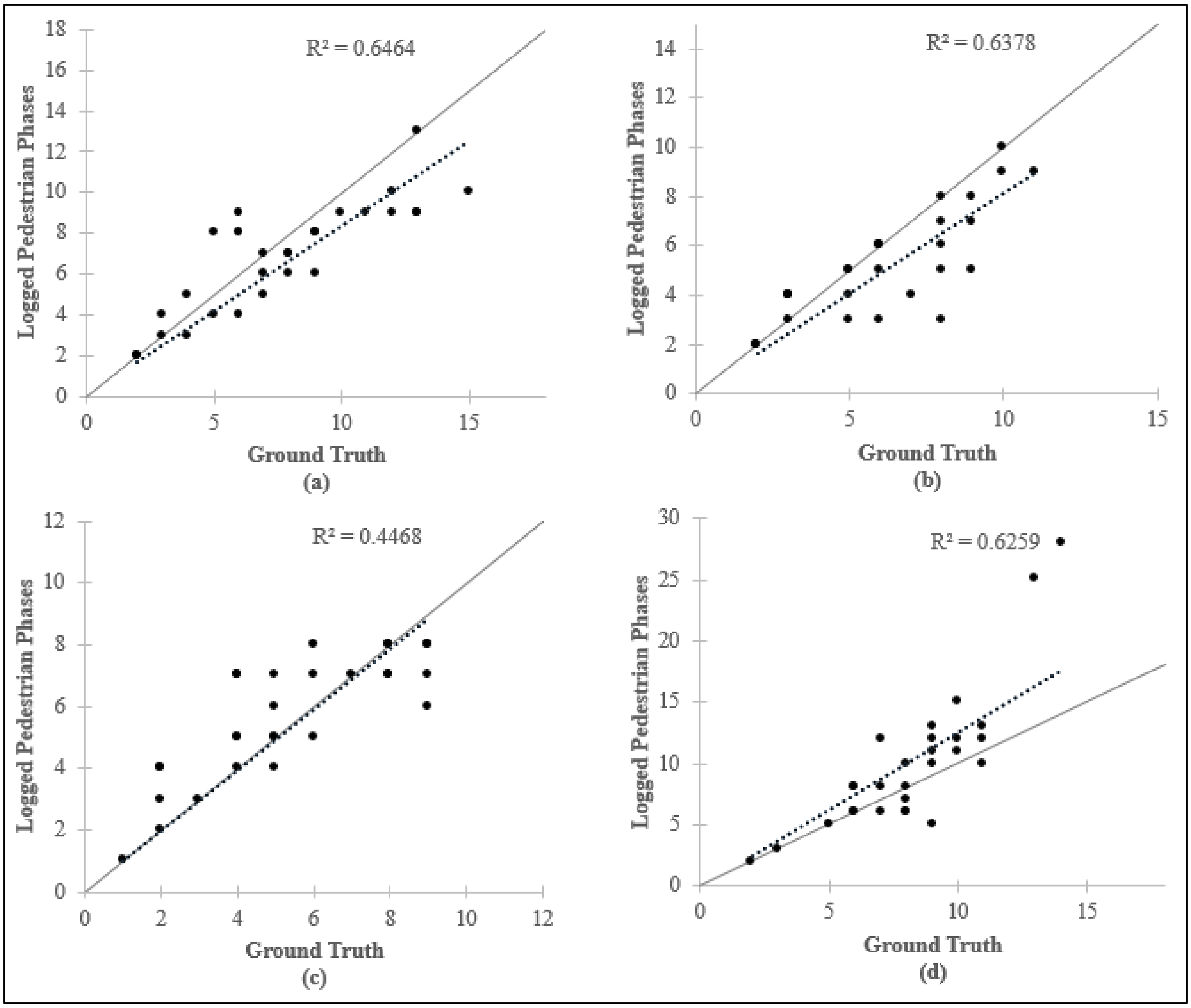


Figure 5.24: Scatter plots of hourly video counts versus hourly logged pedestrian phases: (a) north crosswalk, (b) south crosswalk, (c) east crosswalk, and (d) west crosswalk.

The ratios of pedestrian volumes to pedestrian phases as well as scatterplots were compared to previous research findings, where similar analysis was conducted *(Figliozzi et al. 2014)*. The ratios and R^2 were fairly similar across both studies.

5.2.5 Summary

The purpose of the Hall Blvd. and 99W test was to evaluate the accuracy of pneumatic tubes laid out on the sidewalk and bike lanes, inductive loops (diamond and parallelogram configurations), a thermal camera, a passive infrared sensor and pedestrian pushbuttons.

Accuracy of counts using the pneumatic tube counters was higher that at the Columbia River Highway. Classification counters MPEs ranged between -27% and 9%. Generally, most of the classification counters undercounted bicycles. The volume only counter performed poorly and significantly overcounted bicycles (120%, 187%). Cars swerving into the bike lane, pedestrians stepping over the tubes, and skateboards and strollers being counted as bicycles caused overcounts. Bicyclists swerving over tubes, exiting the bike lane, stopping over the tubes and riding one behind the other were all causes of undercounts. Overall, the improvement in accuracy seen with classification counters may have been due to: a) counting only in the bike lane and sidewalk where there is a reduced propensity for motor vehicles to go over the tubes and b) using shorter length tubes.

Both diamond and parallelogram loops overcounted bicycles along both approaches. Percent errors were higher with diamond loops (553% northbound, 536% southbound) compared to parallelogram loops (424% northbound, 163% southbound). It was hypothesized that the lower error obtained for the parallelogram loop for the southbound approach could be due to smaller number of vehicles passing over the loop.

FLIR thermal camera overcounted bicycles in the right turn and left turn lanes and the sidewalk but undercounted in the bike lane. Further analysis of counts in the bike lane revealed that the thermal camera counted higher number of false negatives than false positives on both northbound and southbound approaches. Analysis of pre-test video showed that vehicles with irregular shapes and sizes such as trucks with protruding equipment and cars with roof attachments were common sources of false positives.

The passive infrared PYRO-box slightly overestimated pedestrians (4%). A greater number of false positives than false negatives were recorded by the device. No correlation was found between hourly pedestrian volume and percent error.

Analysis of the pedestrian phase data found significant correlations between pedestrian volumes and pedestrian phases, obtained from signal controller logs. Ratios of crossing pedestrians to phases were computed for all four crosswalks and provide a method for estimating pedestrian volume, when pedestrian phases are known. These ratios were similar to ratios computed at the same intersection during a previous research study, over two years ago *(Figliozzi et al. 2014).*

6.0 CONCLUSIONS AND RECOMMENDATIONS

This study has focused on evaluating bicycles and pedestrian count technologies in terms of accuracy, cost, and compatibility with ODOT's existing count programs, equipment, and infrastructure. Only equipment that have the potential to integrate well with ODOT's existing equipment, staff, and systems were tested in this study. First, a pilot test was conducted under controlled conditions to verify that all selected technologies were capable of detecting bicyclists. Following the pilot, two field count studies were conducted at mixed traffic locations: Location 1: only bicycles on a rural road segment and Location 2: both bicycles and pedestrians at a signalized intersection. For Location 1, bicycles on a rural road, only pneumatic tubes were tested; for Location 2 pneumatic tubes plus four additional technologies were tested, two for bicycles (loops, and thermal cameras) and two for pedestrians (passive infrared and pedestrian pushbutton).

Test results revealed that all three bicycle counting technologies can accurately count bicycles under controlled conditions, but in mixed traffic conditions only the pneumatic tubes were able to count bicycles with less than 20% error. Both pedestrian traffic monitoring technologies performed well at Location 2. The sections below discuss the conclusions and recommendations for each technology, ending with a summary of recommendations.

6.1 PNEUMATIC TUBE RECOMMENDATIONS

This study finds that **error in counting bicycles in mixed traffic is lowest when bicycles ride close to the equipment (within 5 to 10 feet of tube) and when bicycle-specific counters or bicycle-specific vehicle classification schemes are used.** It may be useful to limit tube length to 15 feet or less for bicycle counting purposes. In addition, in places where pedestrians, skate boarders or rollerbladers may cross the tubes, using mini-tubes is recommended to reduce trip hazard.

If volume only (single tubes) pneumatic tubes are used to count bicycles, they should only be used in bicycle-only environments, such as separated bicycle lanes or, as seen in this study, where bicycles travel predictably in the shoulder and motor vehicles avoid the shoulder. Table 6.1 below indicates recommendations for different scenarios.

Table 6.1: Recommendations for Using Tubes to Count Bicycles

Road Type	**Pneumatic Tube Counter Configuration Options**		
	Higher Accuracy	**Lowest Cost**	**Most Compatible**
Off street paths and sidewalks	1 bicycle-specific or classification counter.	1 classification counter with small diameter tubes.	1 volume counter or classification counter.
Separated bike lanes and other bicycle only facilities	1 bicycle-specific or classification counter.	1 volume counter.	1 volume counter or classification counter.
Two-lane road, <30 feet width– Bicycles shares road with motorists, low AADT	1 bicycle-specific or classification counter.*	1 classification counter with small diameter tubes.	1 Classification counter with small diameter tubes.
Two-lane road with bike lanes or shoulders (<40 feet)	2 bicycle-specific or classification counters,* one on each side of the road in shoulders/bike lane only.	2 volume counters, one on each side of the road in shoulders/bike lane only.	2 classification counters, one on each side of the road in shoulders/bike lane only.
Multi-lane highway with bike lanes or shoulders.	2 bicycle-specific or classification counters,* one on each side of the road in shoulders with separate tubes.	2 volume counters, one on each side of the road in shoulders.	2 volume counters, one on each side of the road in shoulders.
Multilane highway with no shoulders, low AADT	2 bicycle-specific or classification counters,* one on each side of the road with separate tubes. Place tubes only in the outside lane.	2 classification counters, one on each side of the road with separate tubes. Place tubes only in the outside lane.	2 bicycle-specific counters, one on each side of the road with separate tubes. Place tubes only in the outside lane.

* For higher AADT count sites bicycle specific counters (or MetroCount classification counter) are preferred because they are less likely to count motorized vehicles. The mixed traffic test was conducted on low motor vehicle volume roads with less than 1,000 AADT. Accuracy may decrease with higher traffic due to occlusion.

To minimize error, it is recommended that tubes for bicycle counting are placed where bicycles are likely to ride and motor vehicles are not, such as road shoulders, bike lanes, sidewalks, and paths. If bicycles are traveling in mixed traffic, placing the tubes in a motor vehicle traffic lane may be necessary but this may increase the bicycle counting error to unacceptably high levels. This case was not tested in this research, and further research is needed to understand how error varies with motor vehicle traffic volume. Error for the counters tested is expected to be higher with more motorized traffic and bicycles crossing the tubes.

When counting bicycles with a classification counter, a bicycle-specific vehicle classification scheme specific to the instrument being used has been shown to reduce error both in this study and previous studies (*Hyde-Wright et al. 2014*, *Brosnan et al. 2015*). For bicycle-specific counters (Eco-Counter), these schemes are built in. For classification counters, manufacturers sometimes provide bicycle-specific schemes. When using MetroCount 5600, error was substantially lower when the BOCO scheme developed by Boulder County[2] was used instead of ARX Cycle scheme which is provided by the manufacturer. When using TimeMark's Gamma, it is better to use TimeMark's "FHWA with bicycles" classification scheme for mixed traffic situations and the bicycle-only classification scheme for bicycle only locations such as bike lanes and paths. During the course of this study JAMAR made changes to their bicycle counting scheme for the TRAX Cycles Plus counter owned by ODOT which are reflected in the results from Location 2 (Hall Blvd), but not Location 2 (Columbia River Highway)[3]. This revised counting scheme was found to improve accuracy of bicycle counts when using the JAMAR TRAX Cycles Plus counter.

It should be noted that in the mixed traffic condition, TimeMark Gamma counters undercounted bicycles by 65% to 86%. Two setups were tested: ODOT's typical setup for counting motorized vehicles with a 16 foot tube spacing and a slightly closer spacing (10 feet) recommended by the manufacture for bicycle counting. Both set ups significantly undercounted bicycles. To improve accuracy, **a different set up is sometimes needed for counting bicycles than that which is used for counting motorized vehicles**.

Further testing with TimeMark Gamma tubes at Location 2 (Hall Blvd.) showed that with a six foot spacing between tubes, small diameter tubes (mini-tubes), shorter tube length (10 to 15 feet), and tubes placed only on the sidewalk and bike lane, only 12 to 7 percent undercounting was observed. Hence, results suggest that TimeMark Gammas can be used to count bicycles within 5 to 10 feet tube length of the counter; a closer distance between tubes, such as the 6-foot spacing used at Location 2 (Hall Blvd.). To reduce potential for occlusion from motor vehicles shorter tubes should be used (10 to 15 feet). A guidebook for implementing this technology is included in the Appendix G.

6.2 RECOMMENDATIONS FOR CONTINUOUS COUNTING AT INTERSECTIONS

Inductive Loop Recommendation

It is not recommended to use loops at the approach to intersections in mixed traffic for counting purposes at this time. However, if the loop can be placed in a bicycle-only environment (similar to that tested in the pilot study), such as a separated bike lane, loops could be a viable option for both counting and detection. (Note: These results do not apply the bicycle-counting-specific loops currently used by ODOT on paths, bike lanes and shoulders, which have been studied and found to be accurate in bicycle–only situations and in mixed traffic (*Nordback et al. 2011*).

[2] The BOCO scheme is available free online at https://www.pdx.edu/ibpi/short-duration-count-program.
[3] Data from the Columbia River Highway was available to JAMAR during the time they were writing the revised classification scheme.

Additionally, loop configurations and algorithms to separate bicycles from motor vehicles are continuously being refined by vendors. Therefore, as these new configurations and algorithms become commercially available, further testing may be warranted in the future.

Thermal Camera Recommendation

Thermal cameras can detect and count bicycles in bicycle-only environments, but their use is not recommended for counting in mixed traffic at intersections at this time. Further research and testing to evaluate the bicycle counting capability of thermal cameras in mixed traffic may be warranted in the future, after improvements are made by the manufacturer.

Pedestrian Pushbutton Recommendation

Collecting and archiving pedestrian phase calls from ODOT traffic signals is a low cost approach to measure pedestrian activity at pushbutton actuated signalized intersections around the state. Such data can be archived now. Further research can study how these phase calls relate to actual counts depending on time of day, weather, and surrounding land use.

Passive Infrared Recommendation

Passive infrared can work well for pedestrian counting in a pedestrian-only environment with low pedestrian traffic and few people walking side-by-side. Site selection is very important for this technology. Appropriate considerations for device placement include: narrow pedestrian facility, availability of a pole to mount the device, and pointing the infrared beam towards a non-reflective non-moving surface.

6.3 RECOMMENDATIONS FOR SHORT DURATION COUNTS

The recommendations for short duration counts are based on the recommendations discussed above and are summarized in Table 6.2 by scenario.

Table 6.2: Recommendation Matrix for Short Duration Counts based on Test Results

Facility	Bicycles	Pedestrian
Pedestrian Only Facilities (sidewalks, trails)	N/A	Passive infrared (most accurate for low pedestrian traffic sites)
Bicycle Only Facilities (cycle tracks, separated bike lanes)	Tubes – all types	N/A
Bike-Ped Paths & Sidewalks	Tubes – bike specific and classification	Passive infrared (reference) Combine with tubes to distinguish bicycles.
Shoulders and Bike Lanes	Tubes – bike specific and classification	N/A
Roadways (mixed traffic) low volume	Tubes – classification counters low volume roads	N/A
Roadways (mixed traffic) medium to high volume	Manual counts	N/A
Intersections	Manual counts	Pushbutton for pedestrian activity

Note: N/A indicates not applicable.

6.4 CONCLUSIONS

For bicycle counting, pneumatic tubes were found to be the most accurate of the technologies tested, while also integrating well with ODOT's existing traffic monitoring plan and being low cost. However, ODOT's standard set up for counting motor vehicles is likely to result in substantial undercounts, so modifications to the standard setup are recommended for bicycle-specific counting. These include using bicycle-specific classification schemes and reducing the tube length between bicycles and counting device to 5 to 10 feet.

The two intersection-specific technologies for bicycle detection (inductive loops and thermal camera) are not recommended to count bicycles in mixed traffic at this time. However both technologies performed well in bicycle-only environments and other researchers have found that loops can work well when specifically configured for counting, even in mixed traffic.

For counting pedestrians in pedestrian-only environments, passive infrared counters accurately count pedestrians when volumes are low and the counter is well located. Passive infrared can be used for both short duration counts and continuous counting.

Additionally, pedestrian phase actuations can be collected around the state as a low cost measure of pedestrian activity for either short duration or continuous travel monitoring. Additional research can be conducted to better understand the relationship of pedestrian counts to pedestrian phase actuation, but regardless, pedestrian phase actuation can be used in itself as a measure of pedestrian activity. Such data can be collected now around the state at little cost to ODOT. If the state does begin the effort to collect and archive this data, it will be a leader in pedestrian data collection in the US.

Regardless of what equipment is used, verification testing should be conducted and care should be taken in setting up the equipment and processing the data. Bicycle and pedestrian counting is a more challenging task than counting motor vehicles and should be approached with attention to detail.

The results show that there are existing technologies for both bicycle and pedestrian traffic monitoring that are accurate, cost effective, and compatible with ODOT's existing count programs, equipment, and infrastructure. However, mixed traffic conditions with high traffic volumes and intersections still require manual counts or other technologies not tested herein.

These non-motoring solutions can be implemented now, in order for ODOT to better monitor non-motorized travel in the state. Such data are needed to better inform decision makers and transportation professionals for safety analysis, design, planning, construction, maintenance, operations, and economic impact assessment.

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APPENDIX A

LITERATURE REVIEW TABULAR SUMMARY

LITERATURE REVIEW TABULAR SUMMARY

Technology	Authors	Data Type (B/P)	Make/Model	Type	Performance Metrics	Findings
Inductive Loops	Veenstra et al., 2013	B		Parallelogram	RMS – 8%	Good accuracy when bicycle volume ≤ 200 bikes/hr. Undercounting when volume > 200 bikes/hr.
	Kothuri et al., 2012	B		Quadrupole	MAPE – 14%	Underestimation of counts
	Nordback et al., 2011	B	Eco-counter Zelt/ Eco-Twin, Eco-Pilot	Trapezoidal Diamond	MAPE – 7.6 % (separated path) MAPE -23% (Shared roadway)	>95% accuracy on high frequency bicycle routes
	Nordback et al., 2010	B		Double Chevron	MAPE – 19% APE – 4%	Undercounting
	Kidarsa et al., 2006	B		Circular, Octagonal		No difference between circular and octagonal loops for bicycle detection Loops connected independently provide increased sensitivity
	SRF Consulting, 2003	B	Peak ADR 3000		Accuracy – 100% (Ferrous and Non-ferrous Bicycle)	The loops were accurate at detecting both ferrous and non-ferrous bicycles
	Munro, 2013	B	Eco-Counter	Trapezoidal Diamond	100% accuracy	
	ViaStrada, 2009	B	Bicycle Recorder Eco-Counter Zelt	Trapezoidal Diamond	Zelt Accuracy – 90% (on Road) Accuracy – 80% (Off road)	

Technology	Authors	Data Type (B/P)	Make/Model	Type	Performance Metrics	Findings
	Ryus et al. 2015	B		Trapezoidal Diamond	APD – 0.55%, AAPD – 8.87% (Detection zone) APD -14.08% AAPD – 17.62% (Includes bypass errors)	Embedded loops and temporary loops were tested mainly on off-street facilities
	Figliozzi et al., 2014	B		Diamond	>200% error	Sensitivity and percent of right turning traffic impacted the accuracy
Pneumatic Tubes	Hyde-Wright et al, 2014	B	Metro Count 5600 and Eco-Counter		Accuracy 44% to 95%	All tubes were able to count at 95% when placed within 4 feet of the detector, but MetroCount's classification scheme had to be modified to achieve this using BOCO Scheme.
	Brosnan et al. 2015	B	Metro Count 5600 and TimeMark		Percent Error: 6 to 40% Metro Count; 48% to 57% undercount error TimeMark	Problems with occlusion lead to undercounting; accuracy diminishes with distance and vehicle traffic; don't use across multiple lanes; smaller, lighter tubes associated with accuracy.
	Ryus et al. 2015	B			19% AAPD error; 18% APD undercounting error	
Thermal Camera	Kendrick et al., 2014	B	FLIR VIP Bike		AAPD 22% - 31%	Overcounting was encountered in both phases. Bicycles were counted more than once, peds and vehicles were also counted as bicycles.
Microradar	Kendrick et al., 2014	B	Sensys		Accuracy (Detection) – 82%	Evaluated for detection only
	Muralidharan et al., 2013	P	Sensys		False positives – 0.1% Missed detection – 1%	Evaluated for detection only

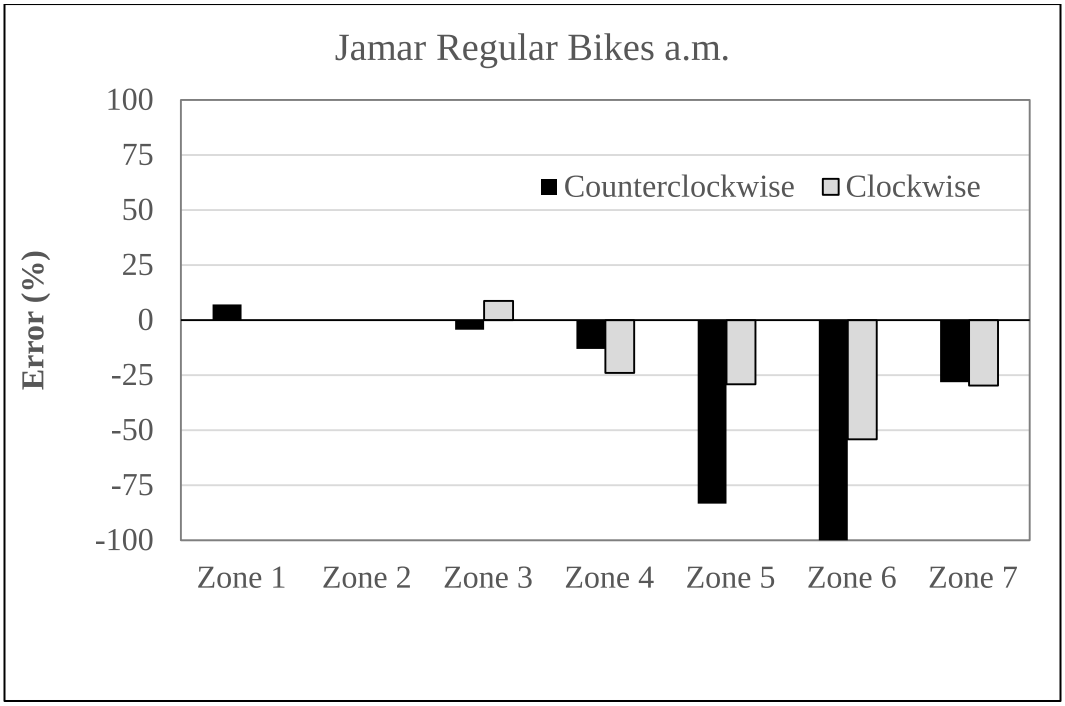
Technology	Authors	Data Type (B/P)	Make/Model	Type	Performance Metrics	Findings
Magnetometers	SRF Consulting, 2003	B	3M Microloop		98% accuracy in controlled test	Can't detect non-ferrous objects, but can detect speed.
	NA	B	TRAFx			
Radar	NA	B	Wavetronix SmartSensor Matrix (AN-0012)		None	Claims to detect bicycles, no differentiation from motor vehicles unless bicycle is in separate 10-foot lane. May not be able to count.
	NA	B	DataCollect SDR bike		None	Claims to detect bicycles
Microwave	NA	B	MS Sedco Intersector			Claims to detect bicycles
	SRF Consulting, 2003	B/P	SmartWalk 1400	sidefire	96% Accurate, in controlled test	
Video	Kading et al., 2015	B	Iteris SmartCycle		90% accuracy for detection, but high error for counting	Significant errors for counting "related to light, shadows, group riding"
Pedestrian pushbutton	Day et al., 2011	P				Analyzed trends in actuations based daily and weekly variations, weather, special events, seasonal changes in activity patterns and changes in pedestrian service.
	Kothuri et al., 2012	P			N/A, Records actuations, not counts	Recorded actuations and delay using internal logic commands in the signal controller per phase
	Figliozzi et al., 2014	P			N/A, Records actuations, not counts	Used pedestrian phase data and adjustment factors to estimate pedestrian AADT.
Passive Infrared	Ryus et al. 2015	B/P			20% AADP error	Varies substantially by product
	Turner et al. 2013	B/P	Eco-Counter TRAFx Trail Master		Ave Error Varies from +23% to -47%	Undercounts more for high traffic locations
	Schneider et al. 2012	B/P			6% to 32% AAPD	Undercounts more for high traffic locations
	Jones et al. 2010	B/P	JAMAR		Undercounting 15% to 21%	

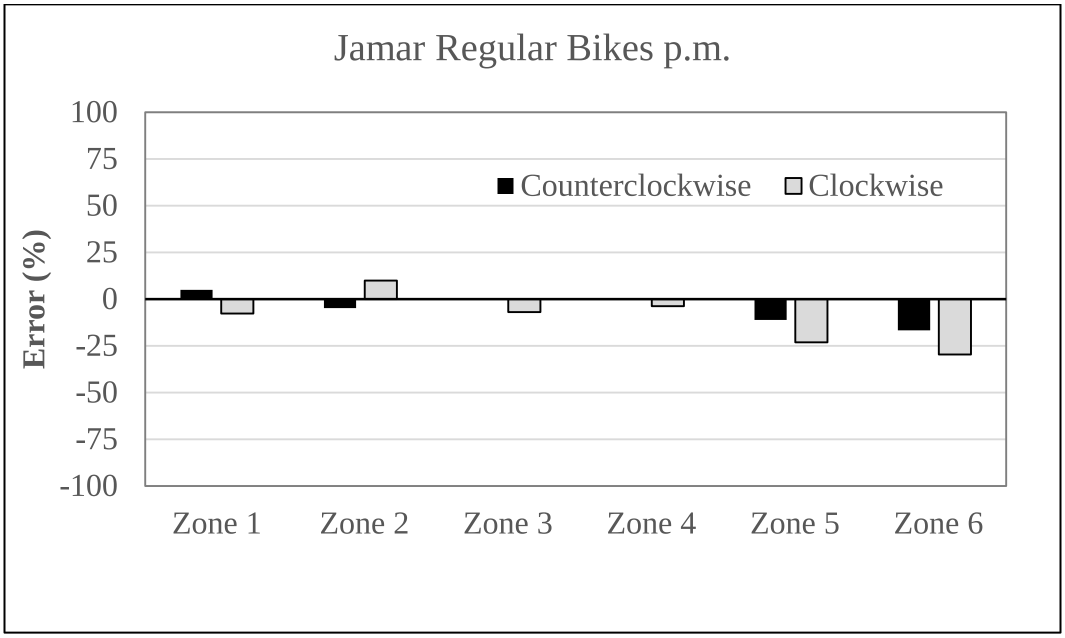
Technology	Authors	Data Type (B/P)	Make/Model	Type	Performance Metrics	Findings
Active Infrared	Jones et al. 2010	B/P	TrailMaster		Undercounting B &P 12% to 18%, Undercounting Peds 25% to 48%	better at lower volume locations
	Ryus et al. 2015	B/P			12% AAPD error	
Piezoelectric strips	Ryus et al. 2015 Erata	B	MetroCount		Roughly 3% AAPD error	Only tested at one site.
	Munro et al 2013	B	MetroCount MC5720, and TDC Systems		97% overall accuracy on paths (90% for TDC on roads)	

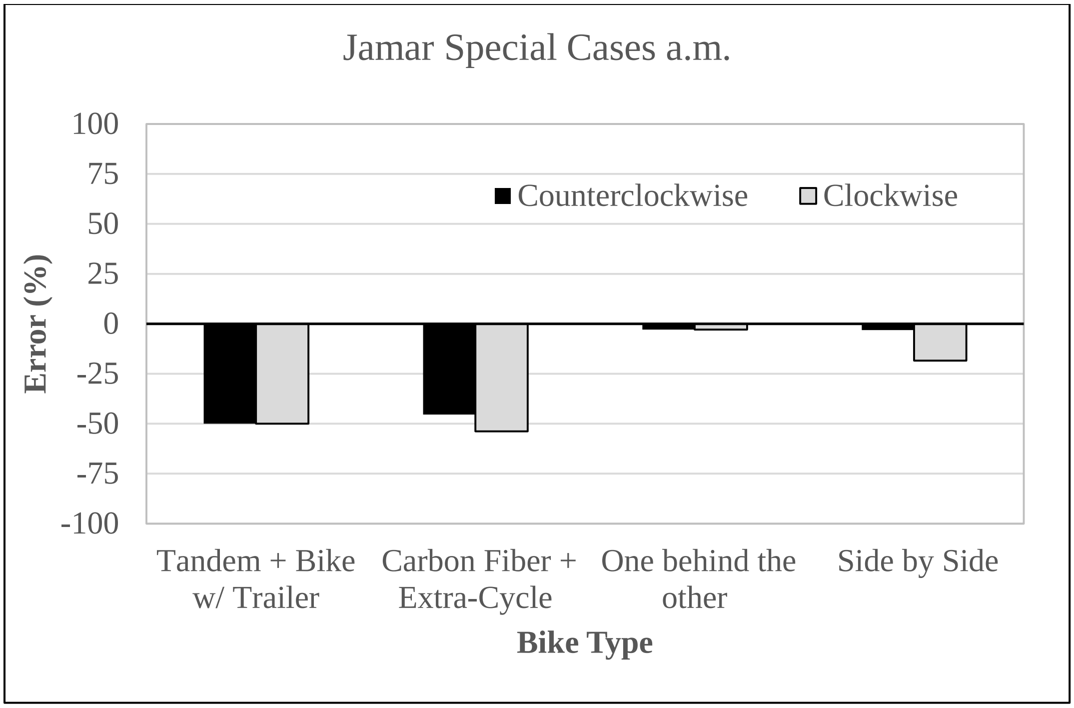
APPENDIX B

PILOT STUDY ADDITIONAL FIGURES

PILOT STUDY ADDITIONAL FIGURES



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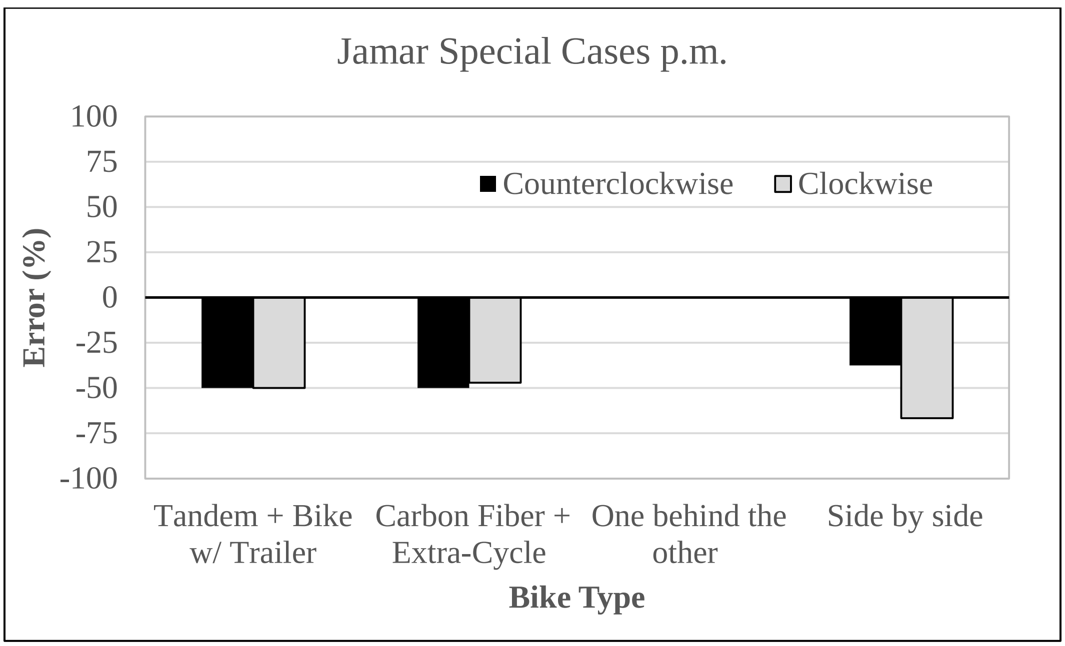
Carbon Fiber + Extra-Cycle
One behind the other
Side by Side
Bike Type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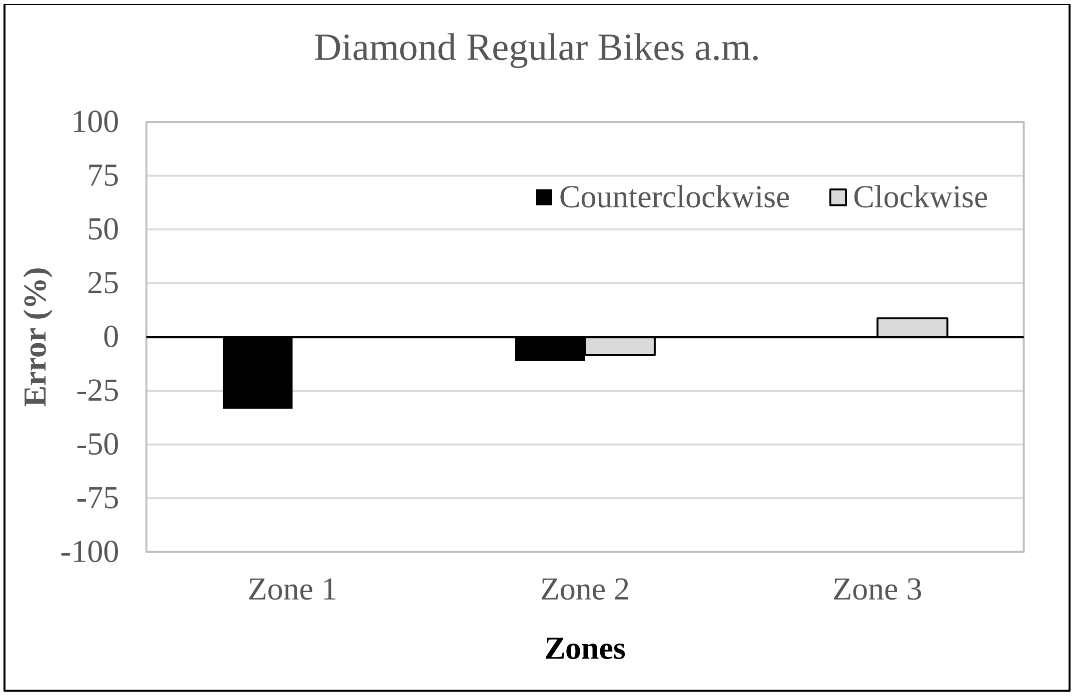
Carbon Fiber + Extra-Cycle
One behind the other
Side by side
Bike Type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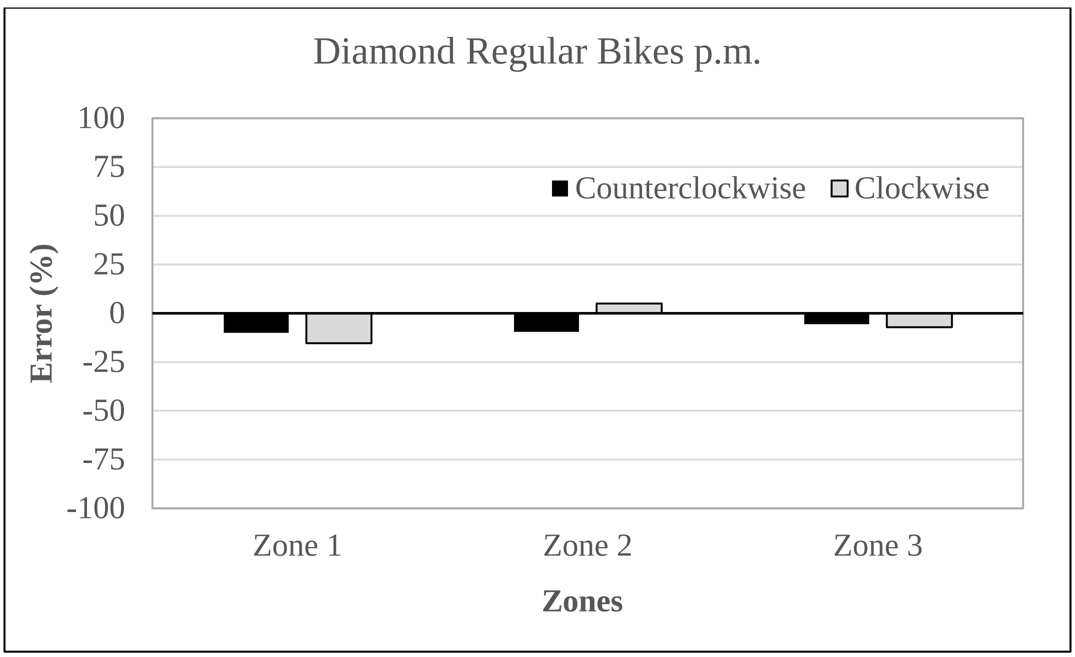
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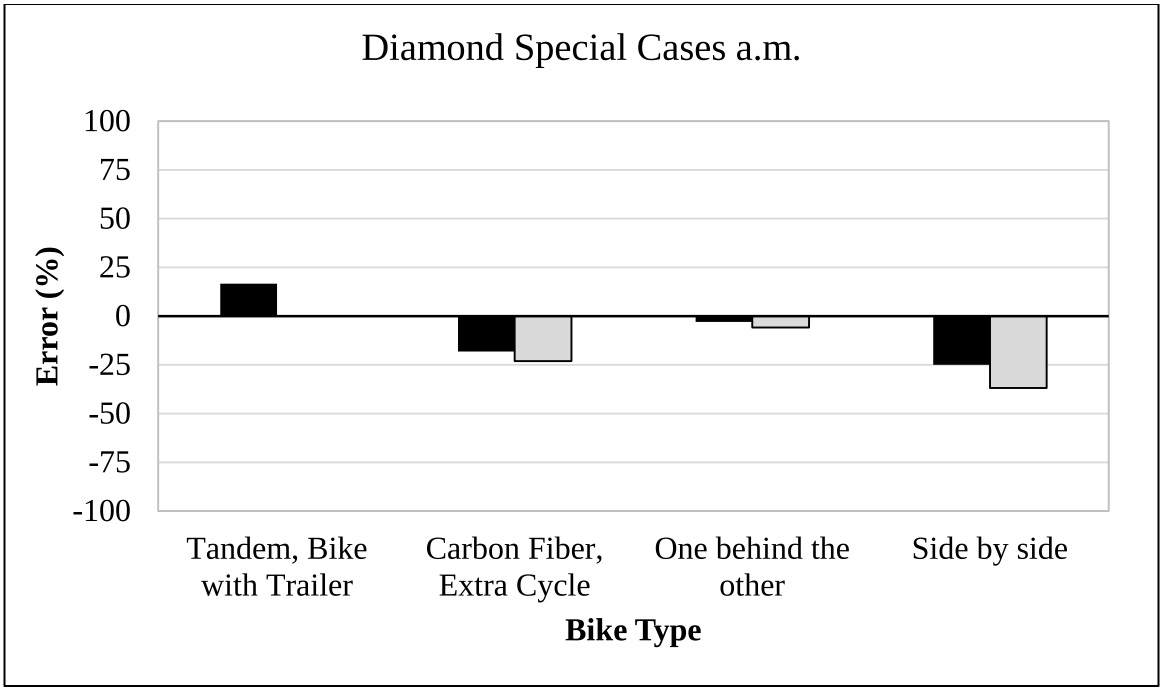
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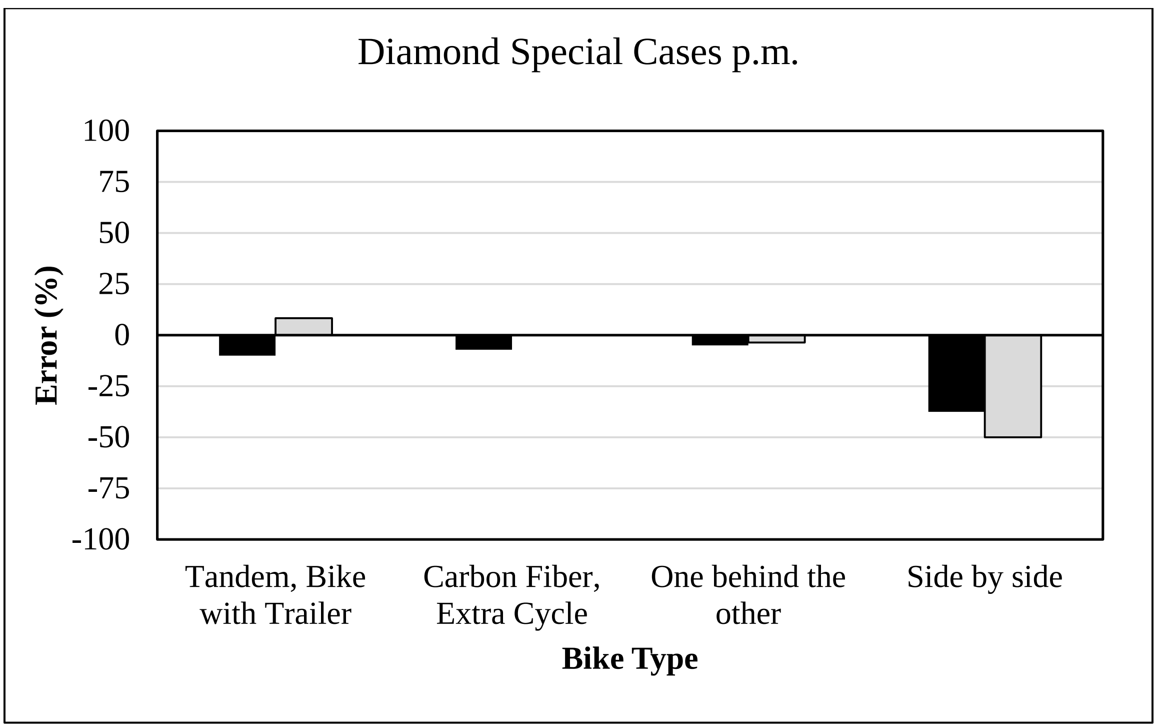
Tandem, Bike with Trailer
Carbon Fiber, Extra Cycle
One behind the other
Side by side
Bike Type


Diamond Special Cases p.m.
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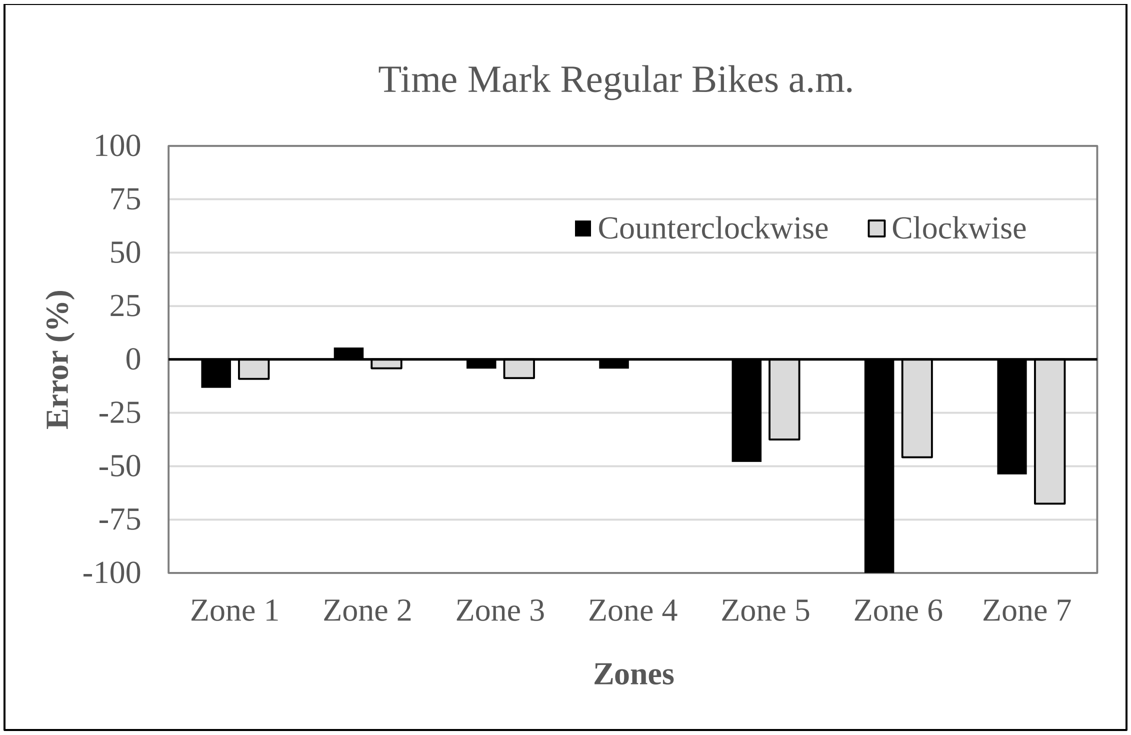
Tandem, Bike with Trailer
Carbon Fiber, Extra Cycle
One behind the other
Side by side
Bike Type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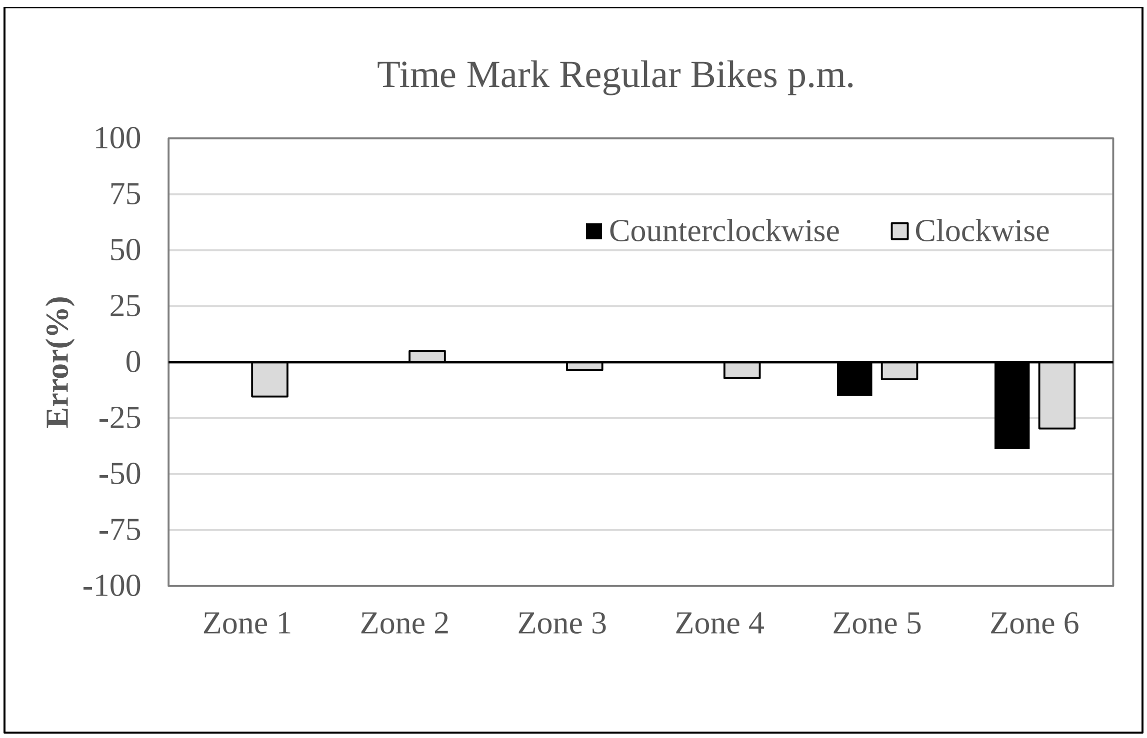
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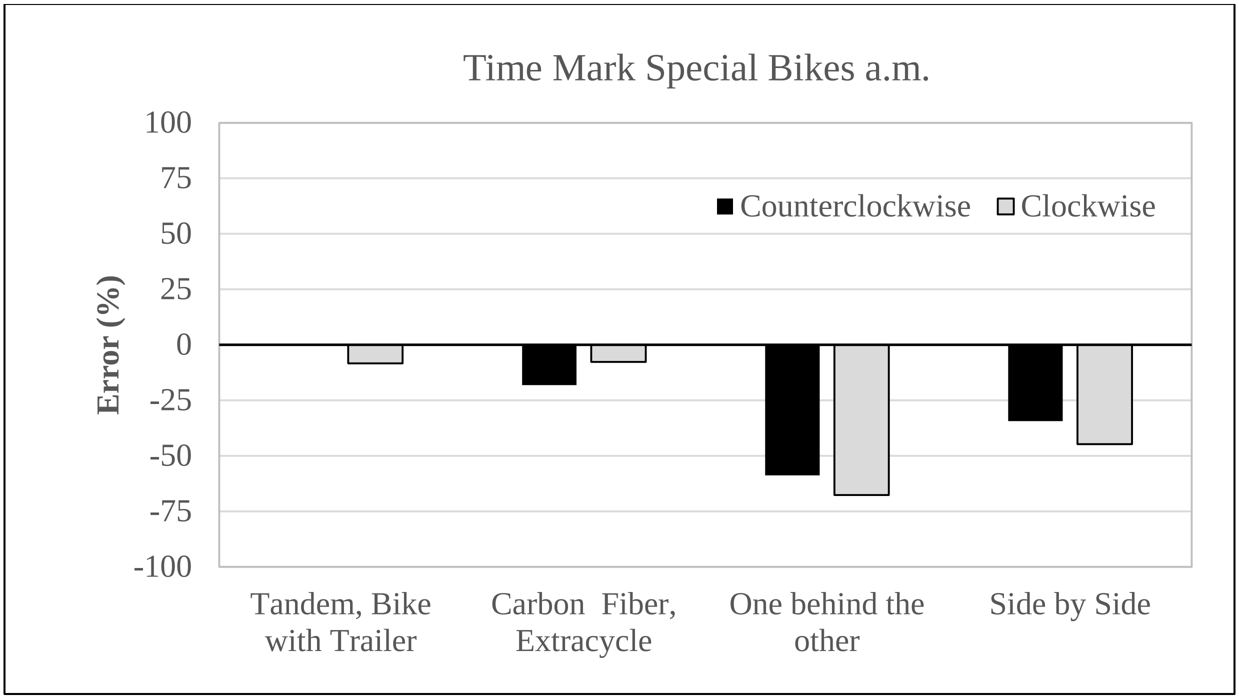
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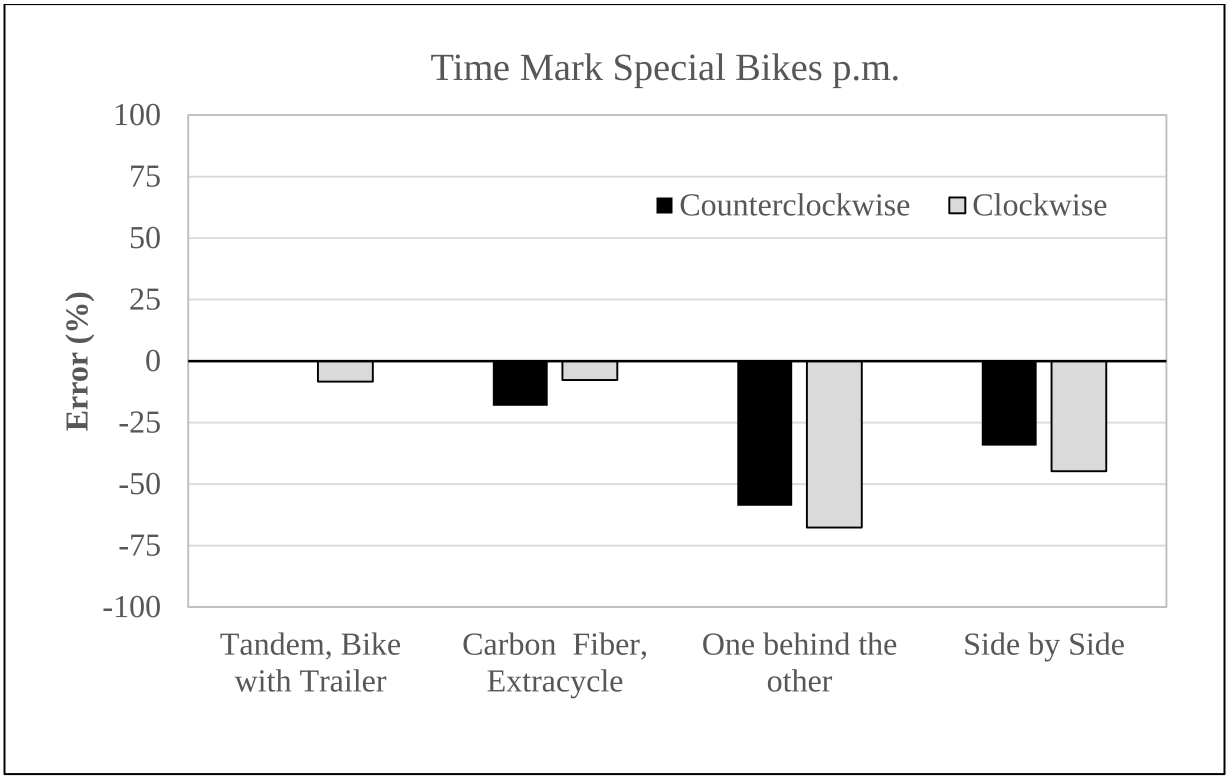
Carbon Fiber, Extracycle
One behind the other
Side by Side


Time Mark Special Bikes p.m.
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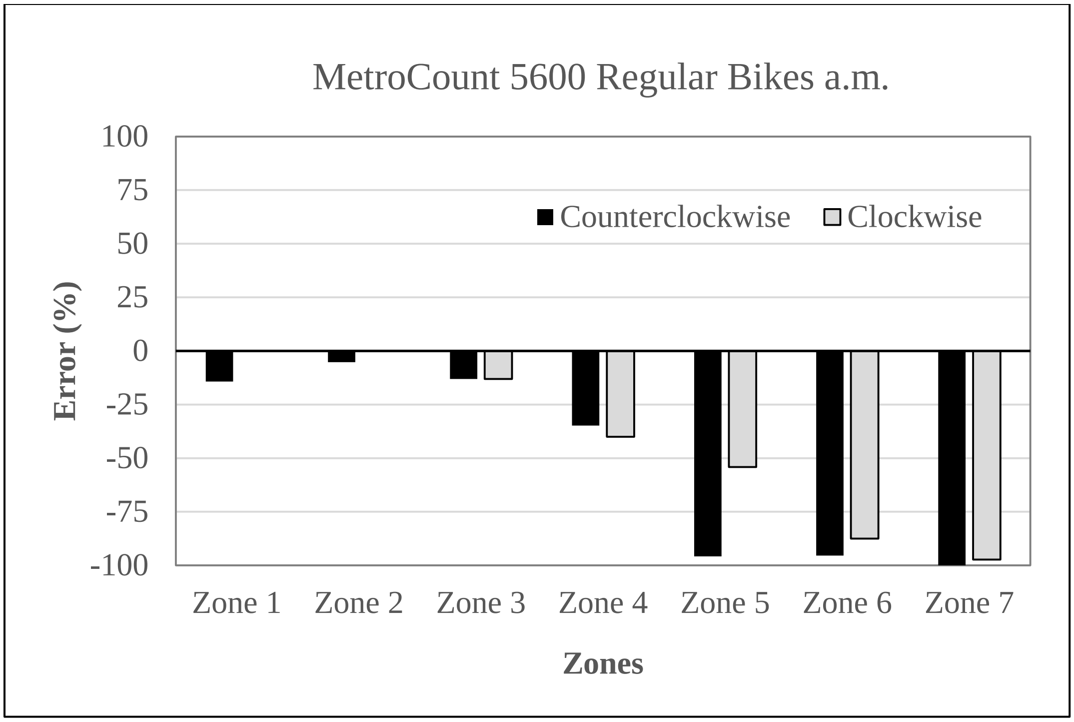
Tandem, Bike with Trailer
Carbon Fiber, Extracycle
One behind the other
Side by Side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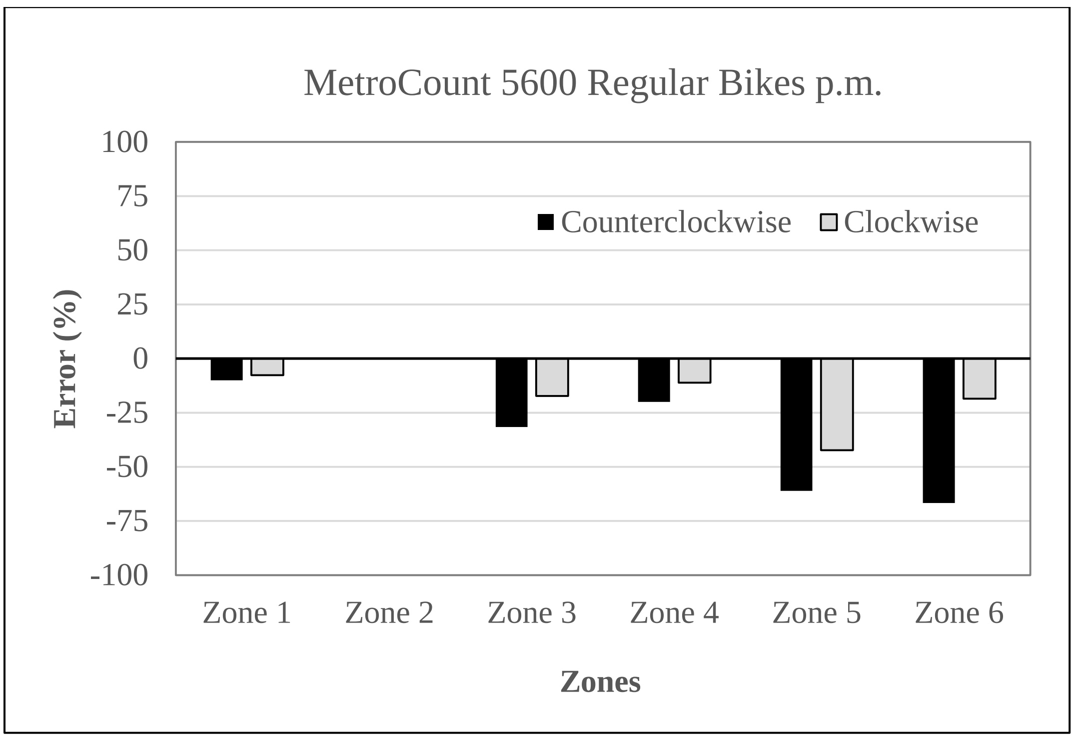
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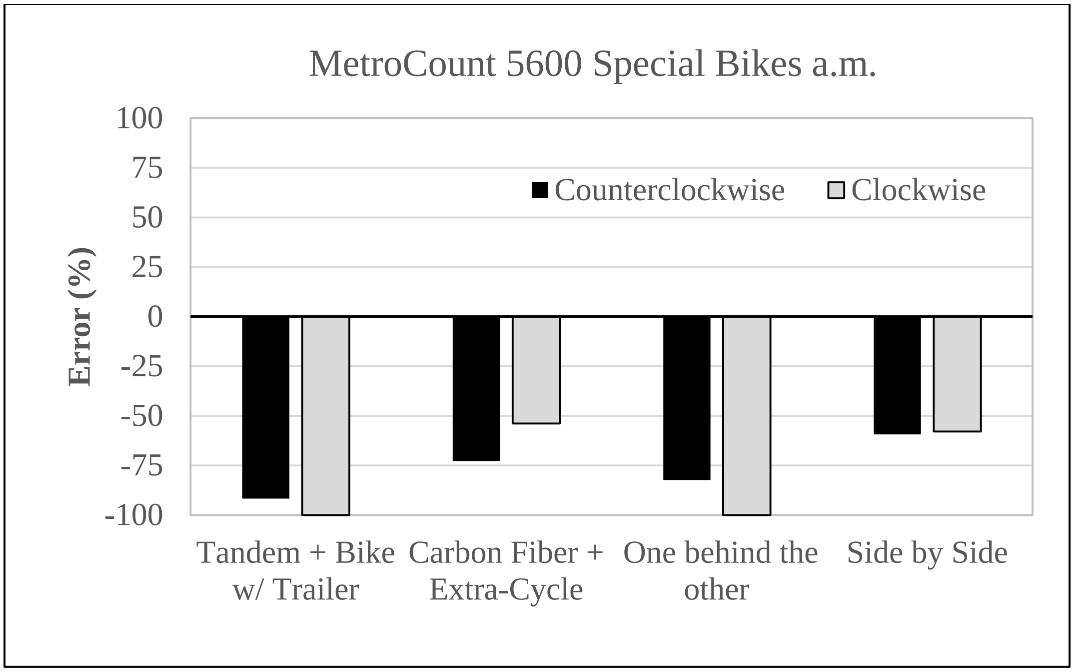
MetroCount 5600 Special Bikes a.m.
Error (%)
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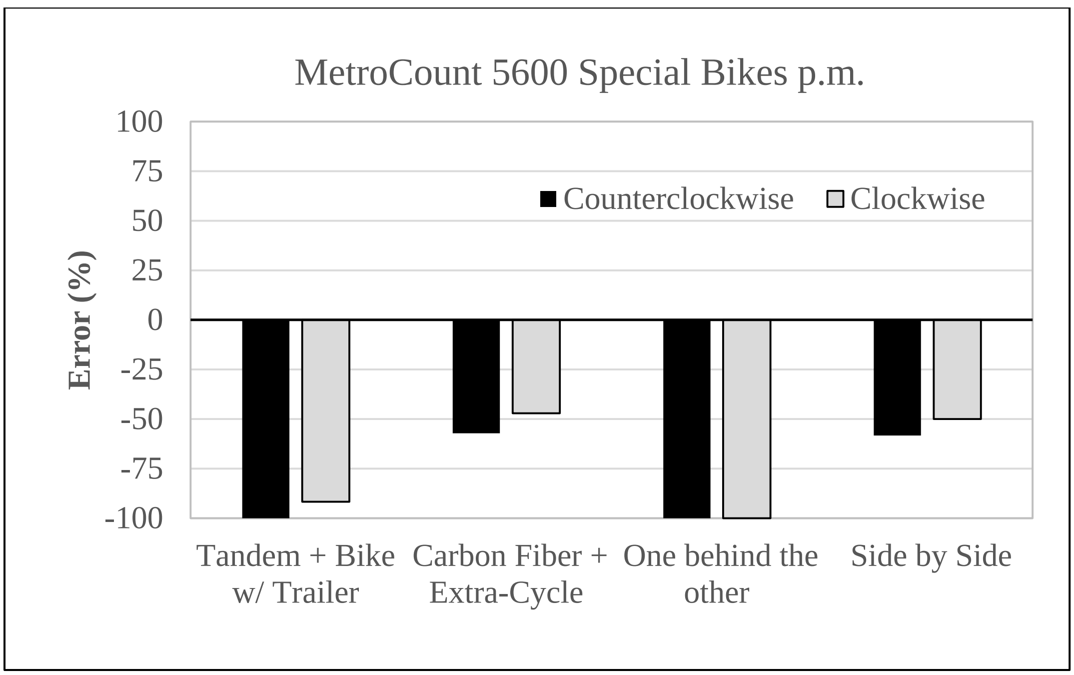
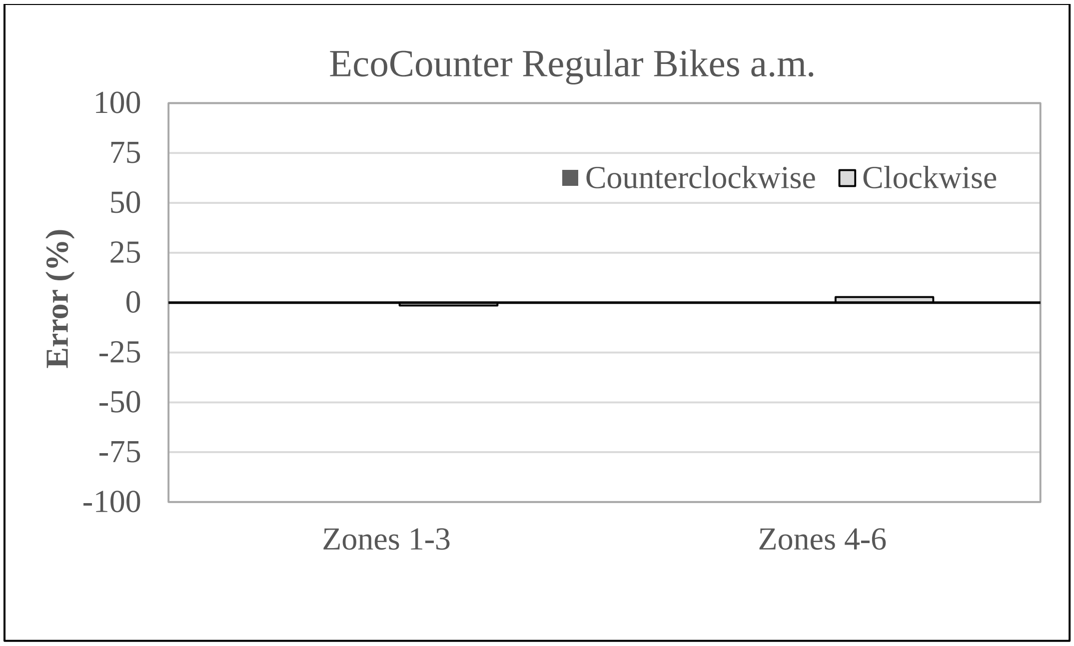
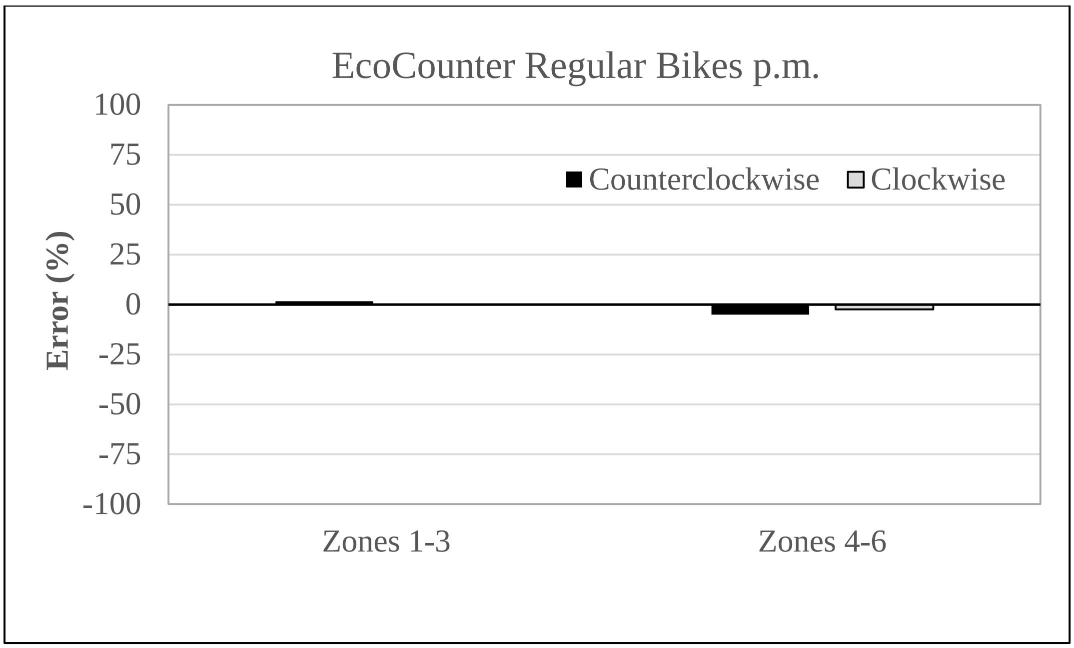
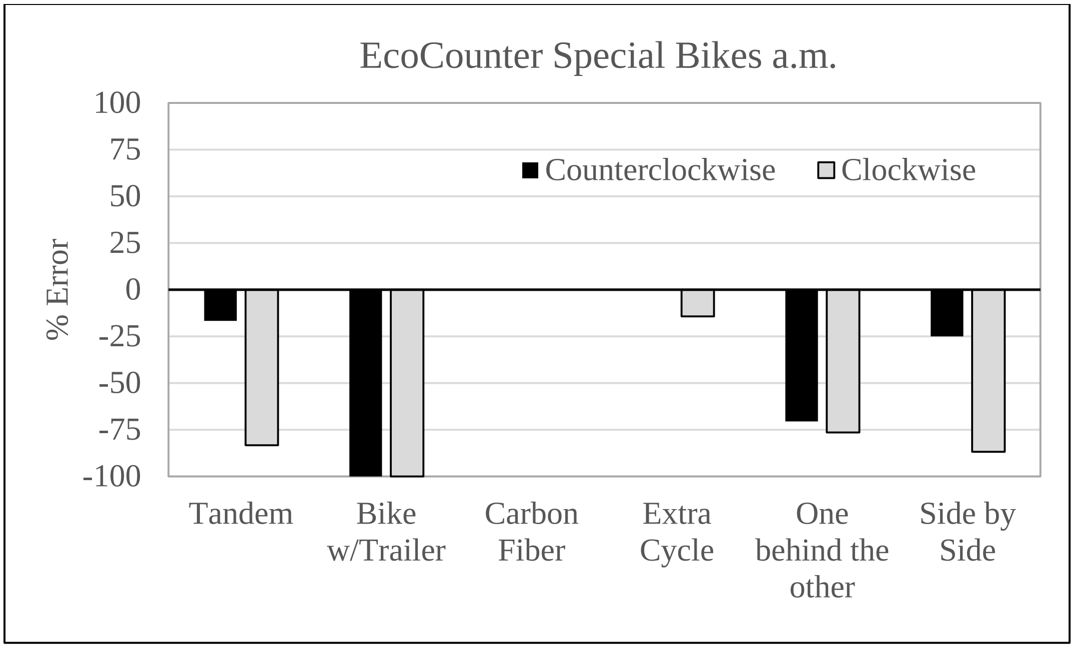
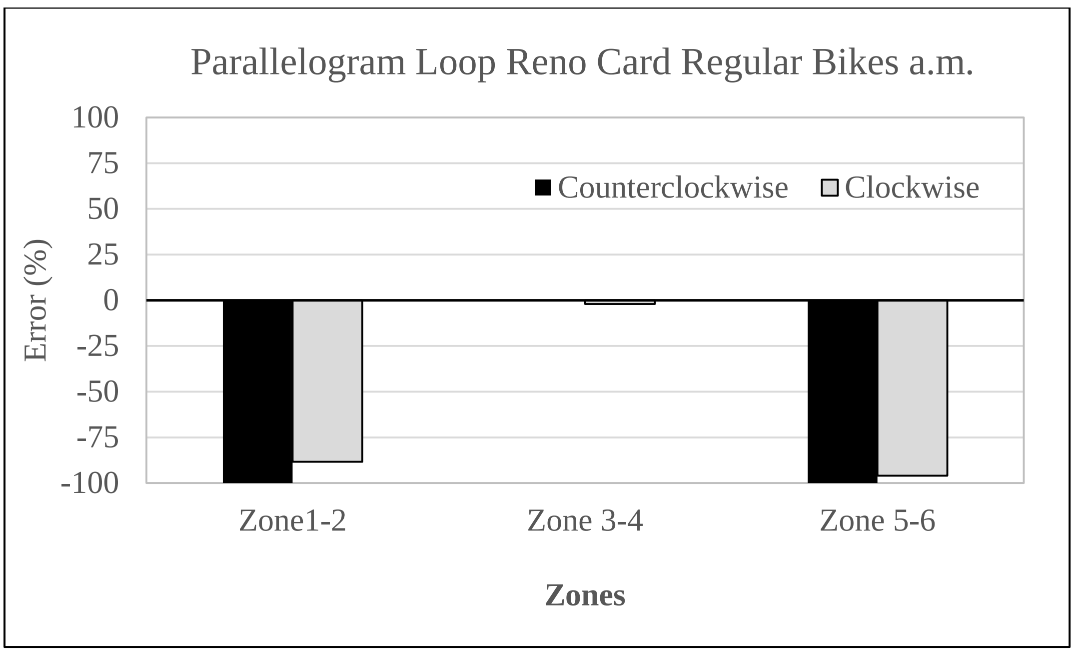
Tandem + Bike w/ Trailer
Carbon Fiber + Extra-Cycle
One behind the other
Side by Side

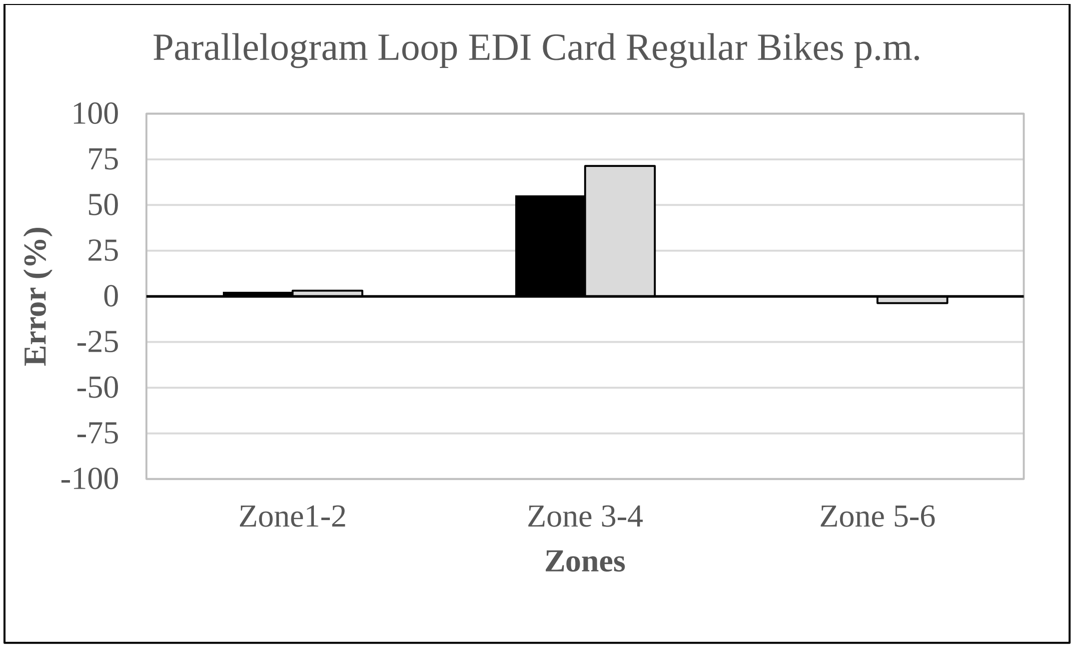

MetroCount 5600 Special Bikes p.m.
Error (%)
100
75
50
25
0
-25
-50
-75
-100
Counterclockwise
Clockwise
Tandem + Bike w/ Trailer
Carbon Fiber + Extra-Cycle
One behind the other
Side by Side

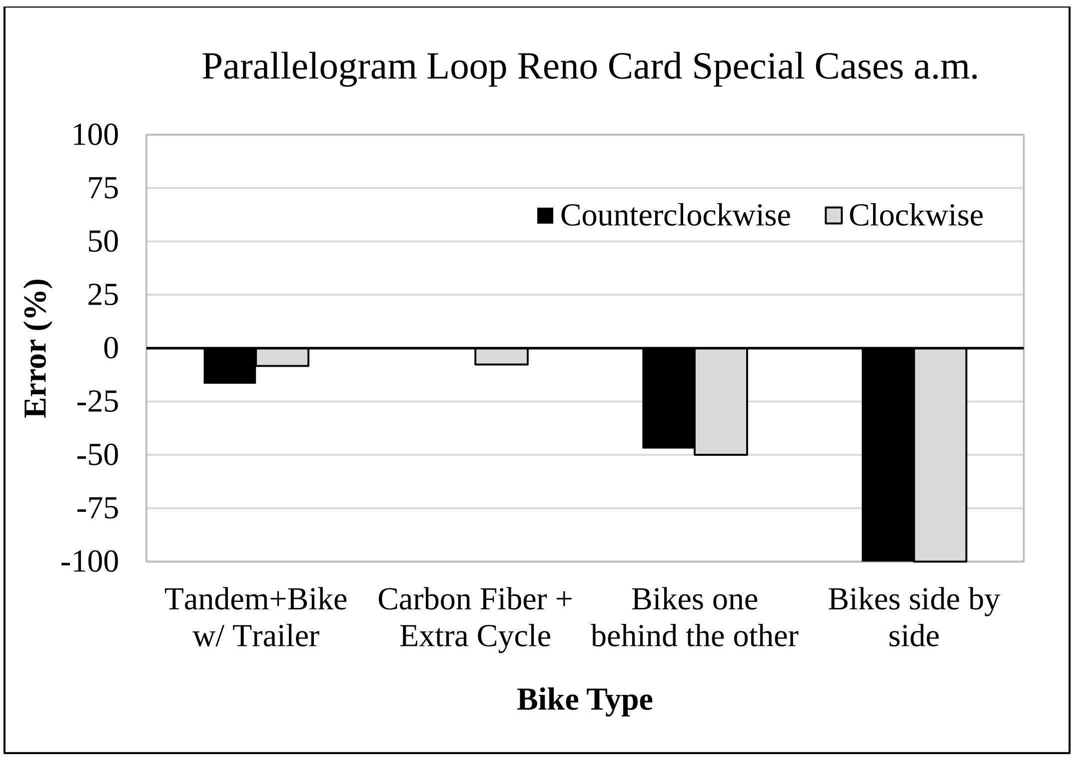

EcoCounter Regular Bikes a.m.
Counterclockwise
Clockwise
Error (%)
100
75
50
25
0
-25
-50
-75
-100
Zones 1-3
Zones 4-6

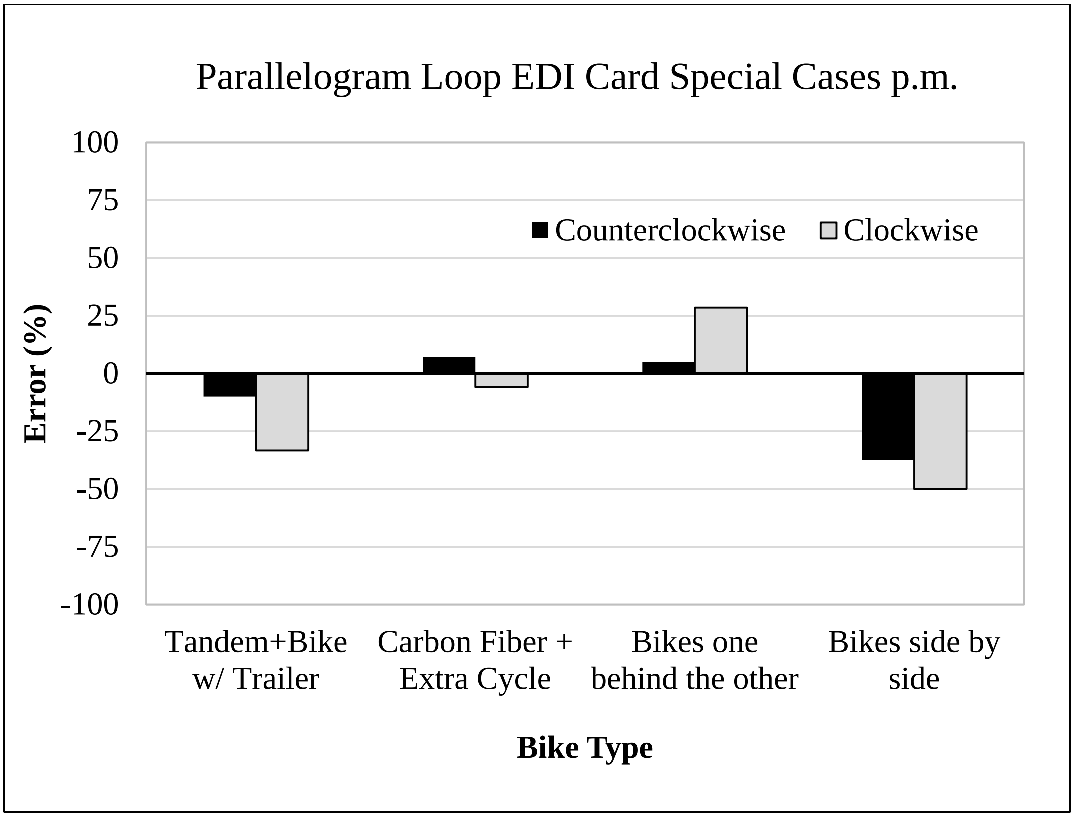

EcoCounter Regular Bikes p.m.
Counterclockwise
Clockwise
Error (%)
100
75
50
25
0
-25
-50
-75
-100
Zones 1-3
Zones 4-6


EcoCounter Special Bikes a.m.
100
75
50
25
0
-25
-50
-75
-100
% Error
Counterclockwise
Clockwise
Tandem
Bike w/Trailer
Carbon Fiber
Extra Cycle
One behind the other
Side by Side

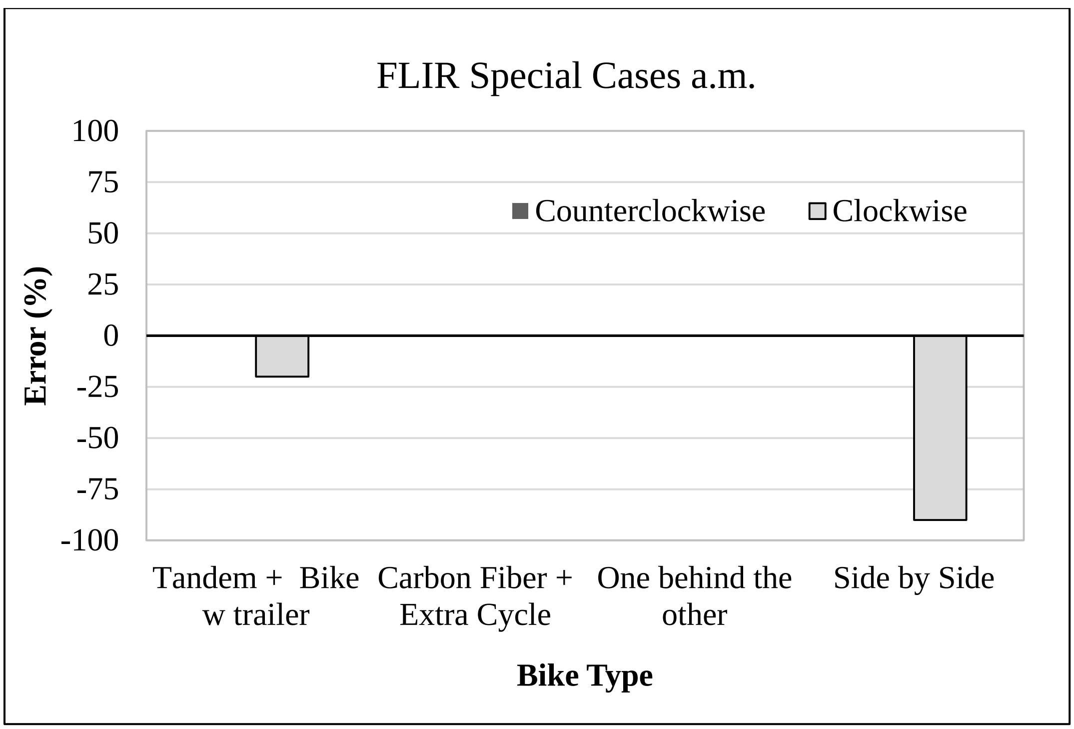

Parallelogram Loop Reno Card Regular Bikes a.m.
100
75
50
25
0
-25
-50
-75
-100
Error (%)
Counterclockwise
Clockwise
Zone1-2
Zone 3-4
Zone 5-6
Zones


Parallelogram Loop EDI Card Regular Bikes p.m.
100
75
50
25
0
-25
-50
-75
-100
Error (%)
Zone1-2
Zone 3-4
Zone 5-6
Zones

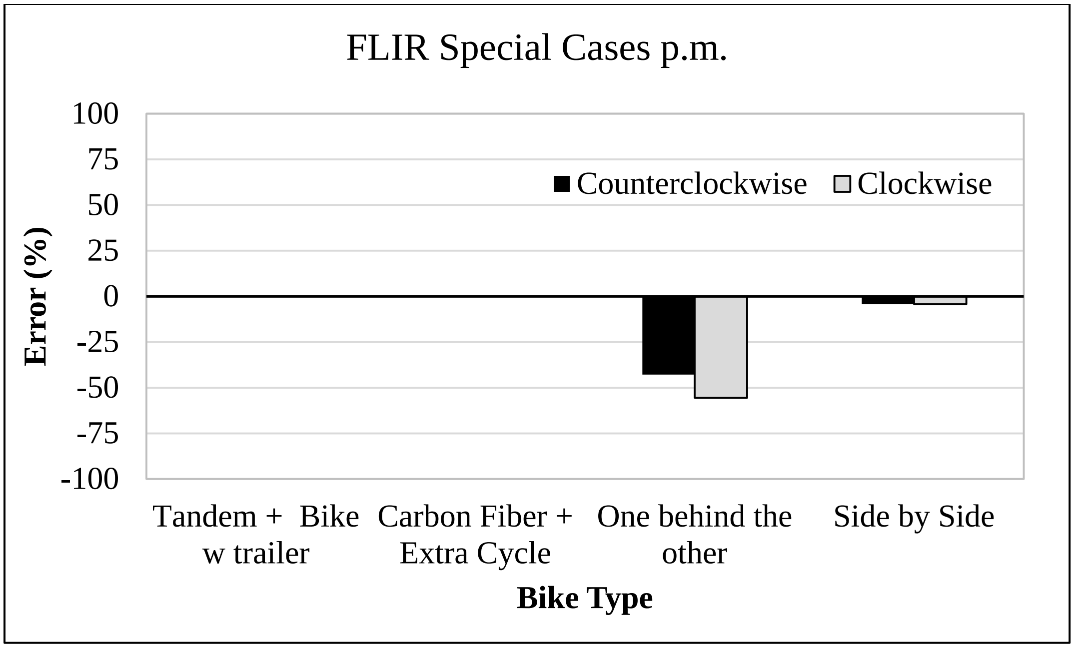

Parallelogram Loop Reno Card Special Cases a.m.
100
75
50
25
0
-25
-50
-75
-100
Error (%)
Counterclockwise
Clockwise
Tandem+Bike w/ Trailer
Carbon Fiber + Extra Cycle
Bikes one behind the other
Bikes side by side
Bike Type



Parallelogram Loop EDI Card Special Cases p.m.
100
75
50
25
0
-25
-50
-75
-100
Error (%)
Counterclockwise
Clockwise
Tandem+Bike w/ Trailer
Carbon Fiber + Extra Cycle
Bikes one behind the other
Bikes side by side
Bike Type



FLIR Special Cases a.m.
100
75
50
25
0
-25
-50
-75
-100
Error (%)
Counterclockwise
Clockwise
Tandem + Bike w trailer
Carbon Fiber + Extra Cycle
One behind the other
Side by Side
Bike Type


FLIR Special Cases p.m.
100
75
50
25
0
-25
-50
-75
-100
Error (%)
Counterclockwise
Clockwise
Tandem + Bike w trailer
Carbon Fiber + Extra Cycle
One behind the other
Side by Side
Bike Type

APPENDIX C

SITE SELECTION RANKING

SITE SELECTION RANKING

	US97 & Pinebrook Blvd., Bend	122nd & Division, Portland	99 & Hall, Tigard	Sunnyside Rd at SE 172nd Ave, Happy Valley	82nd Ave. & Powell, Portland	Bellevue St. (OR22) & Winter St. SE Salem	OR 8 & 185th	99W/Taylors Ferry near the Barbur Transit Center	99E/Jennings Ave
GENERAL CONSIDERATIONS									
Traffic AADT	0.33	0.33	0.33		0.33	0.33		0.33	0.33
Location of poles for cameras	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Presence of Type 2070 signal controllers	1.00	1.00	1.00				1.00	1.00	1.00
Surrounding land use	0.67	0.67	0.67	0.33	0.67	0.67	0.67	0.67	0.67
Distance from Portland	0.00	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50
Presence of sidewalks	1.00	1.00	1.00	0.50		1.00	1.00	0.50	0.75
FOR BICYCLES									
Bicycle volume	0.33	0.67	0.67	0.33	0.00	0.67		0.67	0.33
Strava volume	0.33	0.67	0.67	0.67	0.00	0.33	0.67	0.67	
Volume of right turning traffic	0.67	0.33	0.33	0.67	0.00	0.33		0.67	0.67
Presence of bicycle lane	1.00	1.00	1.00	1.00	0.00	1.00	0.50	0.50	0.50
Possibility of adding inductive loops	1.00	0.75	1.00		0.00			0.25	
FOR PEDS									
Pedestrian volume	0.33	0.33	0.67	0.33	0.00	0.67		0.67	0.67
Presence of bus stops		1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00
Availability of push buttons	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00
Crosswalks	1.00	1.00	1.00	1.00	0.00	1.00	1.00		1.00
Score	**9.67**	**11.25**	**11.83**	**7.33**	**2.50**	**9.00**	**8.33**	**9.42**	**9.42**

	99E/River Rd.	Powell & 112th	OR99W & Baker Creek/Evans, McMinnville	OR34 & 15th in Corvallis	OR 30 & Kittridge Ave	OR 30 & NE Crown Zellerbach Logging Road/Scappoose Veronia Hwy	Lower Boones Ferry @ 72nd/Bridgeport,Hwy1,MP290.57	Route 8 @ 234th Ave, Hwy 29, MP9.06
GENERAL CONSIDERATIONS								
Traffic AADT	0.33	0.33	0.33	0.33	0.67			
Location of poles for cameras	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Presence of Type 2070 signal controllers	1.00						1.00	1.00
Surrounding land use	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Distance from Portland	0.50	0.50	1.00	1.00	0.50	0.50	0.50	0.50
Presence of sidewalks	1.00	1.00	1.00	0.75	0.75	0.75	1.00	1.00
FOR BICYCLES								
Bicycle volume	0.67	0.67	0.67	0.67	1.00	0.67	0.67	0.67
Strava volume	0.67	0.33	0.67	1.00	1.00	0.67	0.67	0.67
Volume of right turning traffic	0.67	0.67	0.67	0.33				
Presence of bicycle lane	0.75	1.00	0.75	1.00	0.50	0.75	1.00	0.75
Possibility of adding inductive loops	0.25	0.50				0.50	0.50	0.50
FOR PEDS								
Pedestrian volume	0.67	0.67	0.67	0.67				
Presence of bus stops	1.00	1.00			1.00		1.00	1.00
Availability of push buttons	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Crosswalks	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Score	**11.17**	**10.33**	**9.42**	**9.42**	**9.08**	**7.50**	**10.00**	**9.75**

	Route 8 @ Cornelius Pass Rd/219th Ave,Hwy29,MP8.32	Route 8 @ Minter Bridge/Cypress St, Hwy 29,MP11.28	Route 99W @ McDonald /Gaarde St, Hwy 91, MP10.36	Route 99W @ Durham Rd, Hwy 91, MP11.48	Route 224 @ 82nd Dr, Hwy 171, MP5.03	26th and Powell	NE Grand & NE Multnomah on Multnomah	Halsey & 122nd	52nd and Powell
GENERAL CONSIDERATIONS									
Traffic AADT						0.33	0.67	0.33	0.33
Location of poles for cameras	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Presence of Type 2070 signal controllers	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Surrounding land use	0.67	0.67	0.67	0.67	0.67	1.00	1.00	0.67	0.67
Distance from Portland	0.50	0.50	0.50	0.50	0.50	1.00	1.00	0.50	1.00
Presence of sidewalks	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOR BICYCLES									
Bicycle volume	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Strava volume	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Volume of right turning traffic									
Presence of bicycle lane	1.00	1.00	1.00	0.75	1.00	0.50	0.50	1.00	0.50
Possibility of adding inductive loops	0.25	0.25			0.50	0.50	0.50	1.00	0.50
FOR PEDS									
Pedestrian volume						0.67	1.00	0.67	0.67
Presence of bus stops	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Availability of push buttons	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Crosswalks	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Score	**9.50**	**9.75**	**9.50**	**9.25**	**10.00**	**11.33**	**12.00**	**11.50**	**11.00**

APPENDIX D

BIKE BY BIKE ANALYSIS, COLUMBIA RIVER HIGHWAY CLASSIFICATION COUNTERS

BIKE BY BIKE ANALYSIS, COLUMBIA RIVER HIGHWAY CLASSIFICATION COUNTERS

A bike by bike comparison was done by matching up classification counter time stamps with those determined from the corresponding video. These comparisons were conducted over 3 hours (8am -11am) on Monday, May 25th, 2015. The counters included were JAMAR, MetroCount 5600 (vendor and BOCO schemes), and TimeMark Gamma (10ft and 16ft tube spacing). Since the tube locations differed along the roadway and there were varying delays associated with each counter, the timestamps did not often line up exactly with the times recorded from the video. However the time differences were consistent enough to determine which events matched which.

Of the counters included in the analysis, the JAMAR counters fared the best, followed by MetroCount, and TimeMark in that order. There were relatively few false positives (where a bike was counted by the counter, but did not exist on the video), most of which corresponded closely enough to a motor vehicle event to confirm it as the likely cause of the miscount. Interestingly, the BOCO scheme seemed to only improve the accuracy of the MetroCount counter placed on the south side of the highway. The same effect can be seen in the TimeMark counters where the shorter tube spacing showed increased accuracy on the south side, but not on the north.

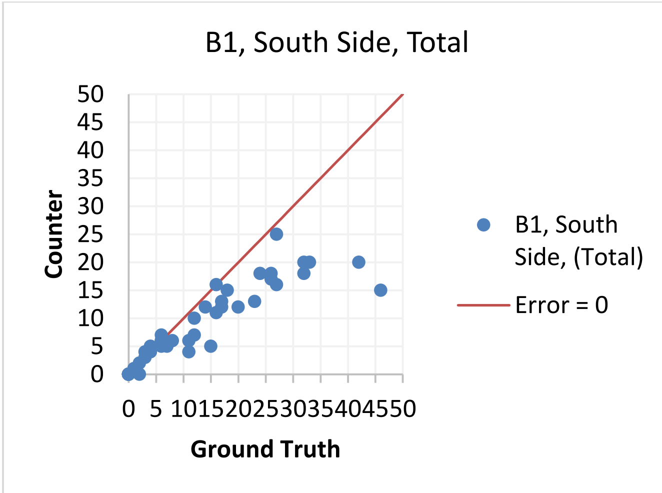
False negatives were much more common than false positives. Bicycles grouped closely together caused problems for counters. Either the counter would interpret the group as a multi-axle motor vehicle or only catch one or two of the bicycles, missing the others all together. For JAMAR and MetroCount the explanation of the false positives was easier to ascertain while TimeMark undercounts were much more difficult to decipher.

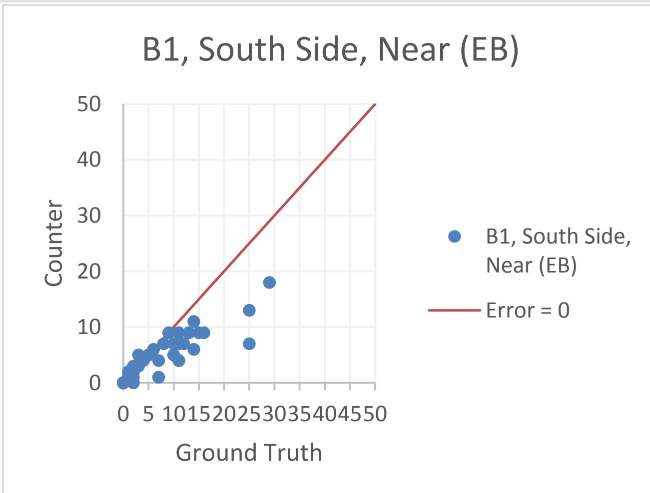
Counter	Counter Alias	Bike Matches	False Negatives	False Positives	False Positives (vehicle caused)
JAMAR_N	C1, north side, (total)	43	15	0	0
JAMAR_S	C1, south side, (total)	41	16	0	3
JAMAR_S_HR	C1HR, south side, near (EB)	31	13	0	1
MC5600_N	C3, north side, (total)	22	36	0	0
MC5600_S	C3, south side, (total)	32	26	0	0
MC5600_S_BOCO	C3, south side BOCO, (total)	44	14	1	0
MC5600_N_BOCO	C3, north side BOCO, (total)	32	26	0	0
TimeMark_N_16ft	C2, north side, 16ft, (total)	12	46	0	2
TimeMark_N_10ft	C2, north side, 10ft, (total)	12	46	0	0
TimeMark_S_16ft	C2, south side, 16ft, (total)	5	53	0	0
TimeMark_S_10ft	C2, south side, 10ft, (total)	19	38	0	0

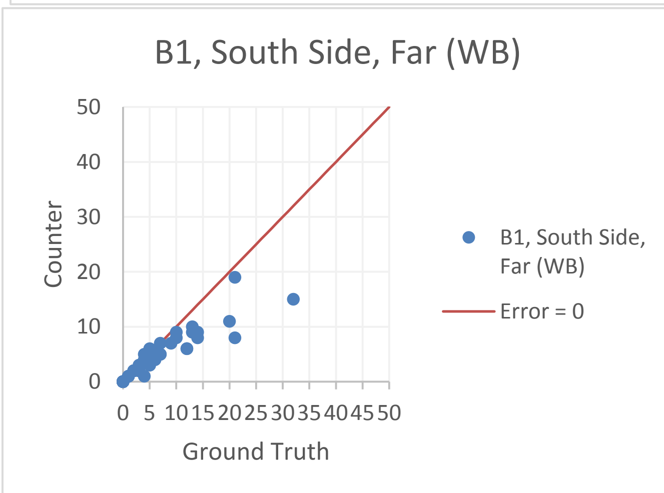
APPENDIX E

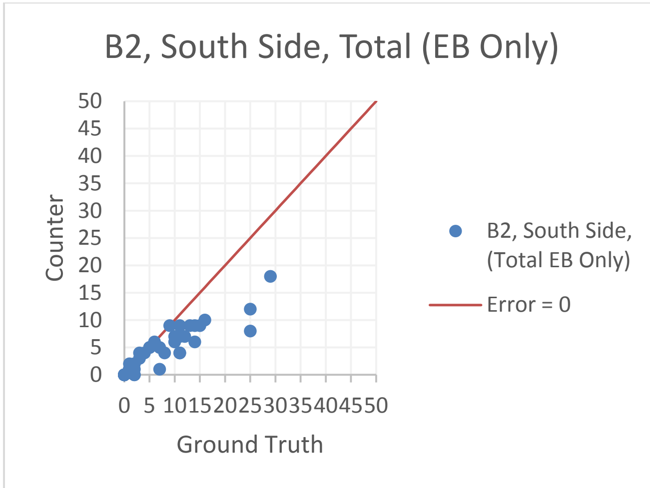
COLUMBIA RIVER HIGHWAY COUNTER VS. GROUND TRUTH

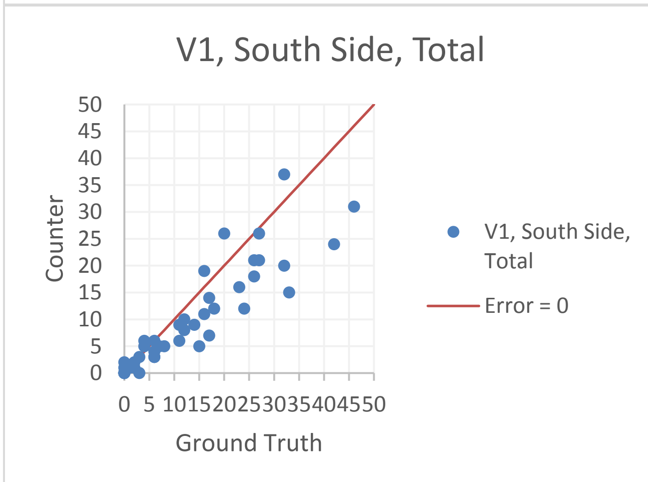
COLUMBIA RIVER HIGHWAY COUNTER VS. GROUND TRUTH

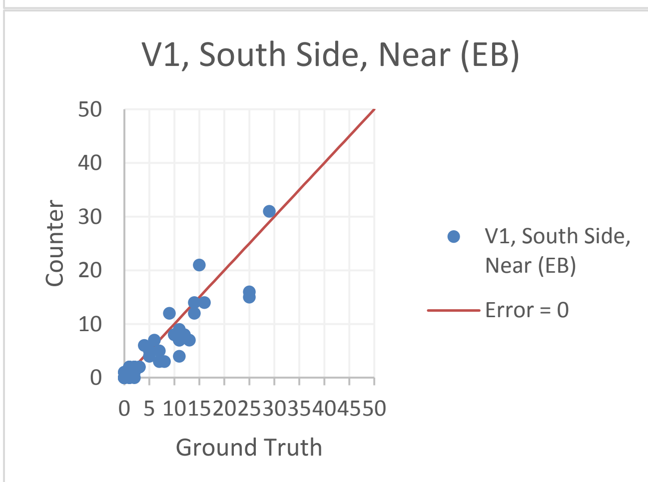


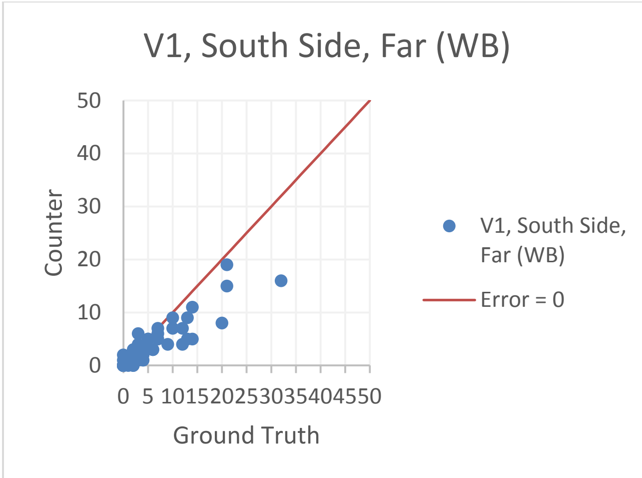


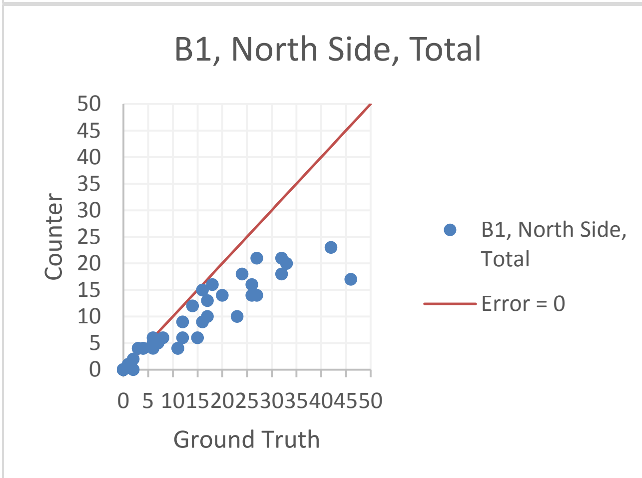


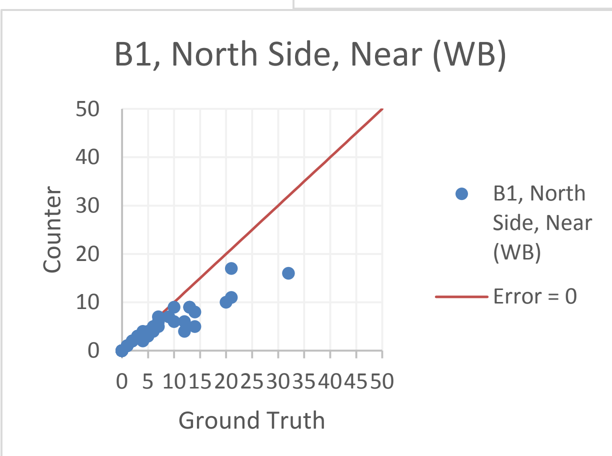

B2, South Side, Total (EB Only)
Counter
Ground Truth
B2, South Side, (Total EB Only)
Error = 0

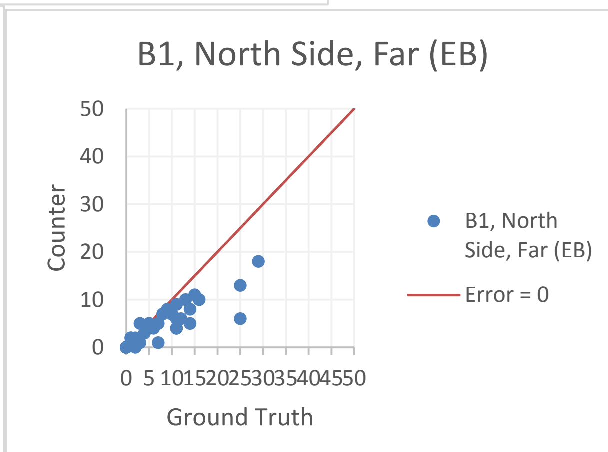

V1, South Side, Total
Counter
Ground Truth
V1, South Side, Total
Error = 0

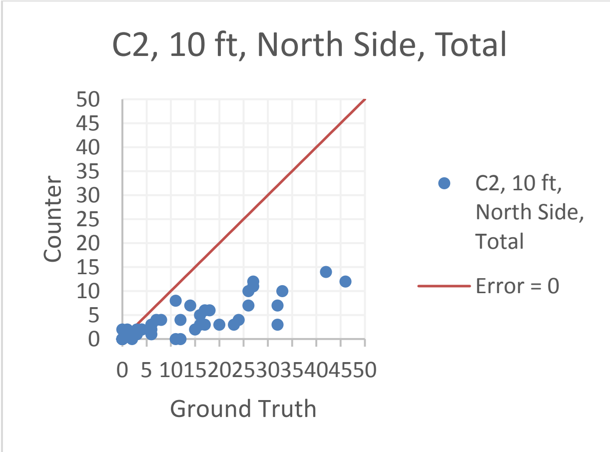

V1, South Side, Near (EB)
Counter
Ground Truth
V1, South Side, Near (EB)
Error = 0

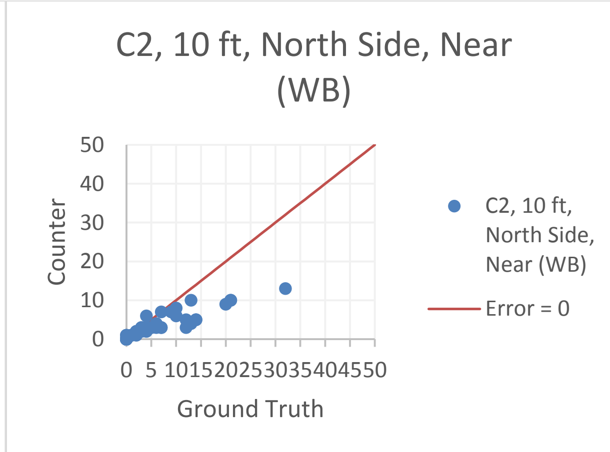

V1, South Side, Far (WB)
50
40
30
20
10
0
Counter
0 5 101520253035404550
Ground Truth
V1, South Side, Far (WB)
Error = 0

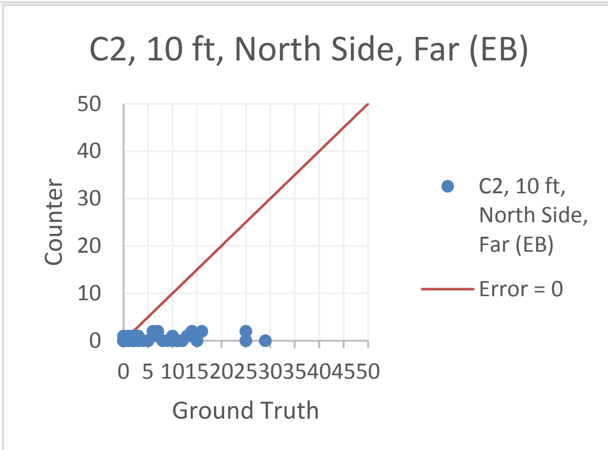

B1, North Side, Total
50
45
40
35
30
25
20
15
10
5
0
Counter
0 5 101520253035404550
Ground Truth
B1, North Side, Total
Error = 0

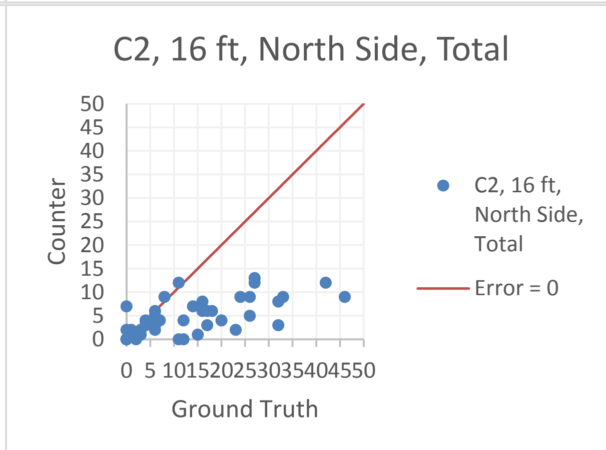

B1, North Side, Near (WB)
50
40
30
20
10
0
Counter
0 5 101520253035404550
Ground Truth
B1, North Side, Near (WB)
Error = 0

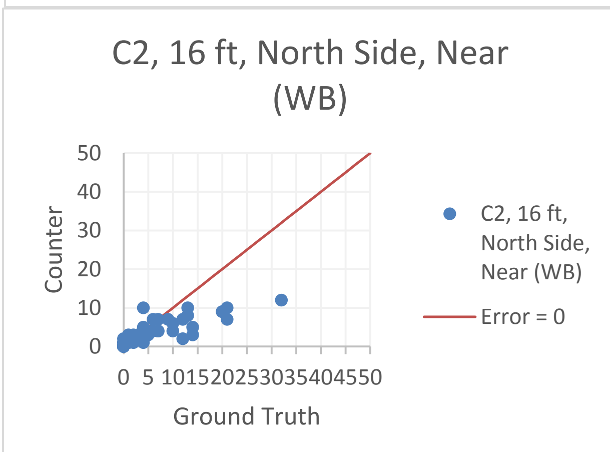

B1, North Side, Far (EB)
50
40
30
20
10
0
Counter
0 5 101520253035404550
Ground Truth
B1, North Side, Far (EB)
Error = 0

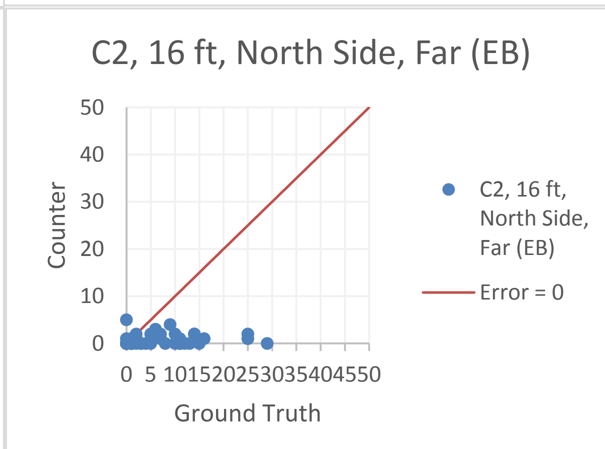

C2, 10 ft, North Side, Total
Counter
Ground Truth
0 5 101520253035404550
50 45 40 35 30 25 20 15 10 5 0
C2, 10 ft, North Side, Total
Error = 0

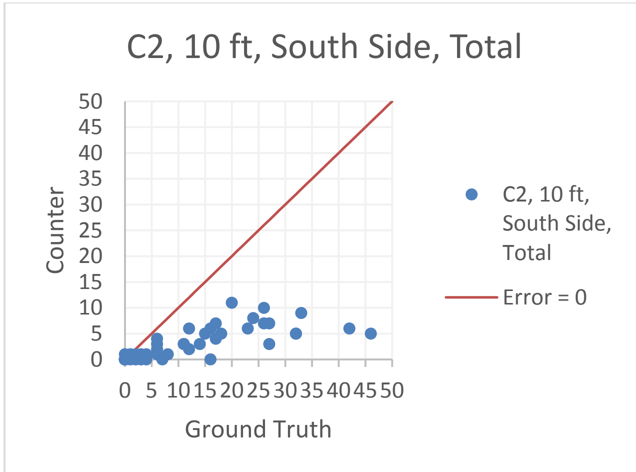

C2, 10 ft, North Side, Near (WB)
Counter
Ground Truth
0 5 101520253035404550
50 40 30 20 10 0
C2, 10 ft, North Side, Near (WB)
Error = 0

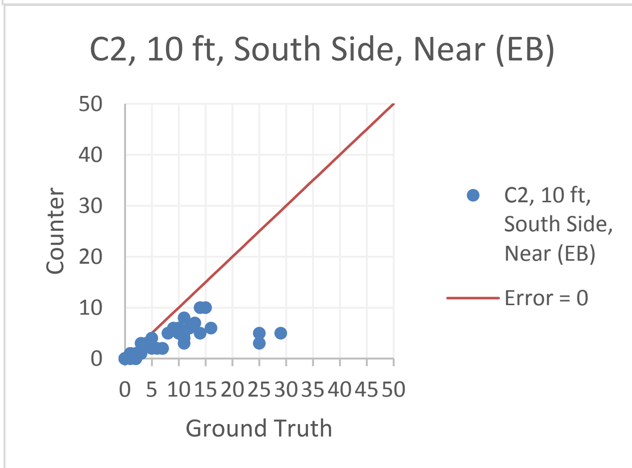

C2, 10 ft, North Side, Far (EB)
Counter
Ground Truth
0 5 101520253035404550
50 40 30 20 10 0
C2, 10 ft, North Side, Far (EB)
Error = 0

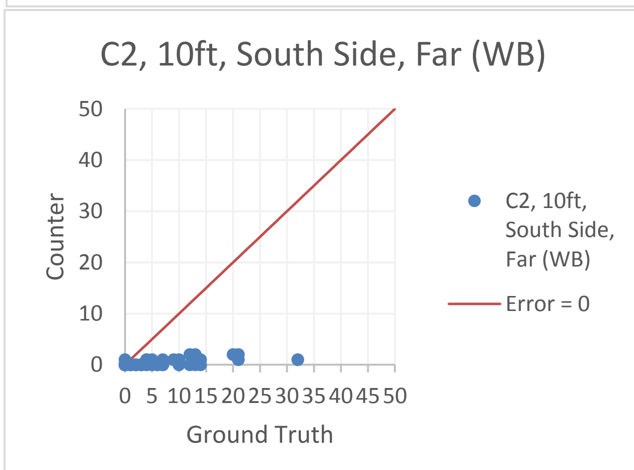

C2, 16 ft, North Side, Total
Counter
Ground Truth
0 5 101520253035404550
50 45 40 35 30 25 20 15 10 5 0
C2, 16 ft, North Side, Total
Error = 0

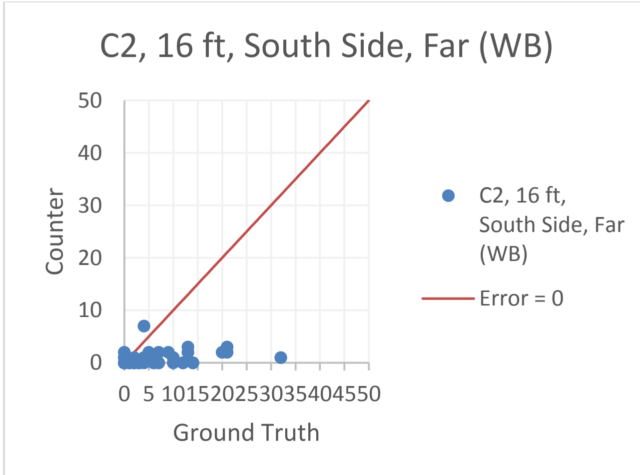

C2, 16 ft, North Side, Near (WB)
Counter
Ground Truth
0 5 101520253035404550
50 40 30 20 10 0
C2, 16 ft, North Side, Near (WB)
Error = 0

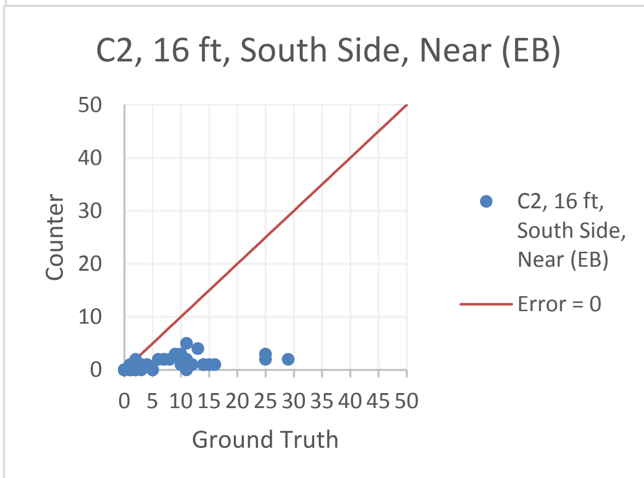

C2, 16 ft, North Side, Far (EB)
Counter
Ground Truth
0 5 101520253035404550
50 40 30 20 10 0
C2, 16 ft, North Side, Far (EB)
Error = 0

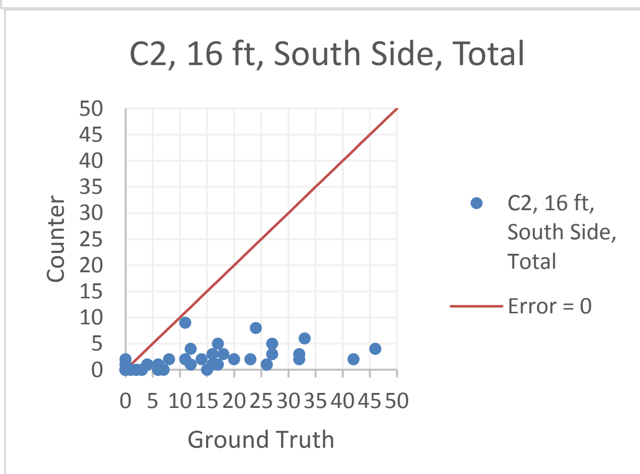

C2, 10 ft, South Side, Total
Counter
Ground Truth
0 5 10 15 20 25 30 35 40 45 50
C2, 10 ft, South Side, Total
Error = 0

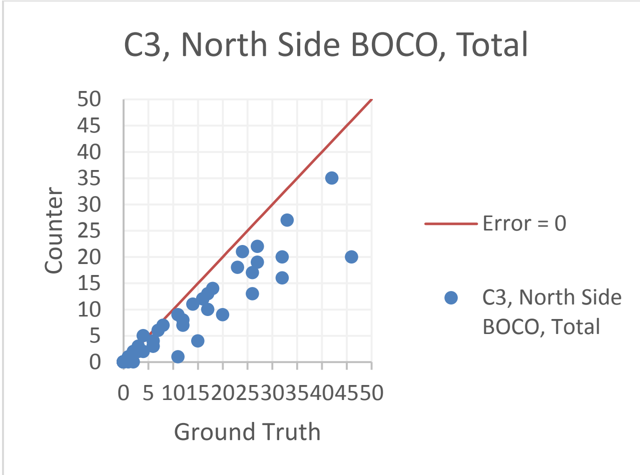

C2, 10 ft, South Side, Near (EB)
Counter
Ground Truth
0 10 20 30 40 50
C2, 10 ft, South Side, Near (EB)
Error = 0

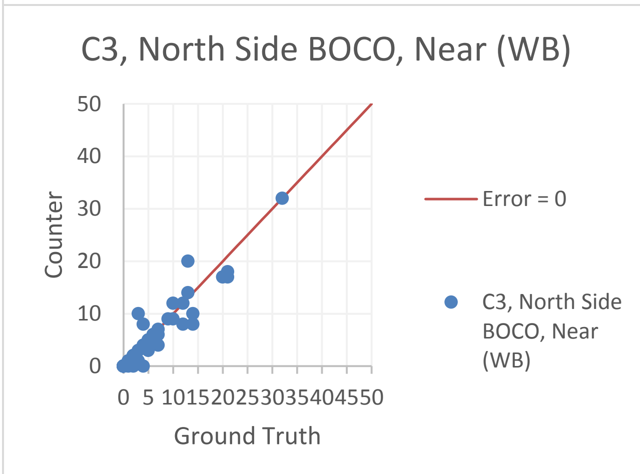

C2, 10ft, South Side, Far (WB)
Counter
Ground Truth
0 10 20 30 40 50
C2, 10ft, South Side, Far (WB)
Error = 0

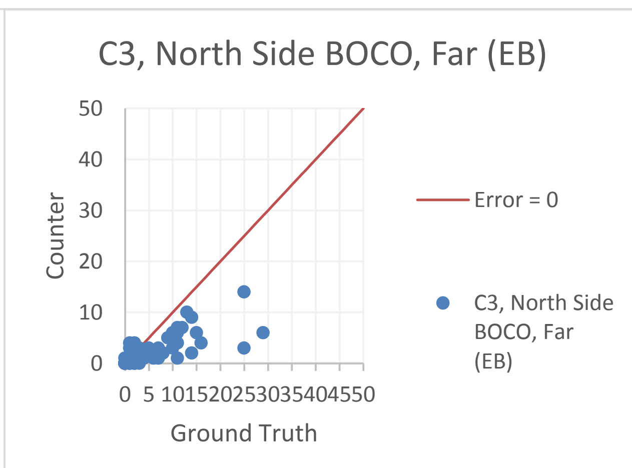

C2, 16 ft, South Side, Far (WB)
Counter
50
40
30
20
10
0
0 5 101520253035404550
Ground Truth
C2, 16 ft, South Side, Far (WB)
Error = 0

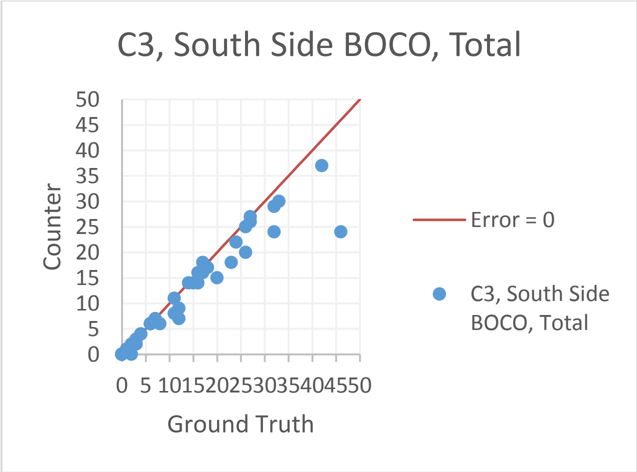

C2, 16 ft, South Side, Near (EB)
Counter
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50
Ground Truth
C2, 16 ft, South Side, Near (EB)
Error = 0

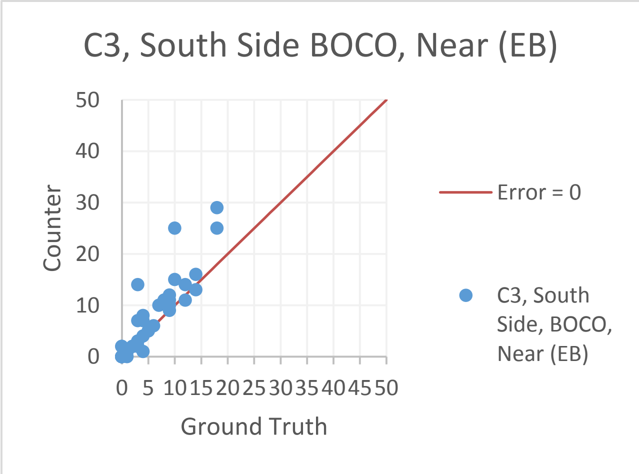

C2, 16 ft, South Side, Total
Counter
50
45
40
35
30
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45 50
Ground Truth
C2, 16 ft, South Side, Total
Error = 0

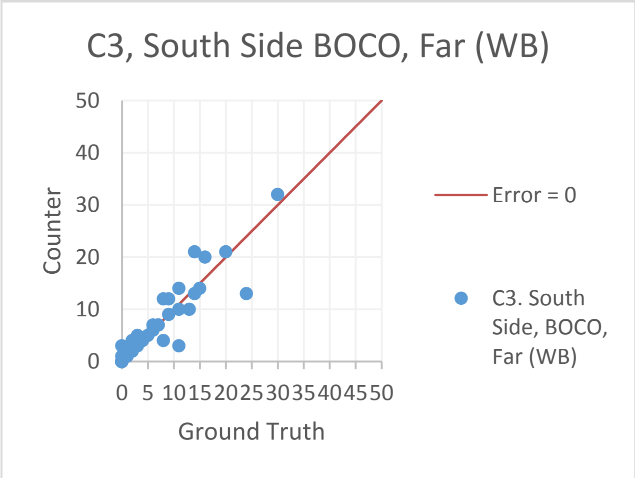

C3, North Side BOCO, Total
Counter
50
45
40
35
30
25
20
15
10
5
0
0 5 101520253035404550
Ground Truth
Error = 0
C3, North Side BOCO, Total

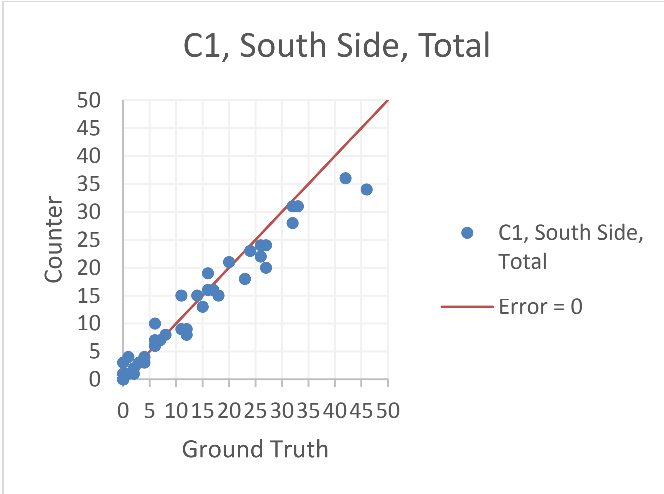

C3, North Side BOCO, Near (WB)
Counter
50
40
30
20
10
0
0 5 101520253035404550
Ground Truth
Error = 0
C3, North Side BOCO, Near (WB)

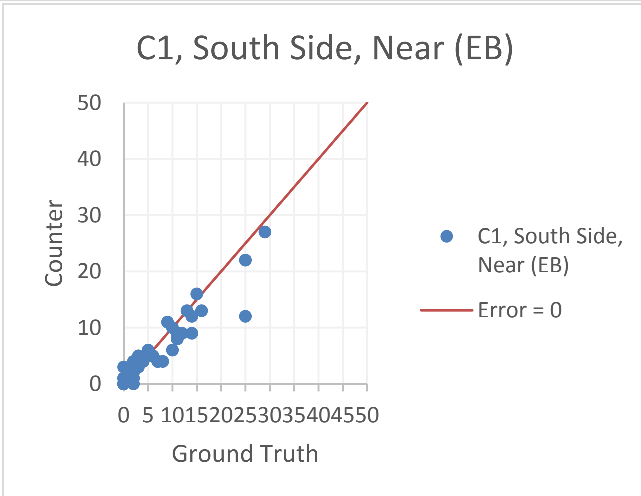

C3, North Side BOCO, Far (EB)
Counter
50
40
30
20
10
0
0 5 101520253035404550
Ground Truth
Error = 0
C3, North Side BOCO, Far (EB)

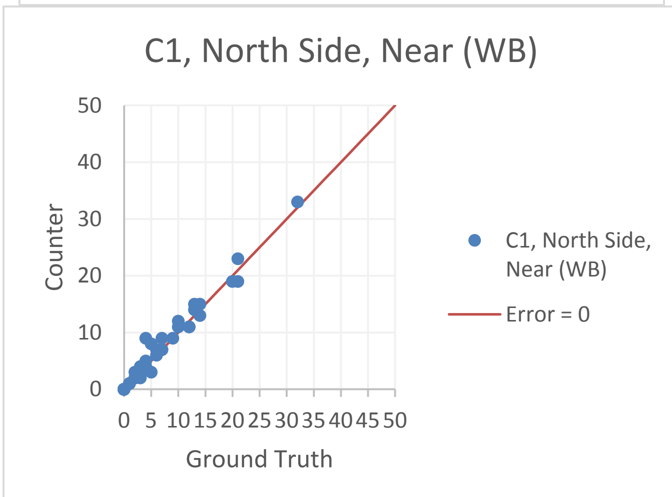

C3, South Side BOCO, Total
Counter
Ground Truth
Error = 0
C3, South Side BOCO, Total

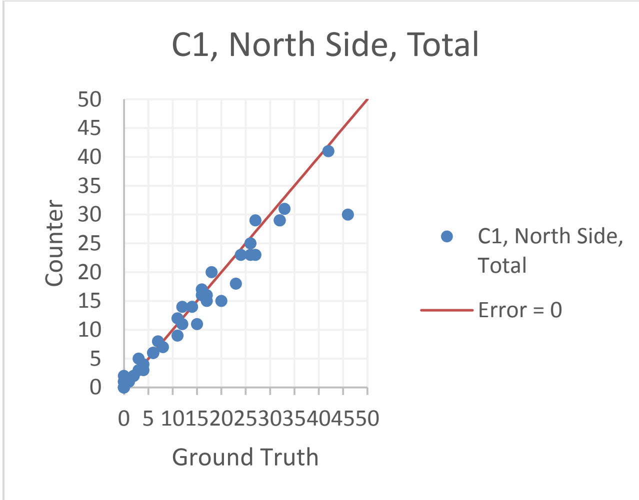

C3, South Side BOCO, Near (EB)
Counter
Ground Truth
Error = 0
C3, South Side, BOCO, Near (EB)

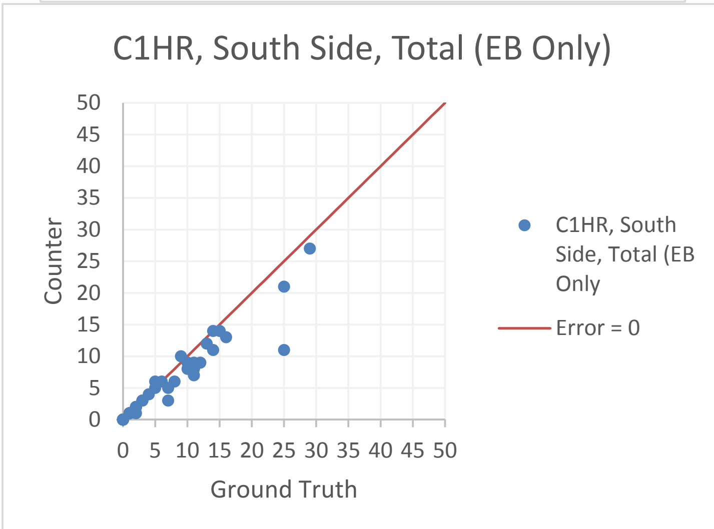

C3, South Side BOCO, Far (WB)
Counter
Ground Truth
Error = 0
C3. South Side, BOCO, Far (WB)


C1, South Side, Total
Counter
Ground Truth
0
5
10
15
20
25
30
35
40
45
50
C1, South Side, Total
Error = 0


C1, South Side, Near (EB)
Counter
Ground Truth
0
10
20
30
40
50
0 5 101520253035404550
C1, South Side, Near (EB)
Error = 0


C1, North Side, Near (WB)
Counter
Ground Truth
0
10
20
30
40
50
0 5 10 15 20 25 30 35 40 45 50
C1, North Side, Near (WB)
Error = 0

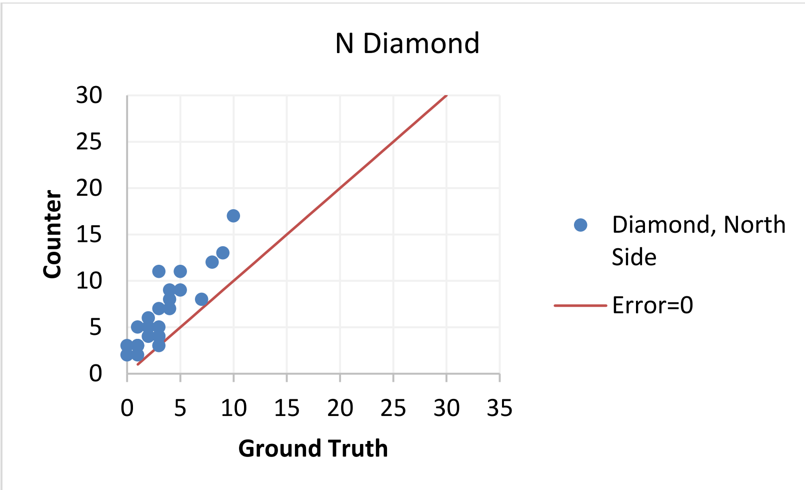

C1, North Side, Total
Counter
50
45
40
35
30
25
20
15
10
5
0
0 5 101520253035404550
Ground Truth
C1, North Side, Total
Error = 0

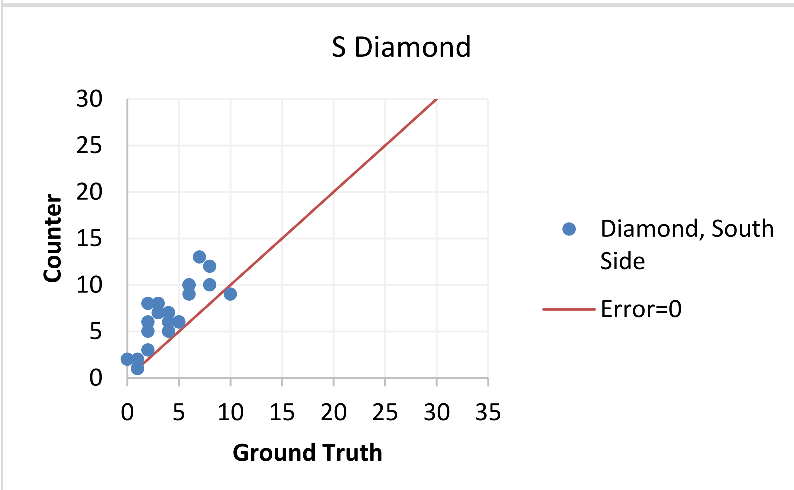

C1HR, South Side, Total (EB Only)
Counter
50
45
40
35
30
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45 50
Ground Truth
C1HR, South Side, Total (EB Only
Error = 0

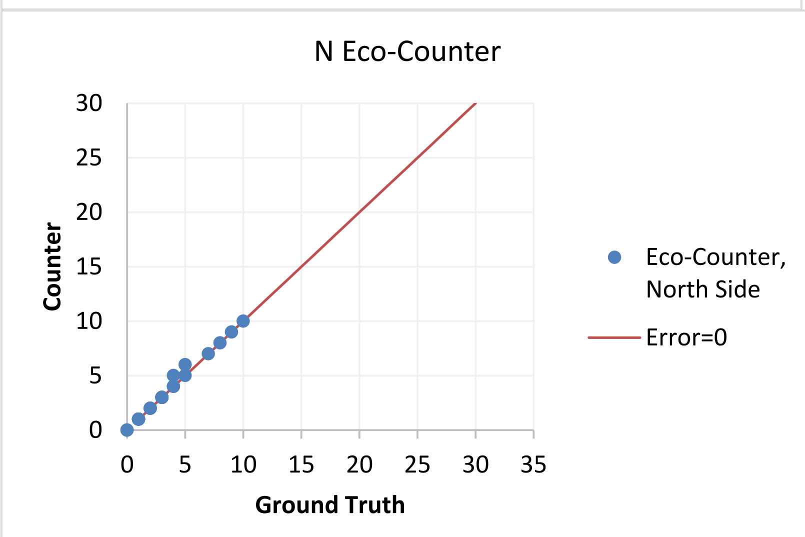
APPENDIX F

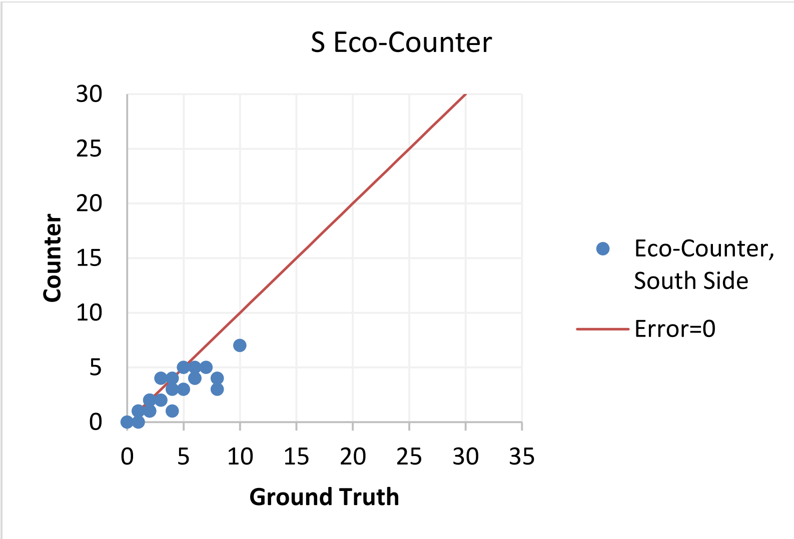
HALL & 99W COUNTER VS. GROUND TRUTH

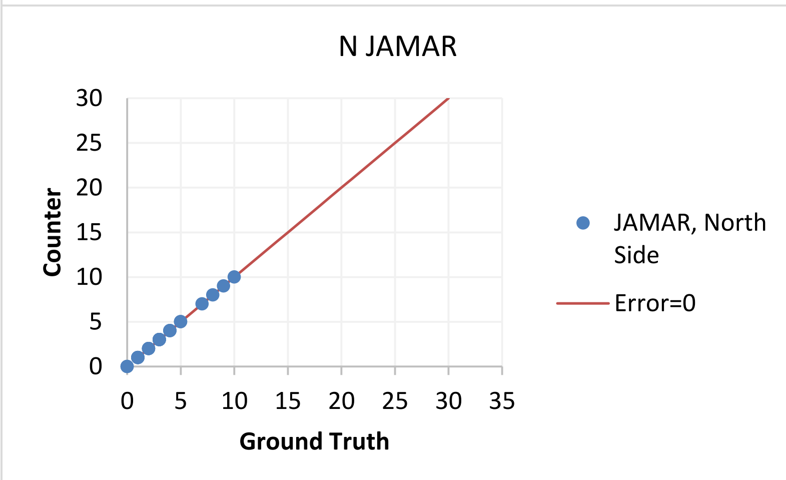
HALL & 99W COUNTER VS. GROUND TRUTH

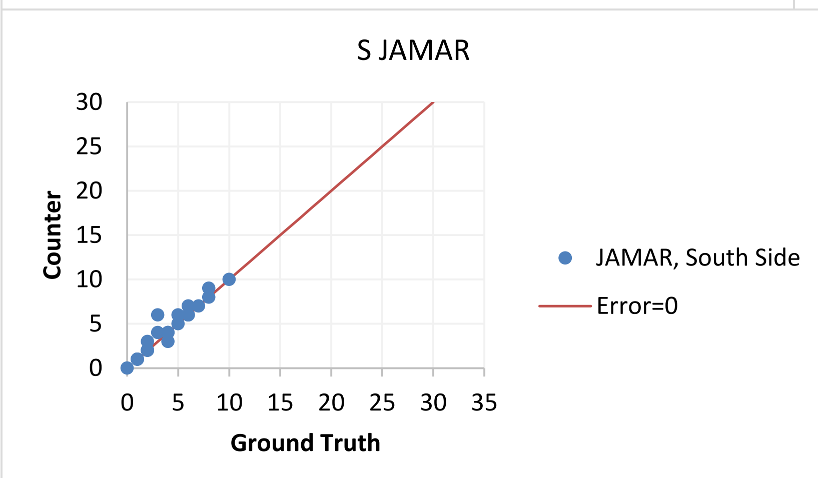


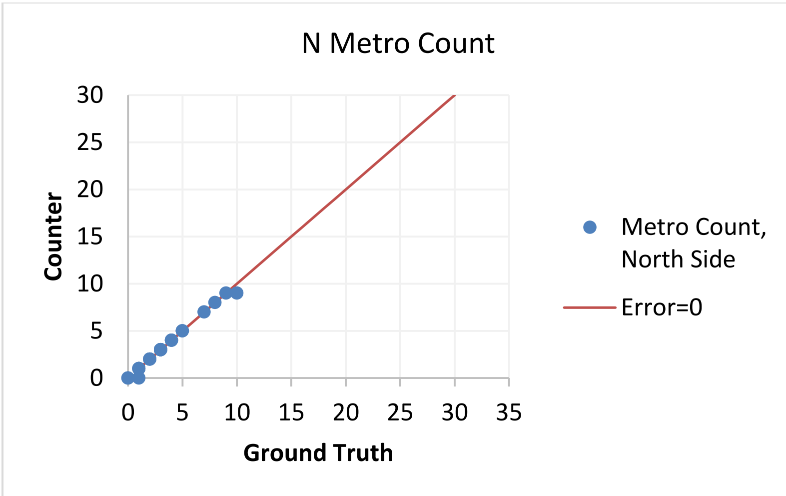


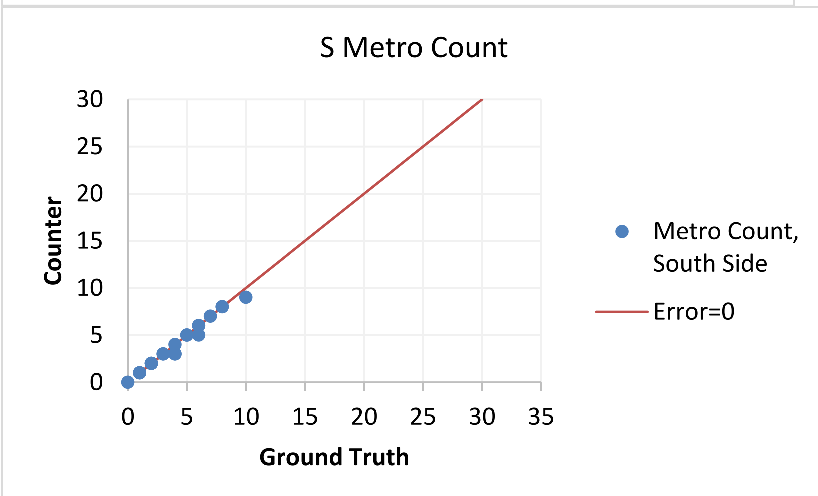


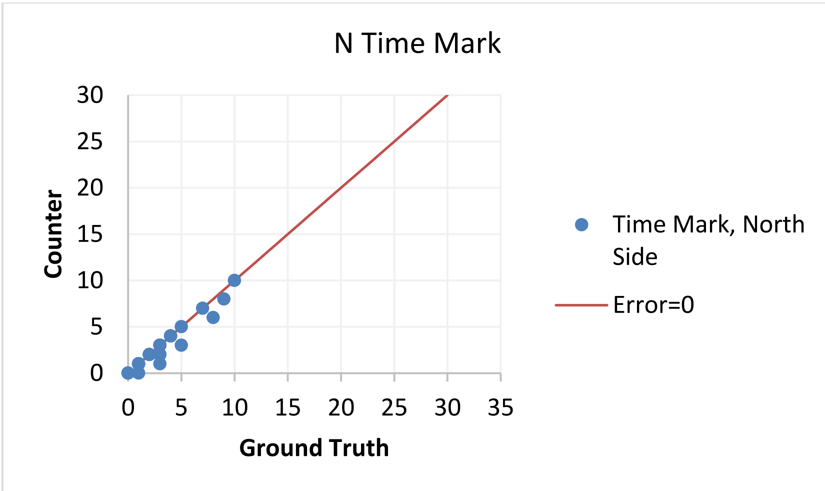

S Eco-Counter
Counter
Ground Truth
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
Eco-Counter, South Side
Error=0

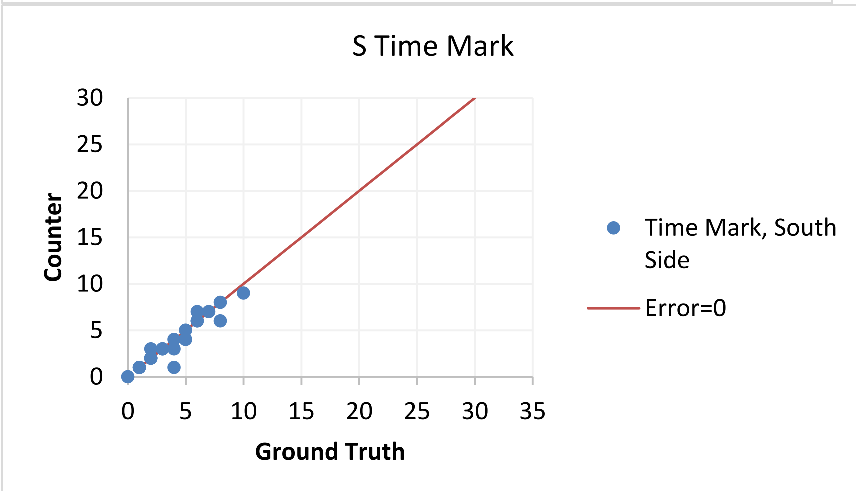

N JAMAR
Counter
Ground Truth
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
JAMAR, North Side
Error=0


S JAMAR
Counter
Ground Truth
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
JAMAR, South Side
Error=0


N Metro Count
Counter
Ground Truth
0
5
10
15
20
25
30
35
Metro Count, North Side
Error=0


S Metro Count
Counter
Ground Truth
0
5
10
15
20
25
30
35
Metro Count, South Side
Error=0


N Time Mark
Counter
Ground Truth
Time Mark, North Side
Error=0


S Time Mark
Counter
Ground Truth
Time Mark, South Side
Error=0

APPENDIX G

GUIDEBOOK – (SEPARATE APPENDIX)