Operating Performance of Passive Infrared Counters Under Different Seasons

by

Nini Johanna Nytepchuk

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University of Manitoba

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ABSTRACT

This research analyzes the operating performance of two commercially available passive infrared counters (PICs) of pedestrians as a function of site, summer, fall and winter seasons in terms of counter sensitivity. Three sites were selected for field analysis in Winnipeg, Canada. Based on a sample of 24,690 people counted by the two PICs from July 2014 to February 2015, this research found that with a 95 percent confidence, Eco-Counter's sensitivity ranged from 73 to 97 percent while TRAFCO's ranged from 57 to 97 percent related to people occlusion. On weekdays, Eco-Counter's absolute error was 16 percent and TRAFCO's was 18 percent. On weekends, Eco-Counter's absolute error was 18 percent and TRAFCO's was 21 percent. In addition to people occlusion, site, seasons, and time of week (weekday and weekend) were found to affect the operating performance of the PICs. Correction factors were also calculated per counter, site, and seasons.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

APD	Average Percentage Deviation
AAPD	Average of the Absolute Percentage Deviation
BG	Bishop Grandin Site
^{o}C	Degrees Celsius
CI	Confidence Interval
CL	Corydon at Lilac Site
CN	Corydon North Site
^{o}F	Fahrenheit
FHWA	Federal Highway Administration
GLM	General Linear Model
IR	Infrared
Km/h	Kilometers per hour
KPI	Key Performance Indicator
N	Sample Size
NBPDP	National Bicycle and Pedestrian Documentation Project
NCHRP	National Cooperative Highway Research Program
PIC	Passive Infrared Counter
Rel. Humidity	Relative Humidity
RPC	Required Pedestrian Count
SPSS	Statistical Package for the Social Sciences
SS	Sum of Squares
Temp.	Temperature
TMG	Traffic Monitoring Guide

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this research was to determine the operating performance of two commercially available passive infrared counters (PIC) for pedestrians as a function of site characteristics, summer, fall and winter seasons in terms of counter sensitivity. The research defines the operating performance of the PICs in terms of counter sensitivity using performance indicators of automated counts and ground truth data. In this research, sensitivity is defined as the ability of a counter to accurately count a pedestrian or other vulnerable road user who passes in front of the counter's viewing range. Passive infrared counters are one of several technologies used to monitor pedestrian traffic volumes. The devices work by using infrared sensors to detect the heat given off by passing users.

The operating performance of these devices was analyzed as a function of summer, fall and winter seasons at three different locations in Winnipeg, Manitoba, Canada.

The PICs analyzed in this research are the: (1) PYRO-Box Sensors, manufactured by Eco-Counter Inc., based in France; and (2) TRAFx Infrared Trail Counter, manufactured by TRAFCO Canada.

1.2 BACKGROUND AND NEED

The procedure for motor vehicle traffic volume counts is well known to transportation agencies, which have developed methods for collecting, managing, summarizing, and distributing motor vehicle traffic volumes (FHWA, 2013). However, procedures are not well developed for pedestrian and bicycle volume data (NCHRP, 2015). The majority of pedestrian data collection is done at a project level after the preliminary selection of a project site. The absence of system-wide pedestrian and bicycle volume data limits the improvement of pedestrian and bicycle facilities and the capacity to develop methods to predict pedestrian and bicycle-related crashes (NCHRP, 2015). Research is therefore needed in order to provide guidance for practitioners regarding existing, new and original technologies and approaches to collect pedestrian traffic volumes.

This research not only analyzed the operating performance of two commercially available passive infrared counters in terms of sensitivity, but also developed correction factors for each counter, site, season, time of week (weekday and weekend), and weather conditions. In addition, this research provides recommendations for future research.

1.3 OBJECTIVES AND SCOPE

The objectives and scope of this research were based on the following questions:

1. Are there any summer, fall and winter conditions that affect the operating performance of these counters?
2. How does the weekday operating performance compare to weekend operating performance of these counters relate to people occlusion?

3. What is the proposed correction factor applied to the people count data for each passive infrared counter tested in this research, based on site, season and weather conditions?
4. What are the main reasons for overcounting or undercounting for each of the passive infrared counters analyzed?

The previous questions were answered by meeting the following specific objectives:

1. Understand the latest developments regarding the two passive infrared pedestrian counters tested in this research. This includes documenting research findings about PIC operating performance as a function of seasonal conditions.
2. Design, develop, and implement a data collection program to record ground truth data in order to identify the main reasons for undercounting and overcounting and their link to seasonal conditions.
3. Identify any changes in counter operating performance on weekdays and weekends, as people traffic volumes and walking behavior, such as people walking side by side or in groups vary per site characteristics.
4. Calculate correction factors that can be applied to each passive infrared counter analyzed based on site, weekday and weekend, and seasonal and weather conditions.
5. Identify future research needs.

This research was conducted in Winnipeg, Manitoba, Canada. The data collection extended over an eight-month period starting in July 2014 and concluding in February of 2015.

1.4 THESIS ORGANIZATION

This thesis is comprises of five chapters. Chapter 2 presents findings from key publications regarding passive infrared counters and pedestrian counting techniques. Passive infrared counter accuracy and the latest pedestrian monitoring techniques are also included in this chapter.

Chapter 3 presents the methodology developed in this research in order to achieve the objectives of the research. The chapter presents: the background for the selection of the technology to be analyzed; a description of the equipment selected and their technical characteristics; the selection of sites for data collection; the design of the data collection system, and the data sampling and data quality assurance process.

Chapter 4 describes the data analysis of the operating performance of the two passive infrared counters tested in this research in terms of counter sensitivity as a function of summer, fall and winter conditions, and on weekdays and weekends. It also presents counter accuracy calculations and correction factors.

Chapter 5 discusses the findings and conclusions of this research and opportunities for future research.

1.5 GLOSSARY OF TERMS

The following terms are used throughout this thesis:

Automated Count: Refers to the people volume counts performed by the passive infrared device.

Counter sensitivity: A measure of performance of passive infrared counters. It refers to the ability of the passive infrared counter to detect and count people that pass in its viewing range.

Datalogger: The electronic device that stores data over time, which is a built-in instrument of the passive infrared counters.

Ground truth data: People traffic volume recorded manually by a person onsite or by performing the counts manually from video recordings. In this research, ground truth data was recorded by a person onsite only. Ground truth data is compared with the automated data from the passive infrared counters in order to evaluate their sensitivity.

Missed Count: When the passive infrared counter does not detect and count the person that passes in its viewing range; consequently, the count is not recorded in the datalogger.

Occlusion: This research defines occlusion as any group of two or more people passing close to each other or side by side in the viewing range of the passive infrared counters. Some examples of occlusion can be from two people walking side by side, a group of 2 or more people walking close to each other, or two people that are walking in opposite directions that happen to cross each other in front of the counter.

People: This research defines people as any person using the sidewalks or recreational paths. As the passive infrared counters are not capable of distinguishing between people walking, on bicycles, wheelchairs, rollerblades or scooters, this definition includes all of them.

Performance Indicator: Also referred to as key performance indicator, KPI, which helps to define and measure progress towards a specific goal. In this research, the performance indicators are represented by the automated counts over ground truth data (counter sensitivity).

Passive Infrared Counter: "Passive infrared counters use a signal transmitter only on one side of the detection area and operate by identifying a changing heat differential in the detection area. If the heat differential and pattern meet pre-defined criteria, then a detection and/or count is registered" (FHWA, 2013).

Valid count: The passive infrared counter device performs a count and records it in the datalogger in the presence of person(s) passing in front of the counter.

2.0 LITERATURE REVIEW

This chapter summarizes the findings from an environmental scan of key publications dealing with passive infrared counters and pedestrian counting techniques. These publications contain methodologies for performing pedestrian and bicycle traffic volume data collection, and accuracy findings about passive infrared counting technology. Bicycle counting literature is considered relevant in the literature review as bicycle and pedestrian traffic monitoring programs are similar in most cases and both fall under traffic monitoring for non-motorized traffic in the Traffic Monitoring Guide (FHWA, 2013).

2.1 PEDESTRIAN TRAFFIC MONITORING PRACTICES

The latest publication of the Traffic Monitoring Guide (TMG) includes information on how to monitor pedestrians, cyclists, and other non-motorized road and trail users. It states that “the monitoring of non-motorized traffic has not been systematic or widespread in the U.S. and, even today, is not nearly as comprehensive as motorized traffic monitoring” (FHWA, 2013). A previous study by Poapst and Montufar (2012) performed an environmental scan with the purpose of understanding the current state of pedestrian traffic monitoring in Canada and the U.S. This study concluded that “there is a significant need for pedestrian traffic data for decision-making purposes, very few jurisdictions in the U.S. and Canada have systematic methods in place to collect this type of data” (Poapst & Montufar, 2012).

While this literature review uses the Traffic Monitoring Guide as the main reference for its pedestrian volume monitoring process, other related publications are also included. These publications are described in this chapter.

According to Griffin, Nordback, Gotschi, Stolz, and Kothuri (2014), volume and spatial variability over continuous count periods are important considerations for site selection. Counting at as many locations as possible helps in determining how pedestrian traffic volumes evolve over time and where the highest volume of pedestrian traffic occurs. Griffin et al. (2014) also describe how differences in pedestrian traffic volume between different facilities, neighborhoods, etc. vary depending on different factors. However, these factors are difficult to identify and quantify, since they are directly related to site characteristics. In large studies, population-based surveys provide representative estimates of active transportation in terms of behavioural patterns. However, in smaller studies this might not be necessary since site characteristics and pedestrian walking patterns can be determined in person by a simple site inspection and through the land use type classification.

Griffin et al. (2014) also state that pedestrian data is exposed to seasonal and regional variations due to weather conditions, and suggest further research to develop adjustment factors and models that make use of local continuous count data, as well as weather and other potential predictors.

Quality assurance is also considered an important factor in pedestrian counting data. Turner and Lasley (2013) discuss the importance of quality assurance principles and their application in pedestrian and cyclist count data. They identified the following three data quality principles: (1) quality assurance starts before the data is collected; (2) the determination of the quality of the data is based on a project purpose; and (3) taking measurements can be quantified by varying quality dimensions.

Turner and Lasley (2013) identify the following challenges associated with data quality:

- The lack of data collection resources has made the process statistically unreliable.
- As pedestrian and bicycle traffic counts have higher variability in time dimensions compared to motorized traffic, it is more difficult to collect statistically representative data.
- As pedestrian and cyclist traffic is considerably lower compared to motorized traffic, a small change or absolute error in the data can result in high percentage changes in trends.
- Automatic counters for pedestrians are still an evolving technology. For this reason, error rates for various technologies and counter configurations are still unknown.

As a result of their work, Turner and Lasley (2013) identified the three following key quality assurance principles:

1) Quality assurance starts before data is collected by:
    - Routine staff training and professional development
    - Effective procedures for equipment procurement
    - Bench testing new field equipment
    - Inspection and acceptance testing of new equipment installations
    - Routine calibration and testing of new equipment
    - Scheduling maintenance activities
    - Considering feedback from data customers
    - Acceptable quality depends on data`s use
    - Measures help to quantify accuracy, validity, completeness, timeliness, coverage and accessibility.
2) Evaluation procedures for analyzing accuracy of the data by controlled evaluation, field evaluation.
3) Procedures for assessing validity by defining criteria that specifies range of acceptable data values and by using automated validity rules with visual or manual review.

Turner and Lasley (2013) recommend the integration of ground truth count verifications through visual reviews of video recordings by trained staff in order to detect data errors that might pass undetected through the automated counting process. Random views of the video recordings will ensure the quality control of the automated data collected. However, these ground truth verifications can also be done by manual observations on site.

2.2 INFRARED COUNTER OPERATING PERFORMANCE

The literature revealed that there have been few field evaluations or analyses of the performance of passive infrared pedestrian counters.

This section focuses on the latest study of passive infrared counting technology under different weather conditions done for the National Cooperative Highway Research Program (NCHRP, 2015). NCHRP (2015) tested a variety of automated counting technologies for collecting pedestrian and bicycle traffic volume data. NCHRP (2015) evaluated the performance of the different pedestrian and bicycle counting technologies under a variety of count settings, different weather and temperature conditions, and different pedestrian volumes and site characteristics in order to determine their accuracy and reliability under different case scenarios.

NCHRP (2015) summarizes the following key findings related to the passive infrared pedestrian counting technology:

- There is no evidence of different temperature ranges affecting the accuracy of the counters. However, the temperatures during the NCHRP research period did not reach below -12 ^{o}C (10 ^{o}F); consequently, no effect was seen of colder temperatures affecting counter accuracy, even at high pedestrian volumes.

- There is no evidence of snow or rain events affecting the counter performance. However, there were limited snow and rain events during the NCHRP research period. The few snow and rain events recorded did not seem to affect the counter performance. The two counters tested in NCHRP (2015) were identified as “Product A” and “Product B” and no specific description about them was provided.
- "One-size-fits-all" correction factors were not recommended for use, but rather product-specific factors.
- Pedestrian occlusion seemed to be the main cause of undercounting issues at sites with high pedestrian traffic volume.
- Accuracy varied between products of the same technology.
- It was recommended that users develop their own local correction factors for their devices whenever possible.
- The accuracy of passive infrared counting technology was found to be site-specific.

2.3 INFRARED COUNTER ACCURACY AND LIMITATIONS

A recent study on passive infrared counting technology, NCHRP (2015), found an absolute error of 20 percent for the two passive infrared brands tested under different site characteristics and weather conditions.

Charreyron, Jackson, and Miranda-Moreno (2013) concluded that the infrared sensors have an undercounting error ranging between 0 and -25 percent. The authors found that counting errors increased when pedestrian volume increases. However, the authors attributed some undercounting or overcounting errors to certain weather conditions without giving further detail. Charreyron et al. (2013) concluded that infrared sensors are the most popular technology used among all available technologies for performing pedestrian counts and the best for counting pedestrians in low to moderate traffic volumes.

Schneider, Patton, Toole, and Rabon (2005) developed a guide for practitioners who are interested in developing or improving a pedestrian and bicycle program in their own community. The authors analyzed TRAFCO passive infrared counters and observed the following limitations of passive infrared counting technology in general:

- It does not distinguish between cyclists, pedestrians, and animals such as deer and raccoons or any other warm-blooded animals that generate body heat, which can be picked up by the sensor.
- Passive infrared data collection raises some reliability concerns. However, Schneider et al. (2005) found these automated counts to be at least 90 percent accurate.
- Pedestrian occlusion seemed to be the main cause of undercounting issues as the device was not able to count people on paths where users

are side by side or pass each other in opposite directions within viewing range of the counter.

- Schneider et al. (2005) proved that aiming the TRAFCO infrared scope at a 45-degree angle to the pathway did not help in maximizing the operating performance of the counters as the TRAFCO user's manual suggested.

2.3 SUMMARY

The following points summarize the literature findings:

- The Traffic Monitoring Guide for Non-Motorized Traffic is the recommended guide to follow for obtaining information about pedestrian counting techniques and guidance for implementation.
- Poapst and Montufar (2012) in their environmental scan of the current state of pedestrian traffic monitoring practices in Canada and U.S. found that "there is a significant need for pedestrian traffic data for decision-making purposes, very few jurisdictions in the U.S. and Canada have systematic methods in place to collect this type of data".
- Quality assurance is considered an important factor in pedestrian traffic data. Turner and Lasley (2013) identified three data quality principles: quality assurance before data collection starts, the determination of the quality based on the project's goals, and taking measurements that can be quantified by varying quality dimensions. Accuracy and validity were recommended as two data quality measures.

- There have been few field evaluations or analyses of the performance of passive infrared counters. The latest field evaluation done by the NCHRP (2015) reports an absolute error of 20 percent.
- Even though some undercounting or overcounting errors are suspected to be attributable to certain weather conditions, NCHRP (2015) did not find evidence of snow or rain events affecting the counter performance.
- Pedestrian occlusion is considered the most significant factor in undercounting issues under high volume pedestrian traffic sites.
- NCHRP (2015) recommended that product-specific correction factors be calculated, as the operating performance between products of the same technology varied as a function of different site-specific characteristics. For this reason, the literature suggested that users develop their own local correction factors for their devices whenever possible.
- Passive infrared counting technology is in a state of continuous evolution.

3.0 RESEARCH METHODOLOGY

This chapter describes the methodology used to compare two infrared counters that are currently used for people counts. This methodology follows the recommendations of the Traffic Monitoring Guide for Non-Motorized Traffic, which "provides basic guidance to improve the state-of-the-practice in non-motorized traffic volume monitoring" (FHWA, 2013). The chapter presents the following: (1) a background for the selection of the technology to be analyzed; (2) a description of the equipment selected and their technical characteristics; (3) the selection of sites for data collection; (4) the design of a data collection system, and (5) the data sampling and quality assurance.

3.1 OVERVIEW OF TECHNOLOGY AND SITE SELECTION

Two types of passive infrared counters were used in this research: PYRO-Box sensor (Eco-Counter) and TRAFx Infrared Trail counter (TRAFCO counters). A total of six counters were installed for testing. Three sites were selected for analyzing counter operating performance. Each site was equipped with one Eco-Counter and one TRAFCO counter. The counters were mounted on the same structure (on an existing pole or a tree) at approximately 1.0 meter above the ground for unbiased comparison purposes. Data collection began in early July of 2014 and ended in February 2015. Two of the three sites are located on Winnipeg's Corydon Avenue, which is classified as a community mixed corridor (City of Winnipeg, 2011). Based on City of Winnipeg (2010), "community mixed corridors serve a main street for one or two neighborhoods which provides for a strong social connection and opportunities for employment intensification over time". The two sites on Corydon Avenue differ in their pedestrian volumes and surrounding land use type.

The third site is located on Bishop Grandin Greenway North of the Seine River and east of St. Anne's Road. Figure 1 shows the three selected sites in Winnipeg. Section 3.3 describes the detailed characteristics of each of the selected sites.

Figure 1: Sites Selected for Field Investigation

3.2 TECHNOLOGY DESCRIPTION

Two passive infrared counters were evaluated in this research: Eco-Counter and TRAFCO. The following presents details about each of these.

3.2.1 TRAFCO Counter

The TRAFCO counter is designed to count traffic such as snowmobiles, cyclists, pedestrians, horseback riders and hikers. The infrared scope can be mounted on a tree. Other than nature and trail environments, TRAFCO counters are also designed to count in busy urban areas. As with any other passive infrared counter, it detects and counts the infrared stamp of warm moving objects.

TRAFCO Canada recommends placing TRAFCO counters inside a locking steel box when they are used in open and busy urban areas in order to reduce vandalism. Figure 2 illustrates the TRAFCO counter mounted on an existing pole in Winnipeg.

Figure 2: TRAFCO Counter inside a Locking Box

Figure 3 shows the additional tools required for placing TRAFCO counters inside a locking box. These tools are not part of the manufacturer's package.

Figure 3: Additional Tools for TRAFCO Counters

Figure 4 illustrates the installation of TRAFCO counters into locking boxes.

Figure 4: Installation of TRAFCO Counters into a Locking Box

Based on TRAFCO LTD. (2015), the following is the recommended list of extra materials needed for the installation of TRAFCO counters in urban areas:

- 1 bag of 1 gram color change silica bags, to keep moisture out of counters.

- 3 metallic boxes.
- 3 Hose clamps to secure counters on post or tree.
- 3 pieces of wire mesh with dimensions of 1.75in x 1.75in or 4.5cm x 4.5 cm each.
- 3 pieces of ½” thick plywood for spacer (2in x 3in; 5cm x 7.6 cm)
- 6 screws to mount infrared scope to plywood spacer.
- Two-part epoxy glue to wire the mesh to the inside of the box to cover the window. The mesh adds protection and it does not interfere with the operation of the counter.
- 3 padlocks to lock the metallic box.

The cost of the extra tools needed to place all three TRAFCO counters into locking boxes was approximately CAD $260. The overall assembly time was about 15 minutes for placing each TRAFCO counter into a locking box.

3.2.2 Eco-Counters

Eco-Counters come ready for installation in urban areas; therefore, preliminary expenses and set up time were not necessary. Figure 5 shows an Eco-Counter as it comes from the manufacturer.

Figure 5: Eco-Counter

Eco-Counter (2012) describes PYRO sensors as a passive infrared pyroelectric technology with high precision lenses that sense a change in temperature when a person passes in the viewing range of the sensor. The sensor is meant to detect two different people with a small space between them. The sensor is self-calibrating and contains two infrared lenses that differentiate the direction of the counts, allowing for bi-directional pedestrian counts. However, since the TRAFCO counter does not execute bi-directional pedestrian counts, only pedestrian volumes were considered in this research.

3.2.3 Technical Characteristic Comparisons

A large component of this research involved familiarization with the two brands of passive infrared counters tested in Winnipeg. In order to ensure proper installation of the counters and maximize counter operating performance, this research followed the Traffic Monitoring Guide for pedestrian monitoring practices and the set up recommendations by TRAFCO Canada and Eco-Counter Inc. Constant communication was maintained with the manufacturers over the length of this research to ensure an understanding of the technology, maximize counter operating performance and receive technical assistance when needed.

Table 1 shows the TRAFCO counter components included in the manufacturer's package.

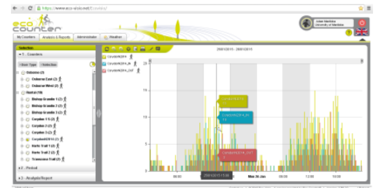
Table 1: TRAFCO Counter Components

TRAFx G3 IR Trail Counter	TRAFx G3 Dock and Field Case*	TRAFx DataNet	Cables	Manual and CD
				
The TRAFx System package contains three TRAFx G3 Infrared Trail Counters. The counter's case is a waterproof field case with a camouflage design to use in trail environments.	TRAFx G3 Dock station allows for configuring and downloading data from counters. It contains two modes: PC Mode: for configuring or downloading data from the counters with a laptop or desktop. Shuttle Mode: for downloading data from counters at site without a computer.	TRAFx DataNet is the software solution to view and manage TRAFx data. This software can be downloaded online and includes a 5 user/5 year plan for it. It is easy to use and suitable with all generations of TRAFx counters.	One TRAFx cable and one USB cable adapter cable.	Printed manual and CD with software needed to download data from Dock.

* Note: Only one TRAFx Dock is needed for serving several counters.
Source: TRAFCO Canada official website at http://www.TRAFx.net/sales.htm

Table 2 shows the Eco-Counter components included in the manufacturer's package.

Table 2: Eco-Counter Components

PYRO Sensor	Eco-link Software	Magnetic Key	Eco-Visio (Online Software)
			
Eco-Counter is designed to avoid vandalism and it can be installed either temporarily or permanently.	Eco-link is the software that allows communication with the counters from a laptop. This software permits: - Retrieving data from the counters, -Transfer data to the Eco-Visio online software, and -Set the settings of the sensors.	The magnetic key activates the bluetooth connection between the counter and a laptop. This bluetooth connection allows for watching the counter's perform live on site with a laptop.	Retrieving data on site is not necessary. Data retrieval can be done through this online software or cloud computing. It also allows for: -Managing all the counting sites available to you at a glance. -Centralizing all the data in a proper way, properly classified and archived. -Analyzing data for any report or analysis form the options available in the software. -Sharing rights management that allows exchanging data with other partners. -Communicating with the counter in order to edit regular reports performed with the counting data.

Source: Eco-Counter official website at www.Eco-Counter.com

Table 3 provides a specification comparison for each analyzed passive infrared counting technology. These specifications are based on information provided by each manufacturer.

Table 3: Technical Specification Comparison per Counter

Manufacturer	**Eco-Counter**[1]	**TRAFCO Canada**[2]
Device	PYRO-Box Sensors	TRAFx IR Trail Counter
Technology	Passive Infrared	Passive Infrared
Sensor Type	Pyroelectric infrared sensor (bi-directional detection)	Thermal infrared micro sensor
Material	Shockproof polyurethane	Gold-plated PCB; silicon conformal protected electronics; electrostatic discharge protection; short circuit protection; RoHS (lead-free).
Waterproof	Yes (seal: IP 66)	Yes (seal not specified)
Mounting Height	80 cm to 1.0 meter	80 cm to 1.0 meter
Operating Temperature	-40°C - +50°C (-40°F to 120°F)	-40°C - +50 °C (-40°F to 120°F)
Power Supply	DC Battery power (type not specified)	TRAFx Counter: 3 alkaline “AA” batteries TRAFx Dock: 3 alkaline “AAA” batteries
Battery Life	10 years	3 years
Dimensions	23 x 10 x 18 cm (9 x 3.9 x 7 in)	11 x 7 x 3 cm (4.3 x2.8 x1.2 in) –without locking box
Detection Range	4m (15ft)	6m (20ft)
Communications	GSM cellular modem network (GPRS)	RS232 serial; 115,000 baud.
Weight	2,6 kg (5.9 lb)	170g (6oz) (without batteries).
Data Storage Capacity	2 year data storage	-14,000 hourly or daily totals => 400 million counts. - 14,000 timestamps. Data and settings are retained even when batteries are removed or die.
Data Recording Intervals	Hourly or 15 min. recording intervals	Hourly, daily totals or timestamps.
Data Retrieval	Automatic daily data transmission to the Eco-Visio platform using the GSM network (GPRS) with the option of data backup. Data collection can also be retrieved by wireless connection on site either by an infra-red or Bluetooth connection using a laptop and the Eco-Link software.	Manually on-site by connecting the TRAFx G3 Dock station directly to the counter.
Data Type	CSV, MS Excel file type	ASCII, TXT file type
Maintenance	No maintenance required	No maintenance required
Preliminary Assembly Time	None	15 minutes per counter when placing counters in locking boxes (as per manufacturer’s recommendation).
Initial Installation Cost	Labour equivalent to amount of hours	Approximately CAD $87 per counter. Additional needs are: 1 gram silica bags, locking box for installation in busy areas to avoid vandalism, Batteries: 3 – “AA” for IR counter and 3 “AAA” for TRAFx G3 Dock station
Commercial Value	USD ($2,000 - $3,000) per counter	USD $2,245 (Package includes 3 counters + docking station, cables, manual and CD, a web-based software solution to view and manage TRAFx data). Any additional counter ranges from USD $445 to USD $545.
Other	Programmable settings include: -Realtime clock -Non intrusive technology -No permission needed for installation -Site counter name -Scope range adjustment *Battery level status from remote access online.	Programmable settings include: -Real time clock -Non intrusive technology -No permission needed for installation -Site counter name -Delay after event -Start date/time *Three color-coded LEDs indicate status of operation. -green light flashes upon detection. *Digital readout of battery voltage level (e.g. 4.2V). *Automatic low battery warning.

1: Source: Pyro Sensor technical characteristics (Eco-Counter, 2012).
2: Source: TRAFx Infrared Trail Counter Instructions (TRAFCO LTD., 2015).

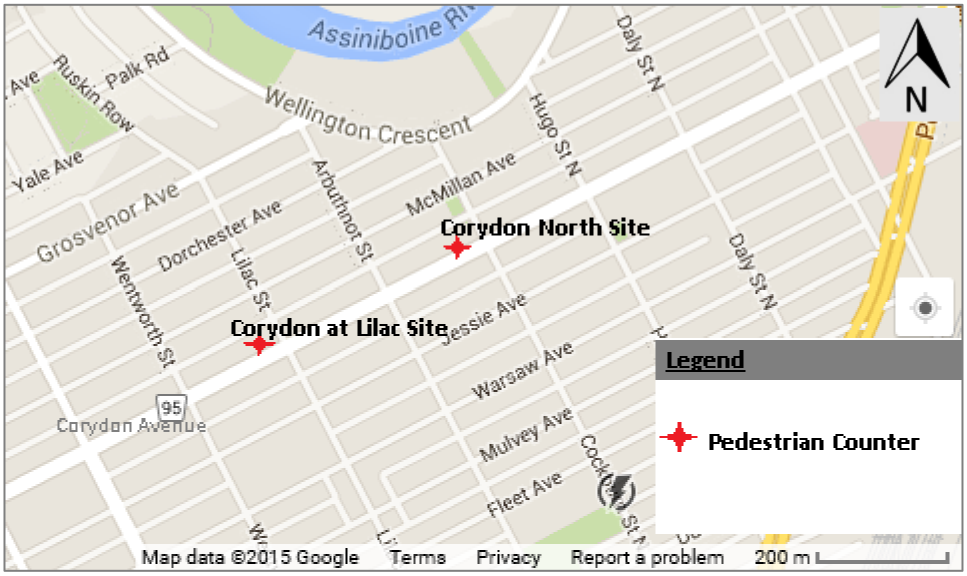
3.3 SELECTION OF SITES FOR DATA COLLECTION

Three sites were selected for data collection in this research based on their different site characteristics and fluctuations in people volume in different seasons. Two of the three sites are located on Corydon Avenue and one on Bishop Grandin Greenway.

Careful field inspection was required to determine whether one site should be selected over another to collect good quality people traffic volume data, and to implement proper installation processes in order to maximize counter sensitivity. It was important to take into consideration people volumes and the land use type (site characteristics) at the moment of selecting counting sites.

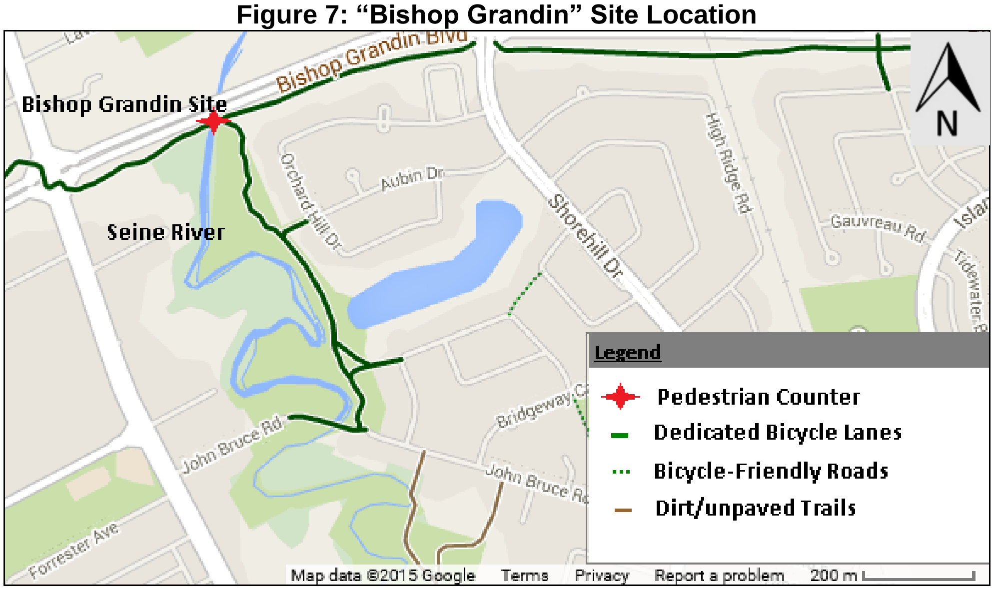
The two sites on Corydon Avenue differ in their people volumes and surrounding land use. Based on field observations, “Corydon at Lilac” (located between Wentworth Street and Lilac Street) is surrounded by less than 85 percent commercial land while the second site, which is referred to as “Corydon North” (located between Cockburn Street and Arbuthnot Street) is surrounded by 100 percent commercial land. Figure 6 illustrates “Corydon North” and “Corydon at Lilac” sites on Corydon Avenue in Winnipeg.

Figure 6: “Corydon North” and “Corydon at Lilac” Sites Location



The third site is located on Bishop Grandin Greenway by the Seine River, east of St. Anne’s Road. Bishop Grandin Greenway serves as a recreational and commuting pathway in Winnipeg. Figure 7 shows the “Bishop Grandin” site.

Figure 7: “Bishop Grandin” Site Location



3.3.1 Corydon North Site

The Corydon North site is located on Corydon Avenue on the north sidewalk between Cockburn Street and Arbuthnot Street. Figure 8 illustrates how the counters were set up at this location. The infrared counters are pointed at a solid wall in order to avoid reflection issues with the windows in front of the counters.

Figure 8: PICs Data Collection Set up at Corydon North Site

The Corydon North site is surrounded by 100 percent commercial land and falls into a Community Mixed Corridor (City of Winnipeg, 2010). People traffic volume is considered high when compared with the people traffic volume at the other two sites, especially in the summer. For instance, in a 15-minute time frame, a maximum of 56 people were observed to walk in front of the Corydon North counters, compared to a maximum of 25 people walking in front of the Corydon at Lilac and Bishop Grandin counters during the same time period.

Corydon North site was selected for the following reasons:

- Good representation of high people volume in all weather and temperature conditions.

- The potential of people traffic during weekdays and weekends.
- A necessity-based people pathway to other business establishments.
- No direct sunlight on infrared scopes that could affect their sensitivity.
- An existing tree available where the counters could be installed.
- Convenient location where manual counts could be performed allowed for a clear view without disturbing normal people behavior.
- Availability of street parking for performing manual counts from vehicle if necessary.
- Business door obstruction was not present in front of the field of view of the infrared scopes.
- No special permission required to install counters.

3.3.2 Corydon at Lilac Site

The Corydon at Lilac site is located on Corydon Avenue on the north sidewalk between Wentworth Street and Lilac Street in front of a business establishment. Figure 9 illustrates how the counters were set up at this location and how the counters were pointed at a solid wall.

Figure 9: PICs Data Collection Set up at Corydon at Lilac Site

The Corydon at Lilac site is surrounded by 85 percent commercial land use and is located in a Community Mixed Corridor (City of Winnipeg, 2010). People traffic volume at the Corydon at Lilac site is considered medium when compared with the traffic volume observed at the other two sites, especially in the winter. For instance, in a 15-minute interval a maximum of 28 people were observed at Corydon at Lilac site, while 48 people were observed at the Corydon North site and an average of 1 person was observed at the Bishop Grandin site in the winter over the same time frame.

The Corydon at Lilac site was selected for the following reasons:

- Good representation of medium people volume regardless of weather and temperature conditions.
- The potential of people traffic during weekdays and weekends.
- A necessity-based people pathway to other business establishments.

- This site was previously selected in past pedestrian related studies.
- Availability of street parking for performing manual counts from vehicle.
- Establishment doors were not obstructing the field of view of the infrared scopes.
- No special permission required to install counters.

3.3.3 Bishop Grandin Site

The Bishop Grandin site is located on the Bishop Grandin pathway by the Seine River near St. Anne's Road. The south of this site is characterized by residential houses. Figure 10 shows how the counters were set up at this location and how the counters are pointed at the ground at the edge of the pathway to limit the viewing range of the infrared scopes.

Figure 10: PICs Data Collection Set up at Bishop Grandin Site

Bishop Grandin Greenway serves as a recreational and commuting pathway for the people that live in the area or its surroundings. This site is heavily affected by weather and temperature conditions as people are less prone to use this pathway when rain, snow, high wind, extreme temperatures are present.

Pedestrian traffic volume at the Bishop Grandin site was considered low when compared to pedestrian traffic volume at the other two sites, especially in the winter season. However, in the summer a high volume of pedestrian traffic was observed, similar to the pedestrian volume observed at the Corydon sites.

3.4 DESIGN OF DATA COLLECTION PROGRAM

The design of the data collection program was done by following the Traffic Monitoring Guide on pedestrian monitoring techniques for passive infrared counting technology. This allows for comparisons of the results obtained in this research with previous and future studies on passive infrared counting technology.

3.4.1 Field Equipment Set up

All six passive infrared counters were installed in May 2014, and started recording continuous data from July 2014 until February 2015. This period included summer, fall and winter seasons. The design of the set up consisted of installing both counters as per the recommendations of the manufacturers, and making sure that they were placed at the same height from the ground. The counters were positioned so that the infrared scope pointed at a wall or solid surface in order to maximize its sensitivity. Figure 11 illustrates the typical set up for the PICs onsite. As each counter comes from different manufacturers, their settings were adjusted to have similar settings whenever these adjustments were possible (i.e., clock time, date, detection distance of the infrared scope, which in general was 3 meters). The recording interval could not be adjusted to be the same in both counters. However, in the data analysis process, TRAFCO's timestamp data were converted to people volume counts of 15-minute intervals. This allowed for equal comparison with Eco-Counter's people volume of 15-minute recording intervals.

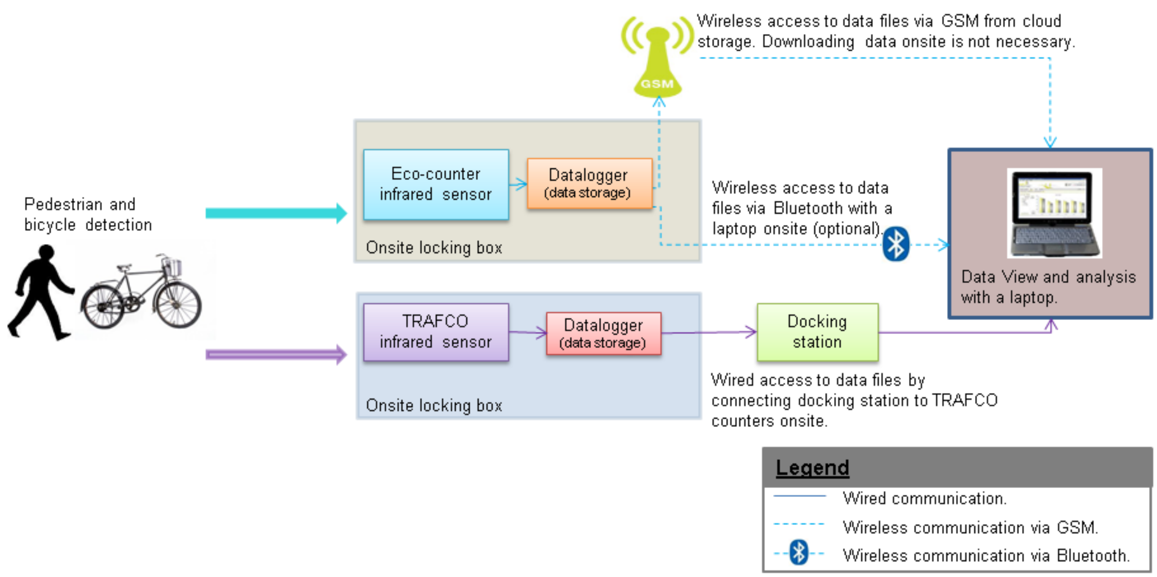
Figure 11: Field Set up of TRAFCO and Eco-Counter

3.4.2 Field Data Collection

The six installed counters continuously counted people traffic volume in front of their viewing range 24 hours a day, seven days a week from summer (July 2014) to winter (February 2015). The ground truth data (i.e., verification counts) were provided by non-continuous manual counts of 17 hours over weekdays and 17 hours over weekends per site over the summer, fall and winter seasons. Each site then had 34 hours of manual counts (weekday and weekends) for a total of 306 hours of non-continuous ground truth data recorded in this research.

Figure 12 illustrates the process used in this research for automated data collection by passive infrared counters. People counts were recorded in the datalogger's internal memory. In the case of TRAFCO counters, people counts were recorded on a time-stamp basis (it recorded the time when a person was detected). In contrast, Eco-Counters recorded people traffic volume as bi-directional counts at 15-minute intervals. From TRAFCO counters, data were downloaded directly from the counter by physically connecting the Dock G3 station. In the case of Eco-Counters, there was an alternative approach to perform data retrieval; instead of retrieving data from the datalogger manually via Bluetooth onsite, data was transferred daily to the cloud storage location via GSM or a cellular network, which was retrieved remotely online at www.eco-visio.net.

Figure 12: PICs Data Collection Schematic



3.4.3 Weather and Temperature Data Collection

Climate data corresponding to conditions at Winnipeg's airport was collected from Environment Canada website (www.ec.gc.ca). The hourly weather data retrieved from Environment Canada's website was limited to climate conditions, temperature, relative humidity and windspeed. In addition, field notes such as date and time, temperature and weather conditions were taken at the moment of performing manual counts.

3.5 DATA SAMPLING AND QUALITY ASSURANCE

In this research, the sample size for ground truth data refers to the number of 15-minute intervals of manual people counts. This provided the resolution for the ground truth comparison review with automated people counts. The main factors used to determine the sample size in this research were feasibility and resources available for performing manual counts over summer, fall and winter seasons. The sample size for ground truth data was found by using the following equation:

$$Sample\ Size = \frac{Z^2(p) * (1 - p)}{C^2}$$

where;

Sample size: number of 15-minute intervals,

"Z" = 1.645 (Z value for a 90 percent confidence), p= the expected prevalence, expressed as decimal value (0.5 for "yes" or "no" case scenario), and C = the chosen marginal error or desired confidence interval in decimal format (0.1 in this research).

The resulting sample size was 17 hours of manual counts over weekdays and 17 hours over weekends, per site and season. Overall, a total of 306 non-continuous hours of people manual counts was performed and used as ground truth data in this research. This resulted in 12,880 people counted by Eco-Counters and 11,810 people counted by TRAFCO counters. Eco-Counter and TRAFCO people counts were analyzed and compared with 15,680 people counted by the ground truth data collection personnel over 306 nonconsecutive hours. Weekday and weekend people volumes were analyzed so the operating performance could be compared under different pedestrian traffic volumes and site characteristics.

After the manual people count was collected from the field, the data was processed before a ground truth comparison review occurred. The processing of the data involved the following steps:

- Downloading data from dataloggers manually from the three TRAFCO counters onsite with the docking station.
- Converting the datalogger data from its original file format to formatted cells in a spreadsheet.
- Organizing the TRAFCO data from time-stamps to 15-minute intervals (for equal comparison purposes with Eco-Counter’s data recording intervals).
- Downloading the Eco-Counter datalogger remotely at www.eco-visio.net.
- Merging TRAFCO and Eco-Counter data into a single spreadsheet per site and season, sorted into ascending records by date and time.
- Downloading weather data associated with the date and time of the PIC

record.

- Saving the combined automated people counts and weather data to individual monthly spreadsheets per site and season.

The record of ground truth data was accomplished by manually performing people counts for the amount of 15-minute intervals determined earlier in the sample size formula. Then, ground truth data was compared with the automated people counts stored in the dataloggers from each of the six counters. As part of the data quality assurance practice, the passive infrared counters were put through several trial tests before the data collection process started.

To ensure that the data was a good representation of summer, fall and winter seasons, the following sampling controls or quality assurance were implemented:

- A manual counting schedule was made in order to monitor automated people counts. These manual counts were done over 2-hour long shifts to avoid fatigue for the person performing the counts. This followed the recommendations made by the Traffic Monitoring Guide for Non-Motorized Traffic (FHWA, 2013).
- In winter, the manual counting schedule was carefully made to test the counters under temperatures below -12 °C. Manual counts also included rainy, sunny and snowy weather conditions.
- In summer, the manual counting schedule was also carefully made in order to include hot temperatures (>25 °C) whenever possible, and when weather conditions were sunny, rainy and cloudy. The idea behind testing

the counters in different weather and temperature conditions was to find concrete evidence of how these conditions affected counter operating performance.

- Weekday and weekend data collection was done in order to analyze possible effects of different people walking behavior and people traffic volumes on counter operating performance at different sites, and in seasonal and weather conditions.
- The hours selected for recording ground truth data were chosen when high people volumes were present. This was achieved by graphically observing the peak of people volume patterns of the continuous automated data at each site. The availability of data collection personnel was also a factor influencing the hours when manual counts were performed. Based on the presence of peak hours at each site, ground truth data was recorded over nonconsecutive hours until reaching the hours specified by the sample size formula used in this research.
- Field notes taken by the ground truth data collection personnel were necessary for this research. The following people walking behaviors were recorded: when people and bicycles passed side by side, when people were walking in groups, and when people were walking on opposite directions and crossed each other in the viewing range of the counters. Abnormal events seen onsite that affected the automated people counts were removed from the data analysis (i.e., a crew of people planting flowers or watering flowers in front of the counter, a snowplow passing by,

etc.).

- The onsite data download process from the TRAFCO counters was performed once a week in order to avoid the counter running out of memory. This was reflected in the need of having a vehicle to move from site to site. This process took approximately one hour each time.
- Additionally, a vehicle was required to perform manual counts during the winter season when it was not possible to do it from inside a building.

4.0 DATA ANALYSIS

4.1 ANALYSIS BACKGROUND

The operating performance of the two passive infrared counters was determined in terms of sensitivity by using missed counts and ground truth data as performance indicators. For a count to be defined as a required people count (RPC), the following criteria had to be met:

- A person(s) had to be present within the viewing range of the counter
- The same person(s) had to enter the viewing range of the counter
- The same person(s) had to pass or cross the viewing range of the counters. In this case, only total counts were considered; consequently, no discrimination by direction was made.

For this research, a missed count was defined as a case where a PIC failed to record a count even though all three previous criteria for a RPC were fulfilled. Using this definition, PIC sensitivity refers to the ability of the PIC to count a person that passes in its viewing range:

$$PIC\ Sensitivity = \left({}^{Automated\ people\ count}\!\big/_{Manual\ people\ count} \right)$$

Sensitivity helps to understand whether the PIC is capable of detecting and counting people that pass in its viewing range. For instance, a PIC sensitivity of

100 percent means that all the people that passed in front of the counter were detected and counted.

The analysis presented in the following sections pertains to summer, fall and winter data. Once all the automated manual people counts were collected from all three sites, the data was divided into weekdays and weekends. The purpose of collecting data on weekdays and weekends was to account for possible changes in counter operating performance attributed to people's walking behaviors. For example, people walking side by side or in groups. Accuracy and correction factors were also calculated per site, season, weekdays and weekends. These are addressed later in the chapter.

This section discusses counter sensitivity per site and season. Details about the analysis for each site and season are included in Appendix A.

4.2 OVERALL COUNTER SENSITIVITY

Overall sensitivity results for each PIC were calculated from the total automated counts and the total manual counts recorded onsite. The following three sections present the sensitivity rates by PIC with 95 percent confidence intervals (CI) for the summer, fall and winter seasons. The 95 percent confidence limits were calculated using the following formula:

$$PIC\ Sensivity \pm 1.96 \sqrt{\frac{PIC\ Sensitivity * (1 - PIC\ Sensitivity)}{sample\ size\ n}}$$

PIC Sensitivity refers to the population proportion (p) in a confidence interval formula and sample size n to the number of 15-minute intervals in a manual count record.

4.2.1 Counter Sensitivity in Summer

The sensitivity rates by PIC and per time of week (weekday and weekend) with 95 percent confidence rates are illustrated for the research sites in Table 4 for the summer season.

Table 4: Overall Counter Sensitivity per Site in Summer

Site Name	Recording Period	Total Manual Count	Sensitivity (%) Eco-Counter	Sensitivity (%) TRAFCO
Corydon North	Weekday*	2,112	80 ± 9	72 ± 10
	Weekend	1,516	76 ± 10	54 ± 12
	Total	**3,628**	**78 ± 10**	**63 ± 11**
Corydon at Lilac	Weekday*	1,012	67 ± 10	59 ± 11
	Weekend	904	73 ± 11	68 ± 11
	Total	**1,916**	**70 ± 11**	**64 ± 11**
Bishop Grandin	Weekday*	631	95 ± 5+	88 ± 7
	Weekend	700	94 ± 6+	81 ± 10
	Total	**1,331**	**95 ± 6+**	**85 ± 9**

Ground truth refers to the manual people counts by the data collection personnel.
*Weekday refers to Monday, Tuesday, Wednesday, Thursday and Friday.
+The $n(1-p)\geq10$ acceptance criteria for the calculation of the CI population proportion was not met, but the $np\geq10$ was. Where; n is the # of 15-minutes intervals in a data record and p refers to the population proportion (See Appendix A).

From Table 4 it can be seen that Eco-Counter has the highest overall sensitivity in summer at 95 ± 6 at Bishop Grandin site. TRAFCO had the lowest sensitivity at 54 ± 12 percent at Corydon North site. One of the acceptance criteria required for applying the confidence interval for a population proportion formula was not met. For this reason, the upper limit of the confidence interval at Bishop Grandin site exceeded 100 percent. Statistically, if one of the two criteria is not met for the calculation of the confidence interval for a population proportion, the sample does not have a normal distribution and there is not a strong certainty of its actual population proportion rate.

In summer, weekday and weekend PIC performance was found to be different depending on the site where the counters were installed. As described in Appendix A, TRAFCO's people counts were always lower than the people counts by Eco-Counters when compared with ground truth data. Summer field observations showed that under people occlusion, TRAFCO had 6 to 15 percent lower sensitivity than Eco-Counter with people occlusion; consequently, it had 6 to 15 percent lower performance than Eco-Counter. For instance, Corydon North had more people occlusion during weekends than weekdays (Corydon North site is surrounded by 100 percent commercial land and it was found to be a highly popular area even at late hours at night for both weekdays and weekends), Bishop Grandin site had a small difference between weekday and weekend in terms of pedestrian occlusion during the summer, even though this site is on a commuting and recreational pathway. On the other hand, Corydon at Lilac site had more people occlusion on weekdays than weekends (Corydon at Lilac site is surrounded by 85 percent commercial land with lower people volume and occlusion observed during weekends in summer).

4.2.2 Counter Sensitivity in Fall

The sensitivity rates by PIC and per time of week (weekday and weekend) with 95 percent confidence limits are illustrated for the research sites in Table 5 for the fall season.

Table 5: Overall Counter Sensitivity per Site in Fall

Site Name	Recording Period	Total Manual Count	Sensitivity (%) Eco-Counter	Sensitivity (%) TRAFCO
Corydon North	Weekday*	1,142	85 ± 8	80 ± 10
	Weekend	1,466	82 ± 9	73 ± 10
	Total	**2,608**	**84 ± 9**	**77 ± 10**
Corydon at Lilac	Weekday*	900	83 ± 9	77 ± 10
	Weekend	865	85 ± 8	81 ± 9
	Total	**1,765**	**84 ± 9**	**79 ± 10**
Bishop Grandin	Weekday*	813	97 ± 4+	84 ± 8
	Weekend	839	95 ± 6+	84 ± 9
	Total	**1,652**	**96 ± 5+**	**84 ± 9**

Ground truth refers to the manual people counts by the data collection personnel.
*Weekday refers to Monday, Tuesday, Wednesday, Thursday and Friday.
+The n(1-p)≥10 acceptance criteria for the calculation of the CI population proportion was not met, but the np≥10 was. Where; n is the # of 15-minutes intervals in a data record and p refers to the population proportion (See Appendix A).

From Table 5 it can be seen that Eco-Counter has the highest overall sensitivity in fall at 97 ± 4 percent at Bishop Grandin site. TRAFCO had the lowest sensitivity at 73 ± 10 percent at Corydon North site. One of the acceptance criteria required for applying the confidence interval for a population proportion formula was not met. For this reason, the upper limit of the confidence interval at Bishop Grandin site exceeded 100 percent. Statistically, if one of the two criteria is not met for the calculation of the confidence interval for a population proportion, the sample does not have a normal distribution and there is not a strong certainty of its actual population proportion rate.

this research observed an episode at the Corydon at Lilac site in the fall season.

In the fall season, field observations showed that Eco-Counter had overcounting and undercounting issues during two non-consecutive 15-minute intervals when heavy rain was observed by the ground truth data collection personnel. Occlusion was not observed when the overcounting issue was recorded. While there were two people walking side by side on two occasions during the undercounting episode, this did not fully explain the undercounting issue. Even though these episodes were found, it was uncertain whether or not to attribute the undercounting and overcounting episodes to the heavy rain event observed, as the Eco-Counters presented a delay in their built-in clock of 5 to 6 minutes over time. This issue was fixed by the end of the fall by resetting the counter's clock manually and on a regular basis afterwards. The manufacturers had fixed this issue in the newer versions of Eco-Counter sensors. In summary, more analysis of Eco-Counter's operating performance under heavy rain conditions is recommended to verify this finding.

4.2.3 Counter Sensitivity in Winter

The sensitivity rates by PIC and per time of week (weekday and weekend) with 95 percent confidence limits are illustrated for the research sites in Table 6 for the winter season.

Table 6: Overall Counter Sensitivity per Site in Winter

Site Name	Recording Period	Total Manual Count	Sensitivity (%) Eco-Counter	Sensitivity (%) TRAFCO
Corydon North	Weekday*	823	82 ± 10	87 ± 8
	Weekend	641	68 ± 14	83 ± 11+
	Total	**1,464**	**75 ± 12**	**85 ± 10**
Corydon at Lilac	Weekday*	634	83 ± 9	85 ± 9
	Weekend	533	82 ± 9	81 ± 9
	Total	**1,167**	**83 ± 9**	**83 ± 9**
Bishop Grandin	Weekday*	47	100 ± 0	100 ± 0
	Weekend	102	105 ± +	100 ± 0
	Total	**149**	**103 ± +**	**100 ± 0**

*Weekday refers to Monday, Tuesday, Wednesday, Thursday and Friday.
+The n(1-p)≥10 acceptance criteria for the calculation of the CI population proportion was not met, but the np≥10 was. Where; n is the # of 15-minutes intervals in a data record and p refers to the population proportion (See Appendix A).

Table 6 illustrates that during the winter season, TRAFCO performed better overall than Eco-Counter. Even though both counters had 100 percent sensitivity at Bishop Grandin site, TRAFCO had an average of 10 percent better performance than Eco-Counter at Corydon North site and 1 to 2 percent better performance than Eco-Counter at Corydon at Lilac site for both weekdays and weekends. Eco-Counter had the lowest sensitivity at 68 ± 14 percent at Corydon North site during weekends. Other than occlusion being significantly less in winter when compared to summer and fall seasons, there were no other obvious events seen onsite explaining TRAFCO'S better performance. In addition, Eco-Counter had overcounting issues at the Bishop Grandin site on weekends. Field observations did not explain this event. Consequently, there is no specific evidence explaining why Eco-Counter overcounted at this site. For example, a total overcount of 5 people was observed at Bishop Grandin during weekends by Eco-Counter. This resulted in a high overcounting error as Bishop Grandin had an average of 2 people passing in front of counter's viewing range per hour.

The influence of seasonal and weather conditions on counters operating performance is described in section 4.4.

4.3 ACCURACY CALCULATIONS

In order to have a better understanding of the performance of the passive infrared counters analyzed in this research, the following accuracy calculations were performed: (1) The average percentage deviation (APD) and (2) the average of the absolute percentage deviation (AAPD). These measures are described as follows:

Average Percentage Deviation (APD)

Based on the NCHRP (2015), the Average Percentage Deviation (APD) is defined as "the overall divergence from perfect accuracy across all data collected". This measure gives a perception of how much each counter is undercounting or overcounting in a specific time frame (i.e., 15-minute intervals, hourly, daily, monthly and yearly time frame). APD is calculated as follows:

$$APD = \frac{1}{n}\sum_{t=1}^{n} \frac{A_t - M_t}{M_t}$$

A_t represents the automated counts for a time period t, M_t the manual counts or ground truth data in a period t, and n is the number of periods analyzed.

The average percentage deviation does not give detailed insight on the total accuracy of the counters as overcount and undercount events can cancel each other out in the different time periods calculated.

Average of the Absolute Percentage Deviation (AAPD)

Based on the NCHRP (2015), the AAPD solves the undercount/overcount cancellation problem with the average percentage deviation. This value represents the total accuracy because as it takes the absolute values, undercounts and overcounts of the same magnitude no longer cancel each other out. However, this measure can bias the results at low volume sites. For instance, in this research the Bishop Grandin site had an hourly pedestrian volume of 2 pedestrians in winter (see Appendix B). An overcount of 1 person corresponds to a 100 percent overcount, while if the same overcount of 1 person is observed in a volume of 100 pedestrians for the same time frame, this corresponds only to a 1 percent overcount. The AAPD is calculated as follows:

$$AAPD = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - M_t}{M_t}\right|$$

The APD and AAPD estimated values are presented in Table 7 with the results of the accuracy of both counters analyzed in this research. These values give a general idea of the accuracy level of each counter at different sites under different seasons. However, caution is suggested when applying these results as each counter performed differently under the same site characteristics and seasonal conditions.

Table 7 shows higher counter accuracy in winter than in summer. As mentioned previously, people traffic volume decreased considerably in the winter season. Because of the difference in pedestrian volume observed at all sites, it is important to note that the APD and AAPD values shown in Table 7 are relative values. The average hourly people volume per site gives a sense of magnitude when comparing counter accuracy between different sites and seasons.

The difference in the counter's operating performance on weekdays and weekends was attributed to more pedestrian occlusion observed on weekends, even in cases where people counts were not necessarily higher than weekdays. Field observations showed that people had the tendency to walk side-by-side or in groups more on weekends than weekdays.

Table 7: Accuracy Calculations per Site, Season and Device

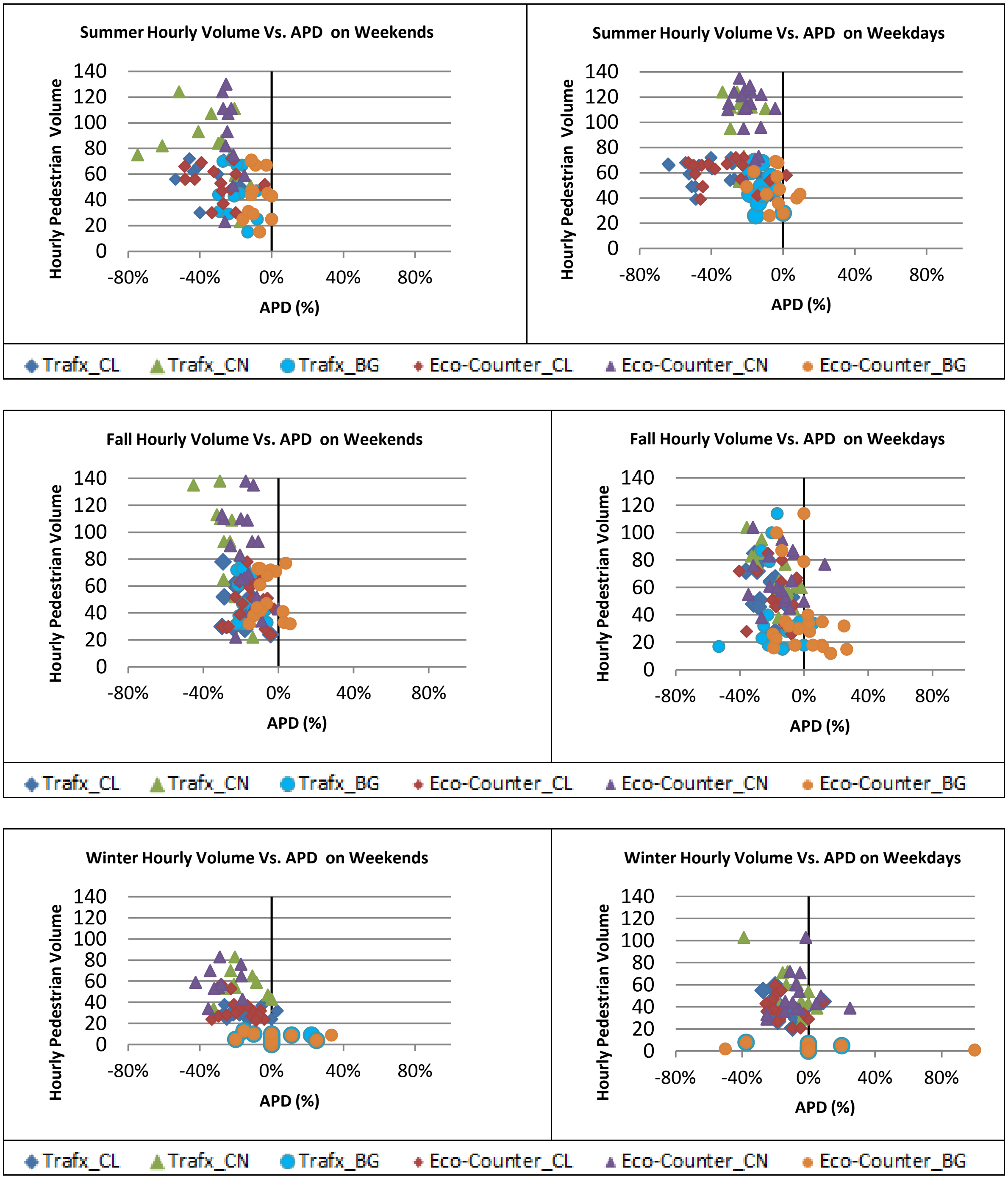
Season	Site	Device	APD (%) Weekday	AAPD (%) Weekday	Average Hourly Volume Weekday	APD (%) Weekend	AAPD (%) Weekend	Average Hourly Volume Weekend
Summer	Corydon North	Eco-Counter	-20	20	108	-23	23	95
		TRAFCO	-27	27		-42	42	
	Corydon at Lilac	Eco-Counter	-33	33	60	-27	27	53
		TRAFCO	-40	40		-31	31	
	Bishop Grandin	Eco-Counter	-4	4	47	-8	8	45
		TRAFCO	-12	12		-18	18	
	Total Average	**Eco-Counter**	**-19**	**19**	**-**	**-19**	**19**	**-**
		TRAFCO	**-26**	**26**	**-**	**-30**	**30**	**-**
Fall	Corydon North	Eco-Counter	-15	16	67	-14	25	81
		TRAFCO	-18	18		-25	27	
	Corydon at Lilac	Eco-Counter	-17	17	56	-16	16	48
		TRAFCO	-22	22		-19	19	
	Bishop Grandin	Eco-Counter	0	11	39	-5	8	54
		TRAFCO	-14	17		-16	16	
	Total Average	**Eco-Counter**	**-11**	**15**	**-**	**-12**	**16**	**-**
		TRAFCO	**-18**	**19**	**-**	**-20**	**21**	**-**
Winter	Corydon North	Eco-Counter	-6	11	51	-34	34	58
		TRAFCO	-9	10		-17	17	
	Corydon at Lilac	Eco-Counter	-14	16	38	-16	16	32
		TRAFCO	-13	14		-16	16	
	Bishop Grandin	Eco-Counter	2	15	3	4	9	6
		TRAFCO	-1	4		1	6	
	Total Average	**Eco-Counter**	**-6**	**14**	**-**	**-15**	**20**	**-**
		TRAFCO	**-8**	**9**	**-**	**-11**	**13**	**-**

APD: average percent deviation (undercounting error). Negative sign represents undercounting by PIC.
AAPD: average of the absolute percent deviation (absolute error).
Average Hourly Volume: Hourly average pedestrian volume based on manual counts.

Figure 13 illustrates the average percentage deviation (APD) values per season that were presented in Table 7.

Figure 14 illustrates the absolute average percentage deviation (AAPD) values per season that were presented in Table 7. Figure 14 shows the total accuracy of each counter at different sites and in different seasonal conditions.

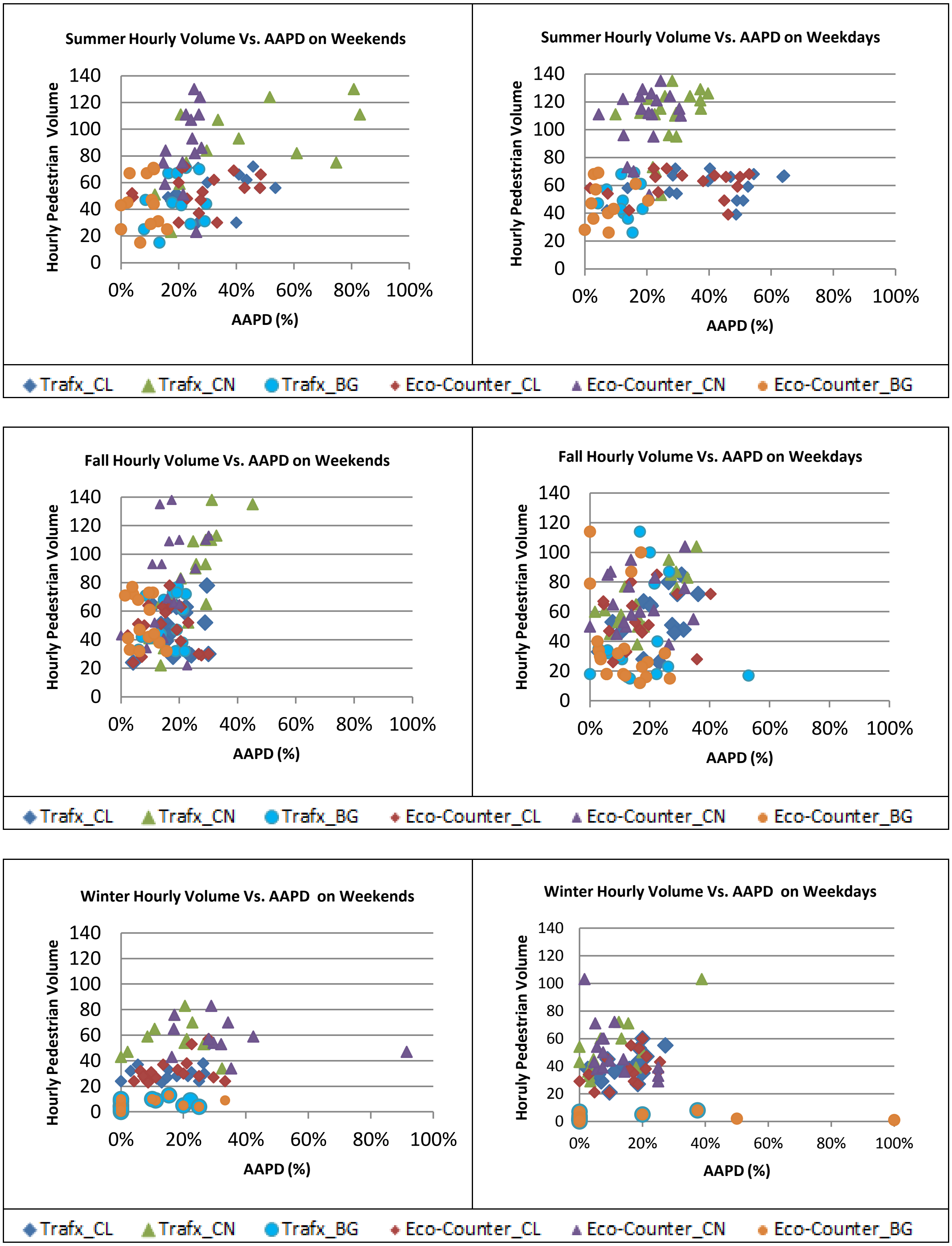
Figure 13: Undercount Error Comparison per Season



Trafx_CL: TRAFCO count at Corydon at Lilac,
Trafx_CN: TRAFCO count at Corydon North,
Trafx_BG: TRAFCO count at Bishop Grandin.

Eco-Counter_CL: Eco-Counter count at Corydon at Lilac,
Eco-Counter_CN: Eco-Counter count at Corydon North,
Eco-Counter_BG: Eco-Counter count at Bishop Grandin.

Figure 14: Absolute Error Comparison per Season



Trafx_CL: TRAFCO count at Corydon at Lilac,
Trafx_CN: TRAFCO count at Corydon North,
Trafx_BG: TRAFCO count at Bishop Grandin.

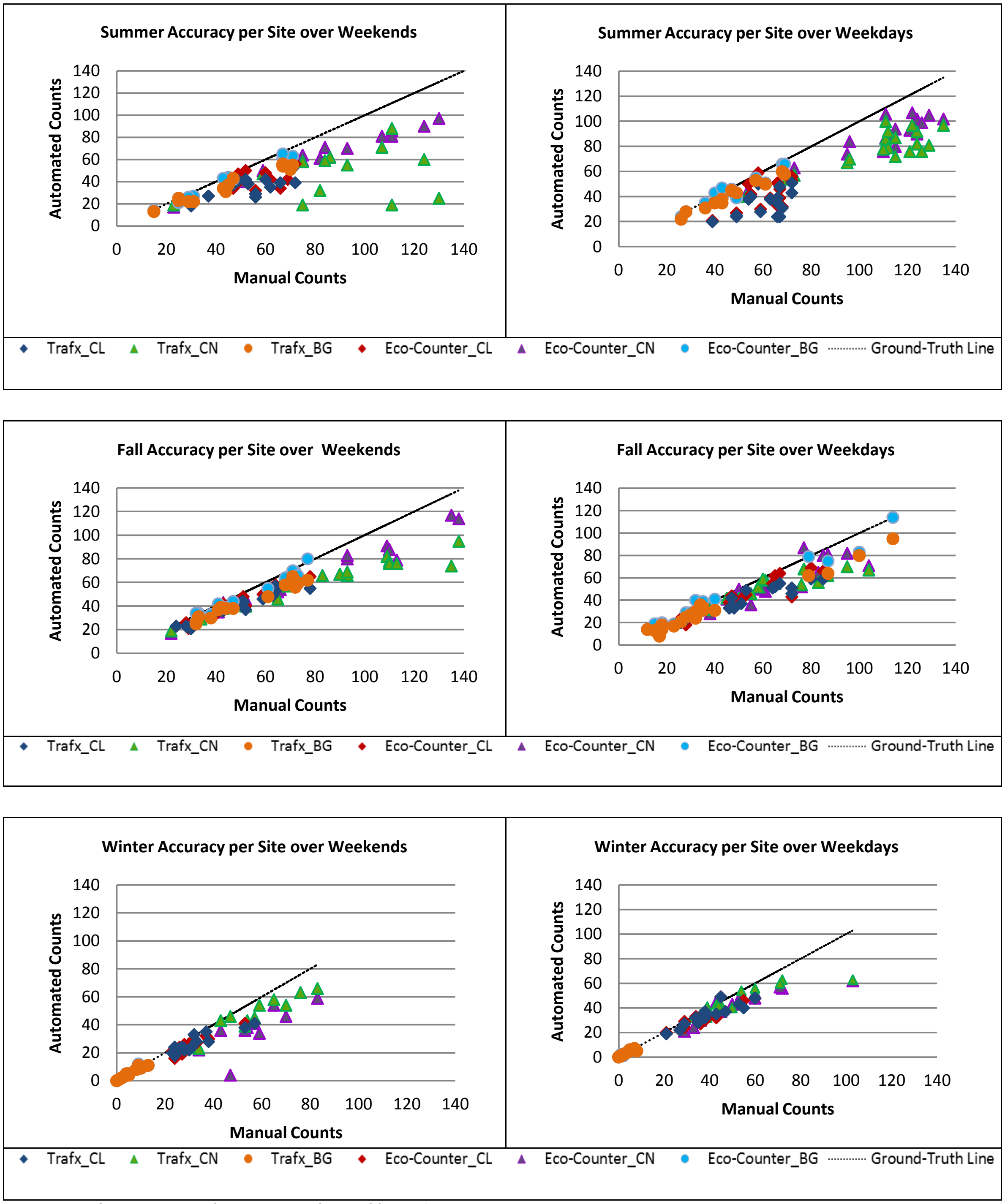
Eco-Counter_CL: Eco-Counter count at Corydon at Lilac,
Eco-Counter_CN: Eco-Counter count at Corydon North,
Eco-Counter_BG: Eco-Counter count at Bishop Grandin.

From Figure 13 and Figure 14, it can be seen that even though the overall counter accuracy improved in winter this season had higher error values than the ones calculated in summer and fall. This research attributes this to the significant reduction of people volume, especially at the Bishop Grandin site. Cold and extreme weather conditions limited the number of people using this site.

Figure 15 illustrates the accuracy plots of each passive infrared counter per season and site during weekends and weekdays. The plots consist of automatic counts (performed by counting devices) on the y-axis versus manual counts (performed manually) on the x-axis. These plots include a dashed diagonal line which can be taken as the “perfect accuracy” line (manual count line of the ground truth data recorded).

Figure 15 below shows the differences in accuracy of two counting devices of the same technology. It can be seen that accuracy of counters of the same technology plays an important part in the operating performance of passive infrared counter. The variety of people volume during each season was observed throughout the seasons, notably in the summer where higher occlusion and people volumes were recorded with lower operating performance than the fall and winter seasons.

Figure 15: Accuracy of Manual Counts Vs. Automatic Counts per Season



Automated counts: People counts performed by PIC.

Trafx_CL: TRAFCO count at Corydon at Lilac,
Trafx_CN: TRAFCO count at Corydon North,
Trafx_BG: TRAFCO count at Bishop Grandin.

Eco-Counter_CL: Eco-Counter count at Corydon at Lilac,
Eco-Counter_CN: Eco-Counter count at Corydon North,
Eco-Counter_BG: Eco-Counter count at Bishop Grandin.

Overall, both counters presented better performance in the winter season than in the summer and fall seasons. However, higher undercount and overcount rates were observed at the Bishop Grandin site, where significantly lower volumes were observed in the winter season. The reasons of overcounting episodes by the Eco-Counter at this particular site are unknown. For this specific site and season, occlusion was present, but at a significantly lower scale. This research found that the accuracy analysis was more robust when higher pedestrian volumes were observed as it gave a better representation of how the counters were performing.

The findings from this research agree with the findings of previous studies on passive infrared counters having a total error of 20 percent, (NCHRP, 2015). This agreement is shown in Table 8, where the total accuracy calculation from a sample of 24,690 people counted by the two PICs from July 2014 to February 2015 at the three sites is illustrated. The undercount error was between 12 to 17.33 percent, and the absolute error was between 16 to 18 percent for Eco-Counter and TRAFCO respectively on weekdays. On weekends, the overall undercount error was between 15.33 to 20.33 percent and the absolute error between 18.33 to 21.33 percent for Eco-Counter and TRAFCO respectively. In total, there is a 2.5 percent difference between Eco-Counter and TRAFCO operating performance.

Table 8: Total Average Undercount Rate (APD) and AAPD

	Device	APD (%)	AAPD (%)
Weekday	Eco-Counter	-12.00	16.00
	TRAFCO	-17.33	18.00
Weekend	Eco-Counter	-15.33	18.33
	TRAFCO	-20.33	21.33

APD: Average Percent Deviation (undercounting error). Negative sign represents undercounting by PIC.
AAPD: Average of the Absolute Percent Deviation (absolute error).

4.3.1 Percentage of Occlusion in Counter's Total Error

This section presents an analysis of how much the error of the passive infrared counters is attributable to occlusion as a function of season, weekday and weekend, and site characteristics. The analysis was performed using the GLM model given the detailed field observations taken at the moment of performing manual counts onsite. Only the factors that were considered significant by the GLM model at a 95 percent confidence level were considered in this analysis.

Table 9 illustrates the parameters and parameter combinations that the GLM found significant in the operating performance of TRAFCO counters and their respective influence in the total error. Table 9 shows that 80 percent of the total error of TRAFCO counters was explained by pedestrian occlusion. Season, site, weekday and weekend factors with their respective combinations also explained the error, but at a smaller scale. Weather conditions are not included in this analysis as this particular analysis was performed at 15-minute intervals to increase the robustness of the model. Correspondingly, weather data was not available under the same time frame in Environment Canada's weather report. This would be an opportunity for future research.

Table 9: Percentage of Factors Influencing in TRAFCO's Total Error

Parameter Combinations	Type III Sum of Squares	Percentage in Total Error*
[Occlusion]	6,826	79.98%
[Season and Occlusion]	555	6.50%
[Season]	291	3.41%
[Season, Week, and Occlusion]	172	2.01%
[Site, Season, and Occlusion]	134	1.57%
[Week and Occlusion]	125	1.46%
[Site and Occlusion]	85	1.00%
[Site, Week and Occlusion]	83	0.97%
[Site and Season]	70	0.82%
[Site, Season, Week, and Occlusion]	65	0.76%
[Site, Season, and Week]	60	0.70%
[Site and Week]	50	0.59%
[Season and Week]	12	0.14%
[Site]	8	0.10%
[Week]	0	0.00%
Total	**8,535**	**100%**

*From the difference between ground truth and TRAFCO data

Table 10 illustrates the parameters and parameter combinations that the GLM model found significant in the operating performance of Eco-Counters with their respective influence in the total error. Table 10 shows that 60 percent of the total error in Eco-Counters was explained by occlusion. There is a 20% difference in the operating performance of the two counters under high people occlusion scenarios. Consequently, Eco-Counter performed better at sites with higher pedestrian occlusion. Other factors, such as season, week, and site characteristics with their respective combinations also influenced the total error, but comparatively at a slightly higher scale than the ones presented in the analysis of TRAFCO counters. As with the TRAFCO analysis, weather conditions were not included in this analysis. This is considered an opportunity for future research.

Table 10: Percentage of Factors Influencing in Eco-Counter's Total Error

Parameter Combinations	Type III Sum of Squares	Percentage in Total Error*
[Occlusion]	4,261	59.88%
[Season, Week, and Occlusion]	659	9.26%
[Season and Occlusion]	449	6.31%
[Site, Season and Occlusion]	348	4.89%
[Site, Week and Occlusion]	294	4.14%
[Site and Occlusion]	291	4.10%
[Week and Occlusion]	220	3.09%
[Site, Season, Week and Occlusion]	192	2.70%
[Site and Season]	180	2.54%
[Season and Week]	53	0.74%
[Site, Season and Week]	48	0.68%
[Site]	46	0.64%
[Site and Week]	35	0.49%
[Week]	20	0.28%
[Season]	19	0.27%
Total	**7,116**	**100%**

*From the difference between ground truth and Eco-Counter data

4.4 CORRECTION FACTORS

Regardless of the brand of passive infrared counter, there is a need for a calibration process by applying a correction factor to the automated data recorded, as counters are not 100 percent accurate. NCHRP (2015) recommends that a correction factor be calculated for each device separately. Other than the error presented by each brand of the analyzed passive infrared pedestrian counters, which can be reduced by following the manufacturer's installation recommendations, there are different factors that can potentially influence the sensitivity of the counters. These factors are the site characteristics as well as seasonal and weather conditions. Each site presented its own particular volume patterns and pedestrian travel patterns. For instance, people walking in pairs are a commonly observed walking behavior. Therefore, more occlusion was observed associated with undercounting problems.

The correction factors estimated in this research were calculated per counter, site, summer, fall and winter and weather conditions as each counter performed slightly differently under same scenarios.

The correction factors were estimated using the General Linear Model, GLM, which is a special form of multiple regression analysis, and is of the form

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

where "Y" corresponds to the hourly difference of people volume counts between the automated and manual counts; β_o refers to the intercept; β_1, β_2,…,β_n correspond to the estimators for the regression equation in order to predict the dependent variable from the independent variable, and X_1, X_2,…,X_n correspond to each qualitative independent variable and their combinations (i.e., site, site and season, site and weather, etc.). Appendix C shows in detail all the significant independent variables and their combinations with their respective estimators, β that were found significant by the GLM model. These different qualitative variables and their combinations were formed in order to compare their significance against the dependent variable "Y".

4.4.1 TRAFCO Correction Factors

The correction factors were calculated to estimate the difference between

TRAFCO automated counts and manual counts, taking into account all the independent variables and their combinations. Appendix B presents the significant variables that were determined by the General Linear model to affect TRAFCO's operating performance.

With the estimators β_o to β_n obtained for the regression equation (see Appendix C), the hourly people volume counts between TRAFCO and manual counts could be estimated. For example, if the hourly difference in people volume between TRAFCO and manual counts was estimated at the Corydon at Lilac site as a function of fall season, weekdays, windspeed =<15 km/h, relative humidity between 45 and 60 percent, clear weather and temperature =<15 ^{o}C, there was an estimation of 7 people being overcounted by TRAFCO per hour. The following equation shows how the hourly difference of people volume was calculated for this particular example:

$$Y_{[Trafco-Manual\ counts]}$$
$$= -89.876 + 63.953X_1 + 53.730X_2 + 80.075X_3 + 53.362X_4$$
$$+ 23.366X_5 - 22.468X_6 - 12.05X_7 - 27.852X_8 - 27.764X_9$$
$$- 10.404X_{10} - 22.588X_{11} - 19.216X_{12} - 8.257X_{13} - 27.176X_{14}$$
$$Y_{[Trafco-Manual\ counts]} = \ 7\ Pedestrians\ overcounted\ per\ hour.$$

The value of each of the estimator β_1 to β_n corresponds to each of the qualitative parameters X_1 to X_n respectively. These values can be found in Appendix C. In this particular example, -89.876 refers to the intercept β_o, X_1 to Corydon at Lilac site, X_2 to weekday, X_3 to fall, X_4 to windspeed =< 15 km/h, X_5 to relative humidity between 45 and 60 percent, X_6 the combination of clear weather and windspeed =< 15 km/h, X_7 to clear weather with relative humidity between 45 and 60 percent, X_8 to Corydon at Lilac and weekday, X_9 to Corydon at Lilac and fall, X_{10} to Corydon at Lilac and windspeed =<15 km/h, X_{11} to Corydon at Lilac and relative humidity between 45 to 60 percent, X_{12} to weekday and windspeed =<15 km/h, X_{13} to weekday and relative humidity between 45 to 60 percent, and X_{14} to fall and windspeed =<15 km/h.

For the calculation of the hourly difference between TRAFCO and manual people counts under a different case scenario than the one stated in the previous example, see Appendix C. For an automated calculation of TRAFCO correction factors under different case scenarios, a spreadsheet was made with the parameters that were found significant by the GLM model in TRAFCO's operating performance.

4.4.2 Eco-Counter Correction Factors

The correction factors were calculated to estimate the difference between Eco-Counter automated counts and manual counts, taking into consideration all the independent variables and their combinations. Appendix C shows all the significant variables that were determined by the General Linear model to affect Eco-Counter's operating performance.

With estimators β_o to β_n obtained for the regression equation (see Appendix C), the hourly difference in pedestrian volume between Eco-Counter and the ground truth data could be predicted. Based on the same example given previously, the hourly pedestrian volume difference between the Eco-Counter and ground truth data at the Corydon at Lilac resulted in 9 pedestrians undercounted. The following equation shows how this was calculated:

$$Y_{[Eco-Counter-Manual\ counts]}$$
$$= -31.461 + 21.013X_1 + 39.831X_2 + 22.149X_3 - 11.301X_4$$
$$- 8.382X_5 - 9.392X_6 - 5.209X_7 - 34.047X_8 - 12.714X_9 + 11.81X_{10}$$
$$+ 8.632X_{11}$$

$$Y_{[Eco-Counter-Manual\ counts]} = 9\ Pedestrians\ undercounted\ per\ hour.$$

The value of each of the estimator β_1 to β_n corresponds to each of the qualitative parameters X_1 to X_n respectively. These values can be found in Appendix C. In this particular example, -31.461 refers to the intercept β_o, X_1 to Corydon at Lilac site, X_2 to fall, X_3 to windspeed =<15 km/h, X_4 to the combination of clear weather and Corydon at Lilac, X_5 to the combination of Corydon at Lilac and weekday, X_6 to the combination of Corydon at Lilac and windspeed =<15 km/h, X_7 to the combination of Corydon at Lilac and relative humidity between 45 to 60 percent, X_8 to the combination of weekday and fall, X_9 to the combination of weekday and windspeed =<15 km/h, X_{10} to the combination of fall and relative humidity between 45 to 60 percent, X_{11} to the combination of windspeed =<15 km/h and relative humidity between 45 to 60 percent.

For the calculation of the hourly difference between Eco-Counter and manual people counts under a different case scenario than the one stated in the previous example, see Appendix C. For an automated calculation of the Eco-Counter correction factor under different case scenarios, a spreadsheet was made with the parameters that were found significant by the GLM model in Eco-Counter operating performance.

Overall, the estimation of the correction factor by TRAFCO and Eco-Counter was different under the same conditions. This confirms that each brand performs differently under same case scenarios.

4.5 DISCUSSION

The operating performance of passive infrared counters is a function of several variables, such as the type of counter used, site characteristics, and weather and seasonal conditions. This section discusses key observations from this research regarding the following: (1) previous research; (2) limitations of the field test; (3) seasonal conditions; and (4) people occlusion.

4.5.1 Previous Research

The results from this research agree with a 20 percent absolute error reported by previous research on passive infrared counting technology, NCHRP (2015). This research found that Eco-Counter's absolute error on weekdays was 16 percent and TRAFCO's was 18 percent. On weekends, Eco-Counter's absolute error was 18.33 percent and TRAFCO's was 21.33 percent.

Even though the NCHRP (2015) did not identify the name of the two passive infrared brands used in their study, this research found that overall, one of the two counters tested had a better performance than the other one as well. For instance in this research, Eco-Counter performed 8 percent better than TRAFCO on weekdays and 13 percent better than TRAFCO on weekends at Corydon North site where high people occlusion was observed in summer. However, TRAFCO performed 5 percent better than Eco-Counter on weekdays and 15 percent better than Eco-Counter on weekends at Corydon North site, where people occlusion was significantly less in winter. TRAFCO also did not have overcounting issues in winter as it was observed by Eco-Counter at Bishop Grandin, where people occlusion was not observed. In contrast with Eco-Counter, TRAFCO did not have undercounting or overcounting issues during a heavy rain event in fall.

4.5.2 Limitations of the Field Test

Even though the installation of the counters onsite was relatively easy in terms of labour equivalent hours needed, preliminary assembly time was required for placing TRAFCO counters in locking boxes. In addition extra materials were needed to do this task.

The counters were set up in May 2014 and data were collected over 306 nonconsecutive hours from July 2014 to February 2015 at the three sites. The following are considered to be limitations of the field test. It is useful to consider these issues in further work related to this topic;

- The temperature and weather data were obtained from Environment Canada's website for the weather station located at the James A. Richardson International Airport in Winnipeg, Manitoba. Weather and temperature are site specific and the geographic separation of the three sites from the airport (9 kilometers from the two sites on Corydon Avenue and 16 kilometers from the Bishop Grandin site) caused situations where differences existed between the actual weather and temperature conditions at the research sites and the recorded data at the airport weather station.

- Weather and temperature data obtained from the airport weather station was available on a one hour basis. The data collected by TRAFCO corresponded to timestamps and Eco-Counter corresponded to 15-minutes intervals. In order to ensure weather and temperature data matched the corresponding TRAFCO and Eco-Counter data, the analysis of seasonal and weather conditions in the operating performance of the counters were done on one hour basis. This task then required extra time to prepare counter data for equal comparison with seasonal and weather data from Environment Canada.

- Data retrieval from TRAFCO counters required that one person physically download data directly from counters onsite once a week to avoid the counter's memory reaching the maximum capacity and losing data. This task was found by the ground truth data collection personnel to be inconvenient, especially in winter conditions. On the contrary, Eco-Counters transferred data daily to their cloud storage location via cellular network. Downloading the Eco-Counter's data was then done remotely via online. This was found to be a convenient feature of this brand.

- The Eco-Counter model used in this research was found to have a delay in its built-in clock over time. Because of Eco-Counter records data on a 15-minute interval, it was hard to determine how many of the people counted corresponded to one 15-minute bin or the following one. This issue was discovered during the fall season and fixed for the rest of the fall season and for the entire winter season by resetting Eco-Counter's clock prior to performing manual counts onsite.

- Extreme low temperatures and weather conditions in winter made ground truth data collection challenging for data collection personnel. For Example, a vehicle was needed for sheltering from the extreme weather while collecting manual counts. In addition, these extreme temperatures and weather conditions affected the number of people passing by. In particular, Bishop Grandin site was the most affected. At this site, it was almost impossible to collect people counts in winter, as there was an average of 5 people per day. Setting the manual counting schedule was a real challenge at this particular site in winter.

4.5.3 Seasonal Conditions

This research found that different seasonal conditions were significant factors affecting the operating performance of the passive infrared counters tested. Even though the NCHRP (2015) did not find concrete evidence of weather conditions affecting the operating performance of the counters, this research observed an episode at the Corydon at Lilac site in the fall season. At this site, Eco-Counter had overcounting and undercounting issues during two non-consecutive 15-minute intervals when heavy rain was observed by the ground truth data collection personnel. Occlusion was not observed when the overcounting issue was recorded. While there were two people walking side by side on two occasions during the undercounting episode, this did not fully explain the undercounting issue. Even though these episodes were found, it was uncertain whether or not to attribute the undercounting and overcounting episodes to the heavy rain event observed, as the Eco-Counters presented a delay in their built-in clock of 5 to 6 minutes over time. This issue was fixed by the end of the fall by resetting the counter's clock manually and on a regular basis afterwards. The manufacturers had fixed this issue in the newer versions of Eco-Counter sensors. This research recommends further analysis of the Eco-Counter operating performance under heavy rain conditions to verify this finding.

In terms of seasonal conditions, this research performed data collection at temperatures below -12 ^{o}C (10 ^{o}F), which were colder temperatures than the ones in which NCHRP (2015) collected their winter data. This research found Eco-Counters presenting overcounting episodes in winter at Bishop Grandin site, one of the three sites analyzed. However, this site had low people traffic volume during the winter time, with an average of 5 pedestrians per day. These findings open up possibilities for future research on this matter.

4.5.4 People Occlusion

Given the detailed field observations made at the moment of performing manual counts onsite, this research found that 80 percent of the total error of TRAFCO counters and 60 percent of the total error in Eco-Counters was explained by people occlusion. This finding also agrees with the literature, which identifies people occlusion as the main factor affecting operating performance of passive infrared pedestrian counters.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses research findings and conclusions, and opportunities for future research.

5.1 CONCLUSIONS

This research evaluated the operating performance of two commercially available passive infrared counters (PICs) as a function of site characteristics, summer, fall and winter conditions in terms of counter sensitivity. Passive infrared counters are commonly used for determining people counts. However, only a few analyses have been performed to determine the influence of seasonal conditions on their operating performance. This research evaluated two commercially available passive infrared pedestrian counters by understanding the technology through a literature review and trial tests before data collection. It also measured the impacts of seasonal conditions by comparing automated counts against manual counts, determining counter sensitivity per site, seasons, weekday, and weekend, determining their accuracy level, explaining how much counter error is attributable to pedestrian occlusion, and finally, developing correction factors per counter, site, seasonal and weather conditions.

The two passive infrared counters analyzed in this research are the: (1) PYRO-Box Sensors, manufactured by Eco-Counter Inc., based in France; and (2) TRAFx Infrared Trail Counter, manufactured by TRAFCO Canada. The Eco-Counter has a pyroelectric infrared sensor with bi-directional detection and

TRAFCO counter has a thermal infrared micro sensor with no bi-directional detection available.

Based on a sample of 24,690 people counted by the two PICs from July 2014 to February 2015, this research found the following:

- Overall, the two PICs analyzed in this research are sensitive in detecting and counting people. With a 95 percent confidence level, the average Eco-Counter's sensitivity ranged from 73 to 97 percent while TRAFCO's ranged from 57 to 97 percent related to people occlusion.

- Eco-Counter's absolute error on weekdays was 16 percent and TRAFCO's was 18 percent. On weekends, Eco-Counter's absolute error was 18.33 percent and TRAFCO's was 21.33 percent. These results agree with the total 20 percent absolute error reported by the NCHRP (2015).

- Based on detailed field observations, this research found that 80 percent of the total error of TRAFCO counters and 60 percent of the total error in Eco-Counters was explained by people occlusion. Eco-Counters were more effective at high people occlusion sites. Season, weekday and weekend, and site characteristics also explained the error, but at a smaller scale.
- The operating performance in terms of sensitivity indicated that overall,

Eco-Counters performed 15 to 20 percent better than TRAFCO counters. However, with winter conditions and significantly less people occlusion, TRAFCO had an average of 10 percent better performance than Eco-Counter at Corydon North site and 1 to 2 percent better performance at Corydon at Lilac site for both weekdays and weekends. The cause of Eco-Counter's lower performance in winter it is unknown as it could not being explained by field observations.

- Overall, the counters had more undercounting than overcounting issues. The undercounting issue was attributed in large part to people occlusion. However, Eco-Counter overcounted at the Bishop Grandin site during the winter season even though occlusion was minimal or not observed at all. The overcounting reasons are uncertain. Therefore, more testing is recommended as this was observed only at one of the three sites in the winter season, with significantly low people traffic volume.

- The difference in the counter's operating performance on weekdays and weekends was attributed to more pedestrian occlusion observed on weekends, even in cases where people counts were not necessarily higher than weekdays. Based on field observations, people have a tendency to walk side by side or in groups over weekends.

- Differences in weather conditions and site characteristics determined the people traffic characteristics (i.e. people walking side by side, in groups or one person at the time). It was found that high people volumes were directly related with nice weather conditions as people tend to be more outdoors when the weather is warm. Similarly, the higher the people traffic volume, the higher the number of people occlusion present.

- Even though Eco-Counter had 5 to 6 minutes delay in its built-in clock over time, this issue did not interfere significantly with the data analysis for this research. This clock delay was discovered by late fall and corrected by continuously resetting the clock for the rest of the data collection period. Eco-Counter Inc. has corrected this issue in its newer counter models.

- This research found that site and seasonal conditions had a significant impact on the operating performance of passive infrared counters. The GLM model shows these impacts, and correction factors were developed specifically per counter and site over summer, fall and winter seasons, weather conditions, on weekdays and weekends. This research observed a clear impact of weather conditions affecting the operating performance of Eco-Counter at Corydon at Lilac site in fall, where Eco-Counter overcounted and undercounted when occlusion was minimal or not present at all. However, these two undercounting and overcounting episodes were observed over two non-consecutive 15-minute intervals.

Because this issue was observed over a short period of time and before the clock delay was fixed in Eco-Counters, further analysis is recommended on this particular observation.

- As occlusion was found to be the most significant source of counter error; it was found that high people occlusion depends on site characteristics and their surrounding land type. For instance, some sites are more prone to have people walking side by side or walking in groups than others. For this reason, it is recommended that correction factors are calculated per counter, site and season as counter's operating performance varied from the same counter technology.

- The accuracy of the counters can be improved by proper calibration and installation practices based on site-specific characteristics. For instance, windows, mirrors and other reflective surfaces should not be positioned behind and in front of the field of view of the passive infrared counters. These surfaces could cause false counts as they collect heat, especially on summer or sunny days.

- With respect to equipment installation, the research found that the Eco-Counter sensor was the most time-efficient to install. Each TRAFCO sensor required 15 minutes of preliminary assembly time and the purchase of extra materials for placing them in a secured locking box prior their installation onsite.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

This research has resulted in the following recommendations for research opportunities in the future:

- More comprehensive analysis is required to understand Eco-Counter's lower performance observed under a heavy rain event and in winter conditions.

- This research found that ground truth data recorded by video cameras can potentially allow for a more detailed analysis of counter operating performance. For instance, the counters could have been evaluated more closely during extreme weather conditions, such as the heavy rain event when Eco-Counter undercounted and overcounted. In addition, counter selectivity could also have been analyzed as the video allows going back and analyzing counter performance under specific scenarios.

- Practitioners should calibrate and collect their own ground truth data to test any counters before they are used. The results drawn from this research are intended to provide detailed information regarding the operating performance of passive infrared counters as a function of different site characteristics, seasonal and weather conditions. This research also recognizes that passive infrared technology is in constant development by its manufacturers. The accuracy and sensitivity results obtained in the research should not be applied to other sites than those where the counters were placed.

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APPENDIX A

Analysis of Counter Sensitivity per Site and Season

OVERALL COUNTER SENSITIVITY PERFORMANCE IN SUMMER

Corydon North Site

The total ground truth data was collected from July 2014 to August 2014. A total of 2,112 pedestrians were counted on weekdays over 19.5 non-continuous hour observations. On weekends, 1,516 pedestrians were counted during 16 non-continuous hour observations. Table A1 shows the total number of pedestrians counted per day of the week at the Corydon North site.

Table A1: PIC Overall Performance at Corydon North Site in Summer

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Tuesday	5.25	21	582	405	447
Wednesday	8.25	33	975	690	776
Thursday	6	24	555	429	461
Week Total	**19.5**	**78**	**2,112**	**1,524**	**1,684**
Saturday	14	56	1,442	751	1,098
Sunday	2	8	74	64	57
Weekend Total	**16**	**64**	**1,516**	**815**	**1,155**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

Table A1 illustrates that Corydon North had a 596 more people over weekdays than weekends. It also shows that TRAFCO counted 160 less people than Eco-Counter on weekdays and 340 less people on weekends. Based on field observations, this is attributable to the high people occlusion observed at this particular site.

Corydon at Lilac Site

The total ground truth data was collected from July 2014 to August 2014. A total of 1,012 people were counted on weekdays and 904 people on weekends over 17 non-continuous hours each. Table A2 shows the total number of people counted per day of the week and per counter at the Corydon at Lilac site in summer.

Table A2: PIPC Overall Performance at Corydon at Lilac in Summer

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	3	12	200	90	101
Tuesday	2	8	130	86	85
Wednesday	3	12	185	141	157
Thursday	6	24	344	178	224
Friday	3	12	153	102	110
Week Total	**17**	**68**	**1,012**	**597**	**677**
Saturday	12	48	671	433	462
Sunday	5	20	233	186	195
Weekend Total	**17**	**68**	**904**	**619**	**657**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

Table A2 shows that Eco-Counter continues to have more accurate people counts than TRAFCO. Field observations showed that Corydon at Lilac site had less pedestrian occlusion than the Corydon North site; however, people occlusion was still the main cause of lower performance by TRAFCO counters when compared with Eco-Counter performance. At Corydon at Lilac, TRAFCO counted 80 less people than Eco-Counter on weekdays and 38 less people on weekends in summer.

Bishop Grandin Site

The total ground truth data was collected from July 2014 to August 2014. On weekdays, 631 people were counted during 13.25 non-continuous hours. However, on weekends, a total of 700 pedestrians were counted during 15 non-continuous hours. Table A3 shows the total number of people counted by day of the week and per counter at the Bishop Grandin site in summer.

Table A3: PIC Overall Performance at Bishop Grandin Site in Summer

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	2.75	11	169	145	160
Tuesday	5.75	23	224	207	216
Wednesday	2.75	11	126	111	118
Thursday	2	8	112	93	105
Week Total	**13.25**	**53**	**631**	**556**	**599**
Saturday	12.25	49	510	423	480
Sunday	2.75	11	190	146	175
Weekend Total	**15**	**60**	**700**	**569**	**655**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

As Table A3 shows, Eco-Counter still continues to perform better than TRAFCO counter when their automated data is compared to the ground truth data recorded. Even though weekends had only 69 more people than weekdays, people occlusion was then main cause affecting counter's operating performance. At Bishop Grandin, TRAFCO counted 43 less people than Eco-Counter on weekdays and 86 less people on weekends in summer.

Overall sensitivity results for each PIC are calculated from the total automated counts and the total manual counts recorded onsite. Table A4 illustrates the sensitivity rates by PIPC with 95 percent confidence intervals (CI) for the summer season. The sensitivity 95 percent confidence intervals are calculated using the following formula:

$$PIC\ Sensivity \pm 1.96 \sqrt{\frac{PIC\ Sensitivity * (1 - PIC\ Sensitivity)}{sample\ size, n}}$$

where PIC Sensitivity refers to the population proportion (p).

Table A4: Overall Counter Sensitivity in Summer

Site Name	Sensitivity (%) Weekday		Sensitivity (%) Weekend	
	TRAFCO	**Eco-Counter**	**TRAFCO**	**Eco-Counter**
Corydon North	72 ± 10	80 ± 9	54 ± 12	76 ± 10
Corydon at Lilac	59 ± 11	67 ± 10	68 ± 11	73 ± 11
Bishop Grandin	88 ± 7*	95 ± 5*	81 ± 10	94 ± 6*
Total Average	**73 ± 9**	**81 ± 8**	**68 ± 11**	**81 ± 9**

*The n(1-p)≥10 acceptance criteria for the calculation of the CI population proportion was not met, but the np≥10 was.

From Table A4, it can be seen that Eco-Counter presented a higher overall sensitivity range at all sites when it was compared with TRAFCO counter. The highest sensitivity was observed at the Bishop Grandin site for both weekdays and weekends at 95 ± 5 percent by Eco-Counter, and the lowest sensitivity was observed at the Corydon North site over weekends at 54 ± 12 percent by TRAFCO. Note that a counter's sensitivity of 100 percent means that all the pedestrians that passed in front of the counter where detected and counted by the counter.

Based on field observations, the high sensitivity presented at the Bishop Grandin site can be attributed to different site characteristics between sites. For example, less pedestrian occlusion was observed at the Bishop Grandin site even though its pedestrian volume was similar to the ones observed at the Corydon North site. The Bishop Grandin pathway is used as a commuting pathway on weekdays and as a recreational pathway over weekends; consequently, less people were observed walking side by side over weekdays at this site.

OVERALL COUNTER SENSITIVITY PERFORMANCE IN FALL

Corydon North Site

The total ground truth data was collected from September 2014 to November 2014. A total of 1,142 people were counted on weekdays during 17 non-continuous hours. On weekends, a total of 1,466 people were counted during the same period over 18 non-continuous hours. Table A5 shows the total number of people counted per day of the week and counter at the Corydon North site in the fall.

Table A5: PIC Overall Performance at Corydon North Site in Fall

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	2	8	105	101	91
Tuesday	3	12	259	200	250
Wednesday	4	16	292	211	222
Thursday	4	16	284	223	242
Friday	4	16	202	179	167
Week Total	**17**	**68**	**1,142**	**914**	**972**
Saturday	11	44	872	641	715
Sunday	7	28	594	431	484
Weekend Total	**18**	**72**	**1,466**	**1,072**	**1,199**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

Overall, Table A5 shows an improvement in the overall counter sensitivity at the Corydon North site in the fall. However, Eco-Counter performed better than

TRAFCO. Comparatively, the total pedestrian volume observed in the fall was approximately 1,000 people less than the pedestrian volume observed in the summer on weekdays. Based on field observations, less occlusion was seen at Corydon North in fall. Consequently, this was reflected in better performance by the counters.

Corydon at Lilac Site

The total ground truth data was collected from September 2014 to November 2014. The corresponding weekday people volume observed was 900 during 16.75 non-continuous hours and 865 on weekends during 18 non-continuous hours. Table A6 shows the total number of people counted per day of the week and counter at the Corydon at Lilac site in the fall.

Table A6: PIPC Overall Performance at Corydon at Lilac Site in Fall

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	4	16	199	139	142
Tuesday	4	16	139	114	121
Wednesday	3.75	15	194	167	176
Thursday	2	8	139	106	115
Friday	3	12	229	169	190
Week Total	**16.75**	**67**	**900**	**695**	**744**
Saturday	10	40	583	468	495
Sunday	8	32	282	230	237
Weekend Total	**18**	**72**	**865**	**698**	**732**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

From Table A6, it can be seen that at this site, the two counters performed better in the fall than in the summer in terms of proximity of automated counts with manual counts. At Corydon at Lilac, TRAFCO counted 49 less people than Eco-Counter on weekdays and 34 less people on weekends in fall. As seen in summer, Eco-Counter continues to have closer people counts to the manual counts. Comparatively, the people volume observed at Corydon at Lilac in fall was approximately 100 people less than the people volume observed in summer. Based on field observations, less people occlusion was seen at this site in the fall season.

Bishop Grandin Site

The total ground truth data was collected from September 2014 to November 2014. A total of 813 people were counted on weekdays during 21.25 non-continuous hours. On weekends, a total of 839 people were counted during the same period during 15.5 non-continuous hours. Table A7 shows the total number of people counted per day of week and counter at Bishop Grandin site in the fall.

As Table A7 shows, both counters performed better at this site in the fall than during the summer. However, Eco-Counter obtained the highest number of valid counts when compared with the valid counts performed by TRAFCO. The people volume at Bishop Grandin site was on average 160 less than the one observed in the summer season. As at the other two sites, Bishop Grandin also had less occlusion over the fall season.

Table A7: PIPC Overall Performance Indicators at Bishop Grandin Site in Fall

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	5	20	398	319	370
Tuesday	4	16	101	88	112
Wednesday	2	8	48	41	46
Thursday	9.25	37	254	217	247
Friday	1	4	12	14	14
Week Total	**21.25**	**85**	**813**	**679**	**789**
Saturday	4	16	158	130	150
Sunday	11.5	46	681	574	644
Weekend Total	**15.5**	**62**	**839**	**704**	**794**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

The sensitivity rates by PIPC with 95 percent confidence intervals (CI) for the fall season are illustrated for the research sites in Table A8.

Table A8: Overall Counter Sensitivity in Fall

Site Name	Sensitivity (%) Weekday		Sensitivity (%) Weekend	
	TRAFCO	Eco-Counter	TRAFCO	Eco-Counter
Corydon North	80 ± 10	85 ± 8	73 ± 10	82 ± 9
Corydon at Lilac	77 ± 10	83 ± 9	81 ± 9	85 ± 8
Bishop Grandin	84 ± 8	97 ± 4*	84 ± 9	95 ± 6*
Total Average	**80 ± 9**	**88 ± 7**	**79 ± 10**	**87 ± 8**

*The n(1-p)≥10 acceptance criteria for the calculation of the CI population proportion was not met, but the np≥10 was.

From Table A8, it can be seen that Eco-Counter had higher overall sensitivity at all sites when compared to TRAFCO counter. However, fall season, Bishop Grandin site had the highest sensitivity at 97 ± 4 percent and the Corydon North site had the lowest sensitivity at 73 ± 10 percent. Based on field observations, these results are attributable to less people occlusion and lower people volumes observed at the Bishop Grandin site when compared to the other two sites. For example, the Bishop Grandin site in the fall season had 200 people less than the

Corydon at Lilac site and 600 people less than the Corydon North site.

OVERALL COUNTER SENSITIVITY PERFORMANCE IN WINTER

Corydon North Site

The total ground truth data was collected from December 2014 to February 2015. On weekdays, a total of 823 people were counted during 15.75 non-continuous hours. On weekends, a total of 641 people were counted during the same period during 11 non-continuous hours. Table A9 shows the total number of people counted per day of the week and counter at the Corydon North site in the winter.

Table A9: PIPC Overall Performance at Corydon North Site in Winter

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	4.75	19	281	248	232
Tuesday	5	20	232	210	199
Wednesday	4	16	229	178	174
Friday	2	8	81	78	67
Week Total	**15.75**	**63**	**823**	**714**	**672**
Saturday	7	28	427	373	288
Sunday	4	16	214	161	145
Weekend Total	**11**	**44**	**641**	**534**	**433**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

Table A9 shows better counter performance in winter than in summer and fall. This time, TRAFCO performed better than Eco-Counter. Other than occlusion being significantly less in winter when compared to summer and fall, there were no other obvious events seen onsite explaining TRAFCO’s better performance. At Bishop Grandin, TRAFCO counted 42 more people than Eco-Counter on weekdays and 101 more people on weekends in winter. This means that

TRAFCO counts were closer to ground truth data than Eco-Counter counts in winter.

Corydon at Lilac Site

The total ground truth data was collected from December 2014 to February 2015. A total of 634 people were counted on weekdays during 16.75 non-continuous hours. On weekends, a total of 533 people were counted during the same period during 16.5 non-continuous hours. Table A10 shows the total number of people counted per day of the week and counter at the Corydon at Lilac site in the winter.

Table A10: PIPC Overall Performance at Corydon at Lilac Site in Winter

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	4	16	135	121	118
Tuesday	2	8	73	61	61
Wednesday	2	8	74	64	57
Thursday	4	16	149	123	124
Friday	4.75	19	203	170	169
Week Total	**16.75**	**67**	**634**	**539**	**529**
Saturday	9.75	39	334	278	283
Sunday	6.75	27	199	154	152
Weekend Total	**16.5**	**66**	**533**	**432**	**435**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

Table A10 shows that at Corydon at Lilac site, TRAFCO counted 10 more people than Eco-Counter on weekdays, but counted only 3 less people than Eco-Counter on weekends in winter. This means that both counters performed similarly at Corydon at Lilac in fall. Field observations showed less number of people occlusion that the ones observed in summer and fall at Corydon North.

Bishop Grandin Site

The total ground truth data was collected from December 2014 to February 2015. On weekdays, 47 people were counted during 16.5 non-continuous hours. The total number of people observed on weekends was almost double the number observed on weekdays. On weekends, a total of 102 people were counted during 17.25 non-continuous hours. Table A11 shows the total number of people counted per day of the week and counter at the Bishop Grandin site in the winter.

Table A11: PIPC Overall Performance at Bishop Grandin Site in Winter

Day	Total Hours of Ground Truth	n	Total Pedestrian Count		
			Ground Truth	TRAFCO	Eco-Counter
Monday	5.5	22	19	16	16
Tuesday	5.5	22	19	22	21
Wednesday	1.75	7	1	1	1
Thursday	3.25	13	7	7	8
Friday	0.5	2	1	1	1
Week Total	**16.5**	**66**	**47**	**47**	**47**
Saturday	4	16	13	13	14
Sunday	13.25	53	89	89	93
Weekend Total	**17.25**	**69**	**102**	**102**	**107**

n = sample size or # of 15-minute intervals in the total hours where the ground truth data was performed.

From Table A11, it can be seen that both counters agreed with the manual counts for the most part. However, Eco-Counter had overcounting issues even when people occlusion was not observed. Performing manual counts at this site was difficult as winter conditions directly affected people traffic volume.

The sensitivity rates by PIPC with 95 percent confidence intervals (CI) for the winter season are illustrated for the research sites in Table A12.

Table A12: Overall Counter Sensitivity in Winter

Site Name	Sensitivity (%) Weekday		Sensitivity (%) Weekend	
	TRAFCO	Eco-Counter	TRAFCO	Eco-Counter
Corydon North	87 ± 8	82 ± 10	83 ± 11*	68 ± 14
Corydon at Lilac	85 ± 9	83 ± 9	81 ± 9	82 ± 9
Bishop Grandin	100 ± 0	100 ± 0	100 ± 0	105 ± *
Total Average	**91 ± 6**	**88 ± 6**	**88 ± 7**	**85 ± 12**

*The n(1-p)≥10 acceptance criteria for the calculation of the CI population proportion was not met, but the np≥10 was.

Table A12 shows that overall; TRAFCO had higher sensitivity than Eco-Counter in winter. The highest sensitivity at 100 ± 0 percent was observed by both counters on weekdays and weekends, and the lowest sensitivity at 68 ± 14 percent by Eco-Counter at the Corydon North site on weekends.

In winter, Eco-Counter had overcounting issues at the Bishop Grandin site on weekends. Field observations did not show evidence of pedestrian occlusion being the cause of the overcounting issues. Consequently, there is no specific evidence explaining why Eco-Counter overcounted at this site. The total overcount was by 5 pedestrians. This resulted in a high overcounting error as the site had a total average of 2 pedestrians per hour.

In general, the operating performance in terms of sensitivity indicated that Eco-Counters performed 15 to 20 percent better than TRAFCO counters at all sites under different seasonal conditions. However, TRAFCO had better performance than Eco-Counter at the Bishop Grandin site in winter. This was attributed to less people occlusion and a low pedestrian volume observed at this site in winter. The counter sensitivity results obtained in the research are relative as the total number of pedestrian volume varies per site and season.

APPENDIX B

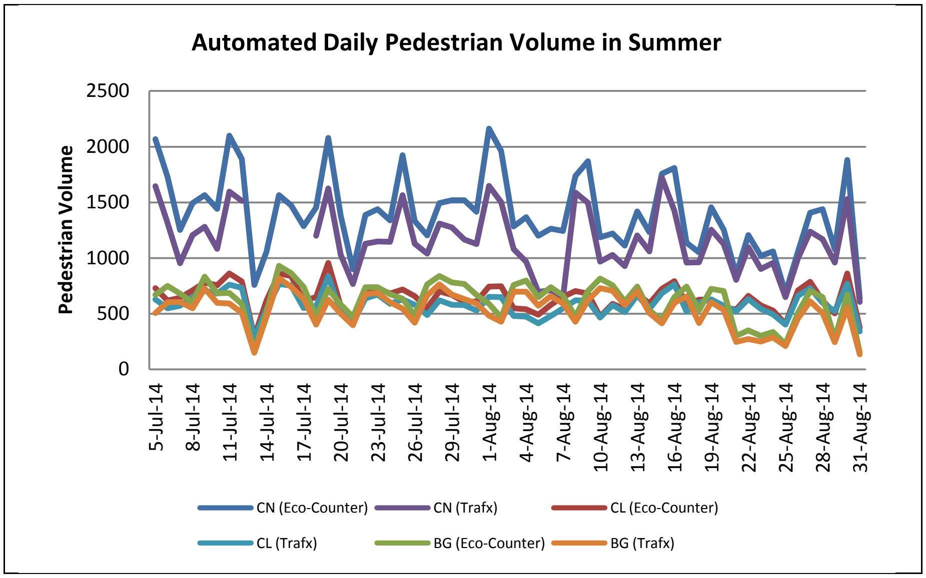
Site Characteristics per Season

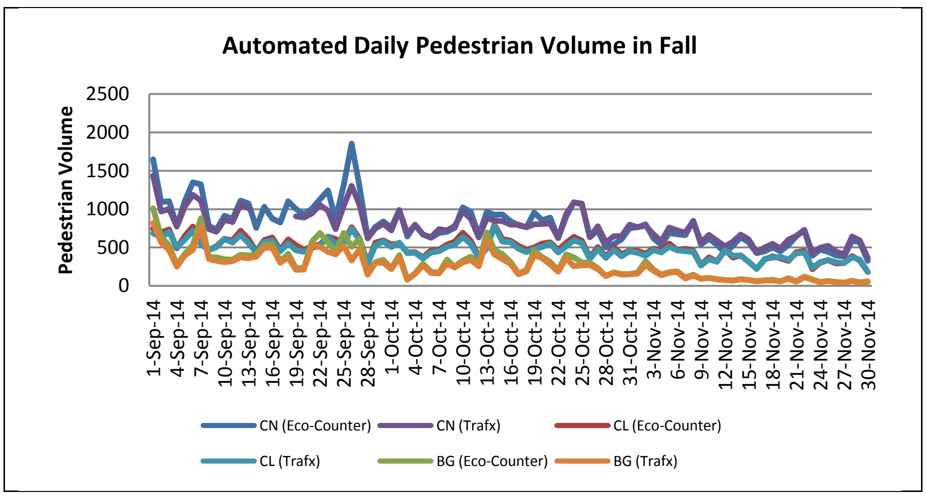
Site Characteristics per Season

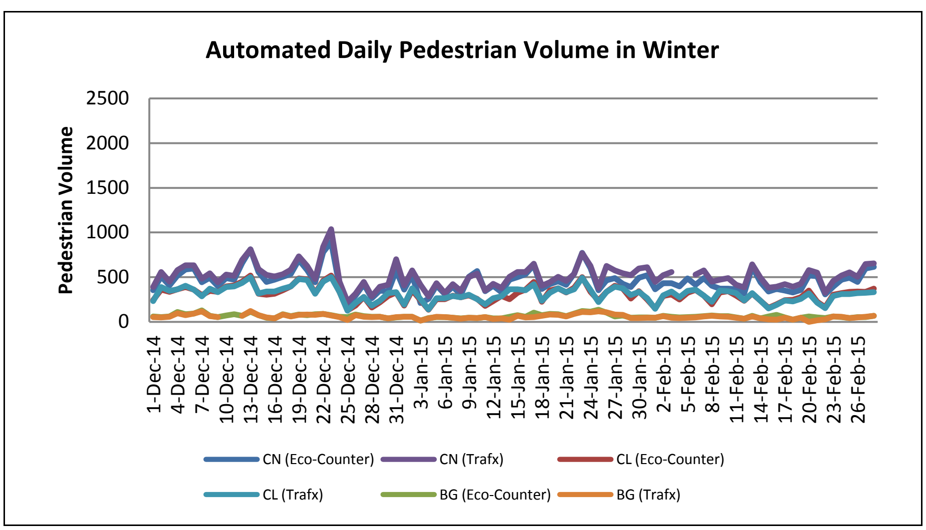
People volume was found to fluctuate significantly between sites over summer, fall and winter seasons. People occlusion was found to be more prominent in summer and fall seasons than in winter. People had a tendency to walk more in groups or side by side during warmer weather conditions. This can be an explanation of counter's lower operating performance in summer and fall and higher operating performance in winter.

Figure B1 illustrates the comparison of daily automated people volume per counter, site and season. This plot demonstrates how people volume fluctuates between sites and seasons.

Figure B1: Automated Daily Pedestrian Volume Comparison per Season







As shown in Figure B1, the Bishop Grandin site presented a significantly lower pedestrian volume over the winter season. The difference in pedestrian volumes for this particular site between summer and winter was approximately 600 people per day. In the winter season, the daily average of pedestrian volume at the Bishop Grandin site was approximately 64 people per day. Comparatively, higher volumes were observed at the Corydon North site with approximately 458 pedestrians per day and 309 pedestrians per day at the Corydon at Lilac site over the winter season.

APPENDIX C

Correction Factor Analysis and Tables

The General Linear Model, GLM has several tools for customizing the hypothesis testing and also allows for comparing specific level combinations of between-variables effects and/or linear combinations of dependent variables. GLM contains methods for computing sums of squares (SS). Type III SS method was the one chosen for the analysis as it is designed especially to deal with unbalanced models with no empty cells. Type III SS method calculated the reduction in Error SS by adding the effect after all the other effects are adjusted. This method is equivalent to weighted-squares-of-means technique (Institute for Digital Research and Education, IDRE, 2015). Hourly weather data (the independent variable) was retrieved from Environment Canada website (Environment Canada, 2015).

A correction factor was estimated per counter during summer, fall and winter seasons and different weather conditions per site, such as temperature, windspeed, relative humidity and windchill. Even though technically the windchill factor does not affect the operating performance of the counters, it affects the pedestrian volume traffic present at each site, which reflects on their operating performance. For this reason, it was included just to see if there was a significant effect over the operating performance of the counters.

Table C1 shows the independent variables and their combinations used to analyze their significance against the dependent variable.

Table C1: Independent Variables in Correction Factor's Formula

Independent Variables	Subgroups	N	Percent
weather	Clear	90	30.9%
	Cloudy	129	44.3%
	Fog	19	6.5%
	Freezing Drizzle	15	5.2%
	Rain	10	3.4%
	Snow	28	9.6%
	Total	**291**	**100.0%**
Site	Bishop Grandin	91	31.3%
	Corydon at Lilac	104	35.7%
	Corydon North	96	33.0%
	Total	**291**	**100.0%**
Week	weekday	146	50.2%
	weekend	145	49.8%
	Total	291	100.0%
Season	fall	104	35.7%
	summer	94	32.3%
	winter	93	32.0%
	Total	**291**	**100.0%**
Temperature Interval (^{o}C)	< -15	27	9.3%
	>= 15	144	49.5%
	[0,15]	61	21.0%
	[0,-14.99]	59	20.3%
	Total	**291**	**100.0%**
Wind speed Interval (km/h)	< 15	84	28.9%
	>=45	9	3.1%
	[15, 30]	157	54.0%
	[30, 45]	41	14.1%
	Total	291	100.0%
Relative Humidity Interval (%)	< 45	53	18.2%
	>=75	95	32.6%
	[45, 60]	68	23.4%
	[60, 75]	75	25.8%
	Total	**291**	**100.0%**

N: Sample Size

Percent: Refers to the number of times an independent variable was present in the total number of observations.

Table C2 illustrates the descriptive analysis of the weather independent variable.

This descriptive analysis gives an insight of their characteristics recorded during the time were ground truth data is collected.

Table C2: Descriptive Statistics of Independent Variables

Weather Condition	N	Min.	Max.	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Temperature (^oC)	291	-30.00	31.90	8.865	0.884	15.075	227.250
WindChill	76	-42.00	-5.00	-20.750	1.232	10.740	115.350
Windsped (km/h)	291	1.00	57.00	22.088	0.631	10.759	115.764
Relative Humidity (%)	291	28.00	97.00	65.881	1.108	18.901	357.268

N: Sample Size

Table C3 shows only the significant variables that were determined by the General Linear model.

Table C3: Significant Variables in the [TRAFCO – Manual Count] Model

Independent Variables and their Combinations	Type III		
	Wald Chi-Square	df	Significance
(Intercept)	10.7	1	.001
weather	17.4	5	.004
Site	5.3	2	.071
Rel. Humidity	35.7	3	.000
[weather and Week]	7.6	2	.022
[weather and Season]	22.5	1	.000
[Weather and Temp.]	6.6	2	.037
[Weather and Rel. Humidity]	21.0	4	.000
[Site and Week]	45.0	2	.000
[Site and Season]	39.6	2	.000
[Site and Temp.]	13.3	4	.010
[Site and Rel. Humidity]	49.8	6	.000
[Week and Season]	8.5	1	.004
[Week and Windspeed]	12.7	2	.002
[Week and Rel. Humidity]	8.6	3	.035
[Season and Rel. Humidity]	16.4	3	.001
[Temp. and Rel. Humidity]	19.9	4	.001
[Windspeed and Rel. Humidity]	19.4	6	.004

Dependent Variable: [TRAFCO – Manual Count] hourly basis.

df: Degree of freedom

In Table C3, The Wald statistic provides a perception of the significance of each independent variable in the equation. The Wald statistic presents a chi-square distribution. If the significance value is less than 0.05, it can be understood that the independent variable does make a strong impact. When the value is more than 0.05, the impact is not considered as strong. However, this research included values of less than 0.1 as significant.

Table C4 presents the estimators β_o to β_n corresponding to the regression equation for predicting the dependent variable from the independent variable (β_o

is the coefficient for the constant or “intercept” in the null model), the standard error around the coefficients for the constant, the lower and upper bounds of the 95 percent confidence interval, the Wald Chi-square statistic, the degree of freedom (df) for the Wald Chi-square test and the significance associated with the coefficients. The windchill factor was found to be not significant by the GLM.

With these β values obtained for the logistic regression equation, the hourly difference in pedestrian volume between the TRAFCO automated count and the ground truth data can be predicted.

Table C4: Parameters Estimates for [TRAFCO – Manual Count] Model

Independent Variables and their Combinations	β	Significance
(Intercept)	-89.876	0.000
[weather=Fog]	35.735	0.115
[weather=Freezing Drizzle]	39.885	0.077
[Site=Bishop Grandin]	49.496	0.000
[Site=Corydon at Lilac]	63.953	0.000
[Week=weekday]	53.730	0.009
[Season=fall]	80.075	0.004
[Windspeed < 15km/h]	53.362	0.000
[Windspeed >= 45km/h]	43.285	0.000
[Windspeed (15 to 30)km/h]	37.059	0.001
[Rel. Humidity < 45%]	-48.296	0.001
[Rel. Humidity >= 75%]	22.220	0.094
[Rel. Humidity (45 to 60)%]	23.366	0.051
[weather=Fog] and [Site=Corydon at Lilac]	-19.952	0.020
[weather=Freezing Drizzle] and [Site=Corydon at Lilac]	-25.865	0.028
[weather=Clear] and [Season=summer]	48.506	0.070
[weather=Clear] and [Temp. >= 15 ^{o}C]	-17.396	0.015
[weather=Clear] and [Windspeed < 15km/h]	-22.468	0.073
[weather=Fog] and [Windspeed < 15]	-22.027	0.081
[weather=Fog] and [Windspeed (15 to 30)km/h]	0.281	0.979
[weather=Clear] and [Rel. Humidity >= 75%]	15.264	0.093
[weather=Clear] and [Rel. Humidity (45 to 60)%]	-12.05	0.022
[Site=Bishop Grandin] and [Week=weekday]	-19.170	0.000
[Site=Corydon at Lilac] and [Week=weekday]	-27.852	0.000
[Site=Bishop Grandin] and [Season=fall]	-34.816	0.026
[Site=Corydon at Lilac] and [Season=fall]	-27.764	0.031
[Site=Bishop Grandin] and [Temp.=< -15 ^{o}C]	-40.076	0.004
[Site=Corydon at Lilac] and [Temp.=< -15 ^{o}C]	-27.089	0.002
[Site=Bishop Grandin] and [Windspeed >=45km/h]	-35.088	0.036
[Site=Corydon at Lilac] and [Windspeed < 15km/h]	-10.404	0.105
[Site=Corydon at Lilac] and [Windspeed (15 to 30)km/h]	-10.062	0.039
[Site=Bishop Grandin] and [Rel. Humidity (45 to 60)%]	-10.455	0.047
[Site=Corydon at Lilac] and [Rel. Humidity >=75%]	-28.186	0.000
[Site=Corydon at Lilac] and [Rel. Humidity (45 to 60)%]	-22.588	0.000
[Week=weekday] and [Windspeed < 15km/h]	-19.216	0.007
[Week=weekday] and [Windspeed >=45km/h]	-39.628	0.002
[Week=weekday] and [Rel. Humidity (45 to 60)%]	-8.257	0.056
[Season=fall] and [Windspeed < 15 km/h]	-27.176	0.027
[Season=fall] and [Windspeed (15 to 30)km/h]	-24.581	0.058
[Season=summer] and [Windspeed < 15km/h]	-38.449	0.006
[Season=summer] and [Windspeed (15 to 30)km/h]	-35.088	0.013
[Season=fall] and [Rel. Humidity < 45%]	19.874	0.004
Temp.=>= 15 C] and [Rel. Humidity =< 45%]	25.610	0.003
[Windspeed=< 15] and [Rel. Humidity >=75%]	-16.619	0.069
[Windspeed=15-30] and [Rel. Humidity >=75%]	-17.378	0.059

Note: Dependent Variable: [TRAFCO – Manual Count] per hour

β: Estimators for the logistic regression equation

Table C5 shows only the significant variables that were determined by the GLM model. The Wald statistic provides a perception of the significance of each independent variable in the equation. The Wald statistic presents a chi-square distribution. If the significance value is less than 0.05, the independent variable does make a strong impact. When the significance value is more than 0.05, significance is not as strong. However, this research included values of less than 0.1 as significant. The GLM model found once again that the windchill factor is not significant.

Table C5: Significant Variables in the [Eco-Counter – Manual Counts] Model

Independent Variables and their Combinations	Type III		
	Wald Chi-Square	**df**	**Significance**
(Intercept)	4.211	1	0.040
weather	9.363	5	0.095
Site	23.202	2	0.000
Temp.	6.100	3	0.107
Rel. Humidity	17.699	3	0.001
[weather and Week]	7.083	2	0.029
[weather and Season]	21.276	1	0.000
[weather and Temp.]	6.435	2	0.040
[weather and Windspeed]	12.837	7	0.076
[weather and Rel. Humidity]	10.821	4	0.029
[Site and Week]	7.542	2	0.023
[Site and Season]	29.834	2	0.000
[Site and Temp.]	20.409	4	0.000
[Site and Rel. Humidity]	24.964	6	0.000
[Week and Windspeed]	9.890	2	0.007
[Week and Rel. Humidity]	8.681	3	0.034
[Season and Rel. Humidity]	16.760	3	0.001
[Temp. and Rel. Humidity]	22.378	4	0.000
[Windspeed and Rel. Humidity]	31.986	6	0.000

Note Dependent Variable: [Eco-Counter – Manual Count] per hour.

df: Degree of freedom

Table C6 presents the estimators β_o to β_n corresponding to the logistic regression equation for predicting the dependent variable from the independent variable (β_o is the coefficient for the constant or "intercept" in the null model), the standard error around the coefficients for the constant, the lower and upper bounds of the 95 percent confidence interval, the Wald Chi-square statistic, the degree of freedom (df) for the Wald Chi-square test and the significance associated with the coefficients. The windchill factor was found to be not significant by the GLM.

Table C6: Parameter Estimates for [Eco-Counter – Manual Count] Model

Independent Variables and their Combinations	β	Significance
(Intercept)	-31.461	0.074
[Site=Bishop Grandin]	23.586	0.007
[Site=Corydon at Lilac]	21.013	0.001
[Season=fall]	39.831	0.059
[Season=summer]	11.571	0.686
[Windspeed < 15km/h]	22.149	0.032
[Windspeed >=45km/h]	27.703	0.001
[Windspeed (15 to 30)km/h]	14.227	0.103
[Rel. Humidity < 45%]	-51.50	0.000
[weather=Clear] and [Site=Corydon at Lilac]	-11.301	0.153
[weather=Clear] and [Season=summer]	37.713	0.061
[weather=Cloudy] and [Season=fall]	-19.339	0.149
[weather=Clear] and [Temp. >= 15^{o} C]	-13.613	0.011
[weather=Clear] and [Rel. Humidity < 45%]	8.306	0.093
[Site=Bishop Grandin] and [Week=weekday]	-5.790	0.094
[Site=Corydon at Lilac] and [Week=weekday]	-8.382	0.006
[Site=Corydon at Lilac] and [Season=summer]	19.162	0.052
[Site=Corydon at Lilac] and [Temp. < -15 ^{o}C]	13.156	0.051
[Site=Corydon at Lilac] and [Temp. >= 15 ^{o}C]	-14.167	0.004
[Site=Corydon at Lilac] and [Windspeed < 15km/h]	-9.392	0.051
[Site=Bishop Grandin] and [Rel. Humidity >= 75%]	-8.022	0.050
[Site=Corydon at Lilac] and [Rel. Humidity < 45%]	15.592	0.001
[Site=Corydon at Lilac] and [Rel. Humidity (45 to 60)%]	-5.209	0.121
[Week=weekday] and [Season=fall]	-34.047	0.025
[Week=weekday] and [Season=summer]	-30.487	0.047
[Week=weekday] and [Temp. < -15 ^{o}C]	-20.731	0.156
[Week=weekday] and [Windspeed < 15km/h]	-12.714	0.017
[Week=weekday] and [Windspeed >= 45km/h]	-24.360	0.011
[Week=weekday] and [Rel. Humidity < 45%]	13.706	0.009
[Season=fall] and [Rel. Humidity < 45%]	20.660	0.000
[Season=fall] and [Rel. Humidity (45 to 60)%]	11.810	0.157
[Temp. >= 15 ^{o}C] and [Windspeed < 15km/h]	-12.417	0.055
[Temp. < -15 ^{o}C] and [Rel. Humidity >= 75%]	12.762	0.067
[Temp. >= 15 ^{o}C] and [Rel. Humidity < 45%]	22.121	0.001
[Temp. >= 15 ^{o}C] and [Rel. Humidity >= 75%]	16.749	0.029
[Windspeed < 15km/h] and [Rel. Humidity (45 to 60)%]	8.632	0.156
[Windspeed (15 to 30)km/h] and [Rel. Humidity (45 to 60)%]	-9.228	0.058

Note: Dependent Variable: [Eco-Counter – Manual Count] per hour
β: Estimators for the logistic regression equation