

# **Analysis of Pedestrian Traffic on Multi-use Trails in Winnipeg, Canada**

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## ABSTRACT

The purpose of this research is to analyse pedestrian volumes on multi-use trails in Winnipeg, Canada. The research methodology consisted of collecting continuous automated pedestrian count volumes at seven locations on four multi-use trails in Winnipeg from January 1, 2014 to December 31, 2014. An average pedestrian volume was calculated for each count site over annual, seasonal, and monthly time periods. Pedestrian volumes were found to vary consistently by month of year and hour of day. Day-of-week patterns were not consistent in terms of pedestrian volume. There was a negative relationship between pedestrian volume and rainfall volume and duration, and average daily wind speed. There was a positive non-linear relationship between pedestrian volume and maximum daily temperature. While pedestrian volume correlates with weather factors, variability remains. This suggests that weather analysis may be useful as a complement, but not a replacement of traditional temporal analysis for estimation of pedestrian volumes.

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# **1 INTRODUCTION**

## **1.1 RESEARCH PURPOSE**

The purpose of this research is to examine the variability of pedestrian traffic on multi-use trails in Winnipeg. In order to conduct analysis, one full year of continuously collected pedestrian volume data was collected at seven count sites on multi-use trails in Winnipeg. The research uses this data to recommend a calculation method for average daily pedestrian traffic on a monthly, seasonal, and annual basis and to examine the relationship between both temporal and weather factors and pedestrian traffic. The findings and recommendations of this research are intended to inform pedestrian data collection and analysis and add to the current body of knowledge in pedestrian traffic monitoring.

## **1.2 BACKGROUND AND NEED**

Pedestrian and bicycle activity, referred to as active transportation (AT) or non-motorized transportation, is steadily increasing in North America (Ryan & Lindsey, 2013; Harris, 2013). Increases in the number of pedestrians and bicycles signal a number of benefits and challenges. The benefits of active transportation are many. Cycling and walking are considered zero emissions transportation modes, and therefore contribute to emissions reduction targets by reducing the number of motor vehicles using the transportation system and decreasing congestion (Bergstrom & Magnusson, 2003; Hankey, et al., 2012; Pratte, 2011; Wadud, 2014; Klassen, 2014). The cost of infrastructure for active transportation modes is low relative to the costs of infrastructure for motor vehicles, because non-motorized modes are not sufficiently heavy to damage pavements and require less road right-of-way (Agarwal & North, 2012). In addition, the positive effects of physical activity on health are well documented (Saunders et al., 2013). Saunders et al. (2013) examined and synthesised literature on the

effects of active transportation on health and found a positive effect of active travel on health, even after controlling for other variables.

One of the current challenges related to the increase in popularity of active transportation is a lack of understanding of the characteristics and volumes of people using the facilities (Markowitz, Montufar, & Lovejoy, 2012; Federal Highway Administration [FHWA], 2013). According to Hankey, Lindsey, and Marshall (2014), “key questions remain on best practices for virtually all elements of monitoring.” Improved data leads to better allocation of and justification for funding, informs planning and project development, helps jurisdictions prioritize infrastructure projects and maintain existing infrastructure, and can be used to make safety improvements (Hankey et al., 2012; Ryan & Lindsey, 2013; Lindsey et al., 2007). Pedestrian data also can improve the assessment of the impacts of development (Schneider et al., 2012). Overall, improved data will assist jurisdictions with managing their growing networks of non-motorized transportation infrastructure (Lindsey et al., 2014).

In many cases, decision makers do not have the basic data needed to adequately address the needs of non-motorized transportation modes (FHWA, 2013). Data collection for active transportation is not as developed as data collection for vehicular traffic or transit, in part because long range planning has historically not been federally mandated for non-motorized modes (Ryan & Lindsey, 2013). Lack of pedestrian and cyclist data means that these modes aren’t as well understood and it is harder to address them in long range planning. Data provide the foundation for transportation planning programs, which means that pedestrian and cyclist data collection is essential to planning complete streets and accommodating non-motorized modes (Hankey et al., 2014).

Along with the need for data comes the need to interpret and understand the story the data are telling. Interpretation of pedestrian data requires procedures which can be easily used by practitioners and provide meaningful results (Lindsey et al., 2007). Standard procedures exist for analysing and

interpreting data for motor vehicles, but these procedures are not yet established for non-motorized traffic (Nordback et al., 2013; Hankey et al., 2012). One specific research need is to quantify pedestrian traffic patterns to create traffic models which function accurately and are simple for practitioners to use (Lindsey & Lindsey, 2004; Lindsey et al. 2007). Better predictions of network-wide traffic volumes are made possible by investigating and understanding the causes of variation in non-motorized traffic volumes (Schneider et al., 2012). One of the key measures of traffic volume for any mode is the annual average daily traffic (AADT), which is a powerful tool for summarizing volume at a given location. AADT can be used to create factors based on pedestrian traffic patterns, and estimate AADT at other locations where continuous counts are not available (FHWA, 2013). This enables practitioners to understand where, and how many, pedestrians are travelling in the transportation network.

This research, which is part of a larger research project on active transportation on multi-use trails, addresses the lack of pedestrian volume data by documenting the methodology used to collect continuous pedestrian counts on multi-use trails and discussing the prevention and mitigation of data collection problems. The research also describes the data quality control issues and investigates methods of calculating average daily pedestrian traffic. Finally the research considers the variability of pedestrian traffic on multi-use trails with respect to both temporal and weather factors.

### **1.3 OBJECTIVES AND SCOPE**

The objectives of this research are to:

- (1) Understand current research and practice concerning pedestrian traffic monitoring on recreational facilities in Canada and the United States.

- (2) Understand and apply a methodology to collect pedestrian traffic volumes on multi-use trails in Winnipeg, including site selection, equipment selection, field set-up of equipment, and monitoring pedestrian traffic.
- (3) Determine an appropriate approach to calculate average daily pedestrian traffic from continuous counts.
- (4) Examine the variation of pedestrian traffic on multi-use trails in Winnipeg with respect to temporal and weather factors.

The scope of this research is limited to multi-use trails in Winnipeg, Canada; however the findings are relevant for similar recreational pedestrian facilities across Canada. The data used in this research comprises seven count sites on four trails and includes one full year of continuous data from January 1, 2014 to December 31, 2014.

## **1.4 THESIS ORGANISATION**

This thesis is organised into five chapters. Chapter two provides an environmental scan including a literature review and a jurisdictional survey. The literature review summarizes the development of non-motorized traffic monitoring programs, including the collection and analysis of non-motorized traffic data. The jurisdictional survey reviews current practices regarding pedestrian traffic monitoring and analysis in Canada and the United States.

Chapter three describes the methodology used to collect pedestrian traffic data. The methodology addresses the selection of sites for pedestrian data collection, the selection of counting equipment, the field set-up, calibration, and collection of pedestrian traffic data, and discusses special issues encountered during the data collection process.

Chapter four describes quality control procedures and analysis of the variation in pedestrian volume with respect to temporal and weather factors. This chapter provides the basis of understanding from which to conduct future research into methods of quantifying pedestrian volumes throughout a network of multi-use trails. Chapter four reviews data quality control, describes an approach to calculate ADPT for different time periods, and summarizes pedestrian traffic patterns with respect to temporal and weather factors.

Chapter five summarizes the conclusions of the research, and discusses opportunities for future research.

## 1.5 THESIS TERMINOLOGY

This thesis contains the following terms, defined as they relate to pedestrian traffic monitoring:

**Non-motorized transportation:** Travel by any mode that does not rely on a motor to move, such as walking and cycling. Non-motorized transportation is also referred to as active transportation. Non-motorized traffic describes the users of non-motorized modes.

**Multi-use trail:** A facility for the exclusive use of non-motorized traffic. Multi-use trails are separated from infrastructure for motorized traffic.

**Average Daily Pedestrian Traffic:** The average number of pedestrians passing a specific point in a given time period. The following terms describe specific types of averages referred to in the research:

- **Annual Average Daily Traffic (AADT):** The average daily traffic at a given location measured over one year (FHWA, 2013). AADT can be representative of any mode of transportation.
- **Seasonal Average Daily Traffic (SADT):** The average daily traffic at a given location measured over a series of high volume months in a location with high seasonal peaking (FHWA, 2013).

- **Average Daily Pedestrian Traffic (ADPT):** The average daily pedestrian traffic measured over an unspecified time period.
- **Annual Average Daily Pedestrian Traffic (AADPT):** The average daily pedestrian traffic measured over a one-year period.
- **Seasonal Average Daily Pedestrian Traffic (SADPT):** The average daily pedestrian volume measured over the months of May to October.
- **Monthly Average Daily Pedestrian Traffic (MADPT):** the average daily pedestrian traffic at a given location measured over a one month period.

**Continuous count:** Traffic volume data which has been collected 24 hours a day over a period of one year (FHWA, 2013). Continuous counts are used to calculate AADT and as a basis for estimating pedestrian traffic in short duration count locations. The location of a continuous count is referred to as a continuous count site.

**Short duration count:** Pedestrian data which has been collected over a shorter time period than continuous counts, usually between two hours and two weeks in duration (FHWA, 2013). The location of a short duration count is referred to as a short duration count site.

**Traffic Pattern:** A repeatable trend in traffic volumes (FHWA, 2013). In this research, pedestrian traffic patterns are linked either to temporal factors such as hour-of-day, day-of-week, and month-of-year, or to weather factors such as temperature, precipitation, and wind.

#### **OTHER ACRONYMS:**

**AASHTO:** The American Association of State Highway and Transportation Officials

**FHWA:** Federal Highway Administration

**TMG:** Traffic Monitoring Guide, produced by the FHWA

**HOD:** Hour of the day

**DOW:** Day of the week

**MOY:** Month of the year

## **2 ENVIRONMENTAL SCAN**

This environmental scan summarizes pedestrian traffic monitoring research and practice through a literature review and a jurisdictional survey.

### **2.1 LITERATURE REVIEW**

This literature review summarizes the current body of research on non-motorized traffic monitoring programs. Non-motorized transportation is also referred to in this report as active transportation (AT). Most of the current research on non-motorized traffic monitoring focuses on either cyclist-only traffic or mixed cyclist and pedestrian traffic. Separation of pedestrian and cyclist volumes for analysis is becoming more feasible as automated detection technologies become less expensive, more accurate, and more readily available (Lindsey et al., 2014). This literature review summarizes the research on non-motorized traffic monitoring only as it relates to pedestrians.

#### **2.1.1 Correlates of Non-Motorized Traffic**

There are a variety of ways to monitor and characterize non-motorized traffic. Methods of analysing traffic volume rely on one or more correlates of non-motorized traffic in order to quantify the variability which occurs. The most common variables used in non-motorized traffic analysis include socio-demographic factors, the built environment, weather, and temporal factors (Wang et al., 2014). Other correlates of non-motorized traffic include transportation mode choice, transportation and land-use policies, network connectivity, existing transportation infrastructure, transit proximity, public support, population density, and employment density (Lindsey & Lindsey, 2004; Schneider et al., 2012; Hankey et al., 2012).

Socio-demographic factors and elements of the built environment are relatively constant over time and are helpful in providing baseline information and estimating demand where no other data is available. Socio-demographic factors include information about the education levels, incomes, ages, ethnicities, gender ratios, and occupations of a population near an AT facility (Wang et al., 2014). Ryan and Lindsey (2014) found that in areas with a lower than average income there was a slight correlation with higher pedestrian volumes. Built environment factors include location, population density, infrastructure, and land-use (Wang et al., 2014; Lindsey & Lindsey, 2004).

Non-motorized traffic monitoring analysis commonly incorporates weather and temporal factors. Lindsey et al. (2014) found that activity patterns on multi-use trails tend to vary consistently in response to temporal and weather factors, regardless of volume. Weather factors explain the variation in pedestrian volumes due to climate conditions, while temporal factors capture the variations of non-motorized traffic over time.

Precipitation and temperature are widely known to affect non-motorized traffic volumes (Schneider et al., 2012). In general, as precipitation increases, non-motorized traffic volumes decrease. As temperature increases, non-motorized traffic volumes tend to increase as well, up to a temperature of roughly 30°C, above which volumes begin to decrease (Ryan & Lindsey, 2013). The perceived temperature, which incorporates the effects of wind chill or humidity, may also be an influencing factor (Nordback, Marshall, & Janson, 2013). Other weather factors, such as the amount of sunlight, wind speed, and humidity have also been found to affect volumes (Nordback et al., 2013a; Hankey et al., 2014; Wang et al., 2014; Lindsey et al., 2007). Expectations about weather events based on daily forecasts, normals for the period, or even the weather from the previous day could affect volume (Lindsey & Lindsey, 2004). Both the weather forecast and the occurrence of a weather event have the potential to influence the non-motorized traffic volume throughout the day, particularly for commuters

(Nordback et al., 2013a). For example, if a weather event such as rain happens in the morning, commuters may choose an alternative mode of transportation, which would affect both the AM and PM traffic volume.

Temporal factors reflect the variations in non-motorized traffic over time, and analysis evaluates traffic variations over a given day, week, month, or year (FHWA, 2013; Wang et al., 2014; Lindsey & Lindsey, 2004). Time-of-day and day-of-week patterns vary based on location, trip purpose, and facility type (FHWA, 2013). Monthly variation depends primarily on geographic location, and is largely a result of seasonal changes. In climates with seasonal variation, the highest volumes are expected during summer and the lowest volumes are expected during winter. Annual variation could occur as a result of changes in attitudes about AT, climate, socio-demographics, or the built environment.

### **2.1.2 Summary Statistics for Non-Motorized Transportation Data**

Non-motorized traffic monitoring is an emerging field in North America and metrics for quantifying AT data are not yet well defined. Current analysis borrows extensively from motor-vehicle traffic monitoring. The 2013 U.S. Traffic Monitoring Guide (TMG), released by the U.S. Federal Highway Traffic Administration, recommends the use of summary statistics to describe non-motorized traffic, including Annual Average Daily Traffic (AADT) and Seasonal Average Daily Traffic (SADT), which are concepts borrowed from motor vehicle traffic monitoring. Both represent an average traffic volume, either over a one year period in the case of AADT, or in the case of SADT, over a shorter time period representing months with high seasonal peaking due to changes in climate or recreational activity.

No research has been conducted to specifically investigate the use of AADT and SADT in pedestrian traffic monitoring; however, some measure of total or average pedestrian volume is useful for describing activity and modeshare on AT facilities, calculating exposure for safety analysis, assessing

traffic changes over time, and giving justification for funding and other infrastructure improvements (Lindsey et al., 2014). Some research in the field of non-motorized traffic is beginning to investigate other measures than AADT. Metrics such as peak hour volumes and total distance traveled are potential alternatives or complements to AADT (Lindsey et al., 2014; FHWA, 2013). Currently there is very limited research available regarding the calculation of summary statistics for pedestrian traffic.

### **2.1.3 Non-Motorized Traffic Monitoring Program Structure**

One of the current challenges in non-motorized traffic research is the lack of existing data (Lindsey et al., 2013). Many jurisdictions do not have well established AT monitoring programs and must rely on non-empirical estimations of seasonal or annual volumes (Lindsey et al., 2014). With a dearth of historical data, and insufficient sample sizes for analysis, it is difficult to understand patterns and trends and impossible to calculate accurate summary statistics (Lindsey et al., 2013). Non-motorized traffic data collection reduces the number of assumptions that must be made and decreases the error of volume estimates (Lindsey et al., 2013). The TMG provides direction for the development of non-motorized traffic monitoring programs and recommends a basic structure combining continuous and short duration counts (FHWA, 2013).

#### *2.1.3.1 Continuous Counts*

Continuous counts are records of all traffic volumes for at least one full season or year (FHWA, 2013). Continuous counts are used to find patterns in non-motorized traffic and calculate summary statistics such as AADT. The traffic patterns and summary statistics obtained from continuous counts are then linked to short duration counts to inform estimates of traffic volumes across a network.

Non-motorized traffic volumes exhibit more variability than motorized traffic volumes (Turner & Lasley, 2013). The variability in non-motorized traffic is correlated to factors such as weather, time, socio-

demographics, and the built environment, as discussed in Section 2.1.1. The number of continuous count sites required to correctly identify the different non-motorized traffic patterns in a network is likely to be higher than the requirements for motorized traffic because of the increased variability (FHWA, 2013).

### 2.1.3.2 *Short Duration Counts*

Short duration counts provide traffic volume data where continuous counts are unavailable. As the name suggests, short duration counts are records of volumes over a smaller time period than continuous counts. AADT can be estimated from short duration counts by linking short duration counts to continuous counts which are expected to exhibit similar traffic patterns. There is an increasing trend toward standardization of count protocols, including standardized forms, specific training, and a system of checks and balances (Lindsey et al., 2013). A single standardized methodology to conduct short duration counts has not yet been established, resulting in many organizations and jurisdictions developing their own procedures. Short duration counts can be collected manually or using automated count technologies. Automated short duration counts can account for more of the variability introduced by weather events such as rain or snow because they can collect data longer than manual counts.

Short duration counts should be conducted during seasons with higher pedestrian activity, such as the summer or early fall because this period yields more accurate AADT estimates (Lindsey et al., 2013). Tuesday, Wednesday, and Thursday are recommended as the best days to conduct counts because AT volumes have been found to be more consistent on those days than the rest of the week (Nordback et al., 2013b). The TMG recommends minimum manual count durations of four hours; however, the optimal manual count duration is 12 hours (FHWA, 2013). For automated counts, durations between one and seven days are recommended. As count duration increases, the error of estimated summary statistics tends to decrease (Nordback et al., 2013a). The current recommendation for AADT estimation

is to use short duration counts of seven days in order to observe traffic on each day of the week, particularly because traffic patterns tend to vary between weekends and weekdays.

Short duration counts can either be conducted over a single period of time or on multiple occasions at the same location (Nordback et al., 2013a). Hankey et al. (2014) examined the error from data used to estimate AADT that was collected five days consecutively compared with data collected on five random days. The study found that there was no significant difference in the accuracy between the two methods. Sampling for five days continuously is preferred from a practicality standpoint because it requires far fewer staff hours to set up and take down the counting equipment (Hankey et al., 2014).

### 2.1.3.3 *Resource Allocation*

Resource allocation calculations are an essential component of an effective traffic monitoring program (Hankey et al., 2014). The design of a traffic monitoring program requires compromises between the acceptable error of volume estimates and the available resources. Some constraints include the equipment availability, financial resources, the network extents, and staff availability. These constraints inform decisions about the number of counts, count durations, count site locations, and acceptable error. Depending on the purpose of data collection, decision makers can assess the level of detail and accuracy they require and plan their traffic monitoring program accordingly (Schneider et al., 2012).

Ideally, continuous counts would be used at all count sites throughout the network, but the cost of employing only continuous counters is prohibitive because it requires dedicated automated counting equipment (Nordback et al., 2013a). Short duration counts are an effective way of increasing network coverage at a lower cost. In a typical monitoring program in North America, most count sites are short duration counts in order to balance the need for network coverage with the existing resource constraints (Nordback et al., 2013a).

## 2.1.4 Automated Counting Equipment

Developments in count technology are rapidly evolving (FHWA, 2013). Some of the most common counting technologies used to collect non-motorized traffic volumes are listed below:

- Infrared beam counter
- Passive infrared counter
- Piezoelectric pad
- Computer vision
- Inductive loops

These technologies encompass both pedestrian and cyclist counting. Technologies which accurately and exclusively count pedestrians in mixed traffic are not currently available (National Cooperative Highway Research Program [NCHRP], 2014). As a result, technologies which count mixed mode traffic are sometimes paired with technologies that exclusively count cyclists in order to calculate the total number of pedestrians (NCHRP, 2014).

### 2.1.4.1 *Infrared Beam Counters (Active Infrared)*

Infrared beam counters, also known as active infrared counters, operate by emitting a continuous infrared beam, which is either transmitted to a receiver at the end of the sensing range or reflected back to the combined transmitting and receiving unit by a reflective device at the other end of the sensing range (Greene-Roesel et al., 2008; NCHRP, 2014; TMG, 2013). A count is recorded when the infrared beam is broken. These counters are capable of determining pedestrian direction using a dual sensor system (Ozbay et al., 2010). Infrared beam counters are inexpensive and commonly available. In addition, they are generally easy to install and have low power consumption. The transmitter and receiver must be aligned precisely in order to function properly, necessitating a solid mounting structure

to prevent false counts in windy outdoor environments (Ozbay et al., 2010). Infrared beam counters are also known to systematically undercount users travelling in groups. Active infrared is not capable of differentiating between pedestrians and other things which could break the beam, such as bicycles, dogs, insects, or even rain (NCHRP, 2014; Bu et al., 2007). In order to collect pedestrian volume data, active infrared counters need to be combined with bicycle counting technology.

#### 2.1.4.2 *Passive Infrared Counters*

Passive infrared counting technology senses heat from moving objects within the sensing range (TMG, 2013; NCHRP, 2014). Passive infrared counting devices record a count when they sense a temperature differential from the ambient conditions (Ryan & Lindsey, 2013). These counters are also capable of determining directionality using a dual sensor system (Bu et al., 2007). Passive infrared has been found to systematically undercount people passing the sensor side-by-side and calibration is required to properly identify groups of users (NCHRP, 2014). Nytepchuk (2016) found that the performance of passive infrared technology is also affected by season, with more undercounting occurring in summer than in winter. Some overcounting was also observed at one site at temperatures below -12°C; however, the results were inconclusive. The difference between summer and winter in the research by Nytepchuk (2016) could also be due to the occurrence of low volumes in winter, sometimes as few as five pedestrians per day. Passive infrared technologies are widely tested and available in North America (Yang, Ozbay, & Bartin, 2010; Ryan & Lindsey, 2013). The passive infrared sensor cannot differentiate between different modes of transportation and must be paired with bicycle counting technology to determine the number of pedestrians (Ozbay et al., 2010).

#### 2.1.4.3 *Piezoelectric Pads*

Piezoelectric pads are installed beneath the pavement and sense pressure changes from footsteps (NCHRP, 2014). The electric properties of the piezoelectric pad change when mechanical pressure is applied, which means that when a pedestrian steps on the sensor, a count is recorded (TMG, 2013; Bu et al., 2007). A timer prevents double counting due to multiple steps by the same pedestrian and several pads can be installed side-by-side to increase the sensing range. Since each sensor is separate, using multiple counters could differentiate between pedestrians walking side-by-side. These counters have low power consumption and can be installed on multi-use trails and in outdoor environments; however, they require subsurface installation which increases cost. Piezoelectric pads require physical contact between the pedestrian and the pad in order to record a count, and the coverage area cannot be changed once installation is completed (Bu et al., 2007). Some models of piezoelectric sensors can distinguish between bicycles and pedestrians (TMG, 2013). Those that cannot distinguish between modes must be paired with a bicycle counting technology to determine the number of pedestrians.

#### 2.1.4.4 *Computer Vision*

Computer vision uses video and intelligent processing and pattern recognition to count non-motorized traffic (TMG, 2013; Ozbay et al., 2010). Computer vision performs best in urban environments with good lighting (Greene-Roesel et al., 2008). Computer vision often requires an external power source, and is currently used primarily for indoor applications (Ozbay et al., 2010). The video and data may also be manually reviewed for calibration. Processing of computer vision continues to improve as new software becomes available, with current capabilities including the ability to distinguish pedestrians and cyclists as well as people moving in groups (TMG, 2013).

#### 2.1.4.5 *Inductive Loop Detectors*

Inductive loop detectors are used to detect cyclists and can be paired with sensors detecting mixed-mode traffic to determine pedestrian volumes. They are composed of a series of wires arranged in loops installed below the surface of a trail, road, or other cycling facility (NCHRP, 2014). A current runs through the wires, which creates a magnetic field that is disrupted when crossed by a metal object, such as a bicycle. Disruptions in the magnetic field are registered as counts.

#### **2.1.5 Equipment Selection**

Equipment selection must take a number of factors into consideration, including the purpose of the counts, the number and duration of counts required, and the resources available to conduct the counts (Ryan & Lindsey, 2013). Ryan and Lindsey (2013) recommend identifying count duration, the optimal count period, and the minimum sample size required before selecting equipment, as different count technologies perform better in different contexts; equipment selection must be based on the specific context in which counts are required (Ozbay et al., 2010).

For example, if the purpose of the counts is to obtain accurate data to validate another technology, the required counts would be for a relatively short duration of a few hours to a few days and computer vision or manual counts might be appropriate (Schweizer, 2005). If the purpose is to obtain long term continuous counts at outdoor locations, a more appropriate alternative might be to use a counter which is not dependent on a light source to conduct counts, is not affected by weather events, has sufficient data storage, and which has a long-lasting battery or permanent power source (Ozbay et al., 2010).

Financial and staff resources also constrain equipment selection. The amount of money available to purchase counters is balanced against the number of sites and the staff required to set up, calibrate, and monitor the equipment (Ozbay et al., 2010). Manual field observations and computer vision have

greater accuracy, but also have higher monetary cost, and require more staff hours (Schweizer, 2005). Less accurate technologies, such as infrared, inductive loops, or piezoelectric pads, tend to be less expensive than video or manual counts, are generally available from a variety of vendors, and are widely tested. Other factors to consider include availability of equipment, level of vendor support, ease of deployment, adjustability, ease of data transfer, and reliability of the equipment (Ozbay et al., 2010).

### **2.1.6 Quality Control**

Ozbay et al. (2007) define accuracy as “the measure of degree of agreement between a data value or set of values and a source assumed to be correct.” The level of accuracy required may vary depending on the purpose of the counts, and should be reflected in quality control procedures (Turner & Lasley, 2013; Nordback et al., 2013b). The three main components of quality control for non-motorized traffic monitoring are validation, calibration, and data cleaning. Validity is defined as the measured accuracy of data relative to the required accuracy of the data (Turner & Lasley, 2013). Validation is the process of determining whether the data meets the accuracy required for data collection. Calibration is a statistical process of adjusting data to improve the accuracy so that it falls within the acceptable range (Ozbay et al., 2010). Data cleaning is the process of identifying and managing erroneous data. The following sections describe each of the procedures commonly used to check the data for accuracy and reduce the occurrence of errors.

#### *2.1.6.1 Validation*

There are two basic validation methods for non-motorized traffic counts: controlled validation, and field validation (Turner & Lasley, 2013). The sample size of a validation count is measured in units of time and depends on the required accuracy and statistical significance, the expected volumes, and the unit of time used for analysis (Pettebone, Newman, & Lawson, 2010).

### ***Controlled Validation***

Controlled validation occurs in a controlled environment such as a lab, and involves repetitive tests of the counting equipment to simulate the effects of different potential count scenarios (Turner & Lasley, 2013). Examples of count scenarios include walking past the counter, standing still in front of the counter, two or more people walking side by side, two people passing the counter at the same time while walking in opposite directions, and close following (Ozbay et al., 2010). Turner and Lasley (2013) suggest that controlled validation include an incremental test of different group spacing, pedestrian and cyclist speeds, distance of counter to detection zone, equipment mounting heights, and ambient air temperatures. Manufacturers provide information about many of these variables.

### ***Field Validation***

Field validation is used to determine the effect of real traffic on the accuracy of counter data. Field validation involves the comparison of ground truth data with automated count data at a given count site. Ground truth data is typically obtained through manual observation or video processing (Turner & Lasley, 2013). Manual count accuracy varies depending on the observer's ability to focus, the complexity and volume of traffic, the number of variables being collected for each count, and the count duration (Ryan & Lindsey, 2014). The error of manual counts can be minimized by training observers, limiting the number of variables being collected, and limiting the count duration. Video combined with manual processing is more accurate than the field manual observation method but requires investment in equipment as well as staff to install and remove equipment, and process the data. As a result, manual observation remains a common way to obtain ground truth data (Turner & Lasley, 2013).

Ideally, field validation would occur at all count sites to capture the unique traffic characteristics at each count site. Correlates of pedestrian traffic should also be incorporated into field validation, including

different seasons, weather, and days of the week (Nytepchuk, 2016). In addition, Nytepchuk (2016) used manual count durations of two hours to prevent fatigue, counted during high volume hours to capture peak traffic, and the collected field notes to document additional details. Depending on the size of the monitoring program, counting at every site may not be possible, and validation may be conducted at a sample of possible count sites (Ozbay et al., 2010). Sampling involves counting at both low and high volume locations, in different seasons, and in different types of weather. Meta-data is also useful and includes detection zone dimensions, air temperature, precipitation type and degree, and equipment settings for each validation count period (Turner & Lasley, 2013).

Validation data is compared to the ground truth data to calculate equipment error. Error is calculated as the percent difference between the automated and ground truth data according to the following equation described by Greene-Roesel et al. (2008):

$$Error = \frac{NP_x - NP_v}{NP_v}$$

Where:

$NP_x$  = the number of pedestrians counted by automatic counters over a given time interval  
 $NP_v$  = the number of pedestrians counted as the ground truth for the same time interval  
(Greene-Roesel et al., 2008)

The time interval over which to conduct each error calculation can vary from five minutes to one hour, and synchronization between the automated counter time and the ground truth time is essential (Greene-Roesel et al., 2008; Ozbay et al., 2010).

#### 2.1.6.2 Calibration

Equipment used for counting non-motorized traffic tends to have systematic errors which can be adjusted through calibration. In this research, the term calibration is used to describe the correction of

systematic equipment errors using analytical methods. Nytepchuk (2016) conducted analysis of two passive infrared technologies in Winnipeg and found undercounting between 12% and 20%, depending on the technology and whether the count occurred on a weekday or a weekend day. Weekends were found to result in a higher degree of undercounting, corresponding with higher occlusion rates on weekends than on weekdays. Occlusion was found to account for about 60% of the error associated with passive infrared counters, and the correction factors were applied using multiple linear regression based on occlusion, day-of-week, season, weather, and count site (Nytepchuk, 2016). This finding corresponds with the general consensus in the research that passive infrared counters systematically undercount due to occlusion (NCHRP, 2014).

Research by Poapst (2015) tested the assumption that passive infrared technology undercounts systematically due to occlusion at two locations in Winnipeg. The automated counters in the study also presented systematic undercounting, as expected. Poapst (2015) also found that error results were more volatile at lower volumes, which is expected because even a difference of one pedestrian could have a large impact on the error.

Linear regression is often used to adjust counts, assuming a linear relationship between ground truth volume and automated volume (Pettebone et al., 2010). Some regression models force the regression line through the origin based on the assumption that automated counters are unable to record negative counts. This simplifies the equation to a single correction factor corresponding to the slope of the regression line. Non-linear regression techniques have also been employed in the calibration of non-motorized traffic data. Wang et al. (2014) used field observation to develop a non-linear correction equation for their data, which has also been applied in research by Lindsey et al. (2014).

Calibration is not always necessary when the analysis depends on relative volume proportions as the basis for comparing different count sites (Miranda-Moreno et al., 2013; Poapst, 2015). In cases where

patterns and relative proportions are the primary objectives of the research, the degree of undercounting between sites is assumed to be consistent and calibration may not be necessary (Nordback et al., 2013a).

### 2.1.6.3 *Data Cleaning*

The TMG recommends objective, formal, and systematic data cleaning procedures for non-motorized traffic monitoring (FHWA, 2013). The purpose of having good data cleaning and quality control procedures is to ensure the equipment is functioning properly and to present summary statistics which accurately represent truth-in-data. The development of formal procedures for quality control of pedestrian volume data is still underway. The following paragraphs summarize the current quality control approaches which have been taken for non-motorized volume data.

Visual review involves examining graphs with random samples of data, such as daily volumes, or hourly traffic (Turner & Lasley, 2013). Abnormally high counts and zero counts are typically flagged and removed from the dataset if they are not justified (Nordback et al., 2013a). Automated data cleaning techniques are useful when there is too much data to review visually; however, visual review is useful for smaller data sets and for catching some errors which pass through automated processes undetected (Turner & Lasley, 2013).

A common problem requiring data cleaning is counter malfunction due to sunlight. Turner and Lasley (2013) discuss this issue in detail and present a statistics-based methodology for correcting overcounting due to direct sunlight. The problem is characterized by higher counts in one direction than the other during specific periods of the day, and only on days with direct sunlight. When a false count is recorded, the counter software always assigns the count to a default direction. The proposed correction methodology involves isolating the false counts by subtracting the volumes in one direction from the

other, calculating the statistical five number summaries, and using the interquartile range to create a cut-off point for removal of false counts. The proportion of the correct counts in one direction relative to the other is then used to create a multiplier to establish new data points (Turner & Lasley, 2013).

## **2.2 JURISDICTIONAL SURVEY**

A jurisdictional survey was conducted in the fall of 2013 to understand the practice of pedestrian traffic monitoring in North America. The survey was sent to each provincial and territorial capital in Canada, as well as major U.S. cities in states bordering Canada. Additional cities in the U.S. were contacted based on recommendations from the jurisdictions which were contacted initially. The jurisdictions were selected in this way to gain a representative cross-Canada understanding of the state of AT monitoring in Canada, as well as to learn about the approaches taken in U.S. jurisdictions with similar seasonal changes in climate. Additional jurisdictions identified by initial survey respondents as leaders in the field of AT were contacted to learn from their more extensive experiences in AT traffic monitoring. In total, 18 jurisdictions in Canada and 18 jurisdictions in the U.S. were contacted and asked to fill out an online survey. Of these, 12 Canadian jurisdictions and 16 jurisdictions in the US responded. The results of the survey are described in this section. Table 2-1 shows the list of cities in Canada and the U.S. who responded to the survey, ordered geographically from east to west.

**Table 2-1: Cities that responded to the jurisdictional survey**

<b>Canadian Jurisdictions</b>	<b>U.S. Jurisdictions</b>
Halifax, NS	Manchester, NH
Fredericton, NB	Rochester, NY
Moncton, NB	Philadelphia, PA
Charlottetown, PEI	Columbus, OH
Quebec City, QC	Ann Arbor, MI
Ottawa, ON	Milwaukee, WI
Saskatoon, SK	Minneapolis, MN
Calgary, AB	Fargo/Moorhead, ND
Edmonton, AB	Albuquerque, NM
Yellowknife, NW	Denver, CO
Whitehorse, YT	Billings, MT
Victoria, BC	Boise, ID
	Sacramento, CA
	Portland, OR
	Seattle, WA
	Anchorage, AK

### **2.2.1 Extent of Pedestrian Volume Data Collection**

Table 2-2 shows the number of respondent jurisdictions in Canada and the U.S. which collect pedestrian volume data as well as the frequency of data collection. In Canada, seven of the twelve jurisdictions reported that they collect pedestrian volume data. In the U.S., fourteen of the sixteen jurisdictions reported that they collect pedestrian volume data. Of the respondent jurisdictions collecting pedestrian data, 57% of Canadian jurisdictions and 100% of respondents from the U.S. collect pedestrian data on a seasonal basis. About half of respondents collect data on an as needed basis and about one third of respondents collect data continuously. Respondents were given the option to check as many frequency measures as would apply, and as a result some jurisdictions selected more than one frequency to account for different types of counts.

**Table 2-2: Canadian and U.S. Jurisdictions Collecting Pedestrian Volume Data**

	Canadian Jurisdictions		U.S. Jurisdictions	
	Total	Percent	Total	Percent
<b>Collecting pedestrian data</b>	7	58%	14	88%
<b>Frequency of Data Collection</b>	(of 7)		(of 14)	
<b>As Needed</b>	3	43%	9	64%
<b>Seasonally</b>	4	57%	14	100%
<b>Continuously</b>	2	29%	5	36%

## 2.2.2 Selecting Sites for Pedestrian Volume Data Collection

Table 2-3 shows a summary of the most common reasons provided for selecting count sites, based on the seven Canadian respondents and the fourteen respondents from the U.S. who collect pedestrian volume data. Many respondents selected all of the five of the options shown in Table 2-3. In Canada, the responses were similar for each of the five approaches. In the U.S., a greater proportion of respondents identified establishing screenline counts as a reason for selecting sites. Selecting sites based on screenline counts may indicate that jurisdictions are starting to be intentional about developing an established monitoring program, rather than performing counts on an as needed basis. Relative to the other options, fewer respondents in both Canada and the U.S. choose their pedestrian volume count sites with vehicle counts.

**Table 2-3: Reasons for Pedestrian Count Site Selection**

	Canadian Jurisdictions		U.S. Jurisdictions	
	Total	Percent	Total	Percent
<b>Part of a Screenline Count Program</b>	4	57%	10	71%
<b>Project Based</b>	5	71%	8	57%
<b>Request Based (Professional)</b>	5	71%	8	57%
<b>Request Based (Citizen)</b>	5	71%	4	29%
<b>With Vehicle Counts</b>	3	43%	4	29%

### 2.2.3 Methods of Collecting Pedestrian Volume Data

Table 2-4 shows the methods of data collection used by jurisdictions currently collecting pedestrian volume data. In both Canada and the U.S., there were more jurisdictions that had some form of automated counting equipment than those who relied exclusively on manual counts. Of the respondents who have automated data collection in Canada, 100% used video imaging, and 50% paired infrared with inductive loops. Passive infrared counters are not capable of distinguishing between cyclists and pedestrians, but capturing cyclist volumes using inductive loops allows the calculation of pedestrian volumes. Of the respondents with automated data collection equipment in the U.S., 100% use either passive or active infrared, 36% use a combination of infrared with inductive loops, and 22% use video imaging.

**Table 2-4: Methods of Pedestrian Data Collection**

	Canadian Jurisdictions		U.S. Jurisdictions	
	Total	Percent	Total	Percent
<b>Data Collection Method</b>				
<b>Manual only</b>	3	57%	5	36%
<b>Automated*</b>	4	57%	9	64%
<b>Type of Equipment Used</b>	(of 4)		(of 9)	
<b>Infrared</b>	0	0%	9	100%
<b>Inductive Loops + Infrared</b>	2	50%	3	33%
<b>Video Imaging</b>	4	100%	2	22%

\*most jurisdictions collecting automated data also collect manual data

### 2.2.4 Short Duration Pedestrian Counts

Table 2-5 describes the durations and analysis of short duration counts performed by the survey respondents. Of the respondents collecting pedestrian volume data, 100% conduct short duration counts. 71% of respondents in the U.S. and 29% of Canadian respondents collect two-hour pedestrian counts. Two-hour counts are typically collected to identify peak volumes. Of the sub-24-hour counts, some respondents count during three peak periods during the day, others conduct 12-hour counts, and

a variety of other durations were given. Of the jurisdictions collecting pedestrian data, about 20% in Canada and 40% in the U.S. perform factor analysis on the data. These results correspond with the number of jurisdictions performing continuous counts. There was no consistent analysis approach listed in the responses of the type of analysis conducted. Responses included using the National Bicycle and Pedestrian Documentation Project (NBPD) approach, calculating hourly proportions of daily traffic, using vehicle factors, and applying calibration factors. The lack of a consistent methodology for jurisdictions to perform analysis may explain the low numbers of respondents who use their count data for further analysis.

**Table 2-5: Pedestrian Count Durations and Analysis**

	Canadian Jurisdictions		U.S. Jurisdictions	
	Total	Percent	Total	Percent
<b>Collecting Short Duration Counts</b>	7	100%	14	100%
<b>Count Durations</b>				
<b>Two Hours</b>	2	29%	10	71%
<b>Between Two Hours and One Day</b>	5	71%	4	29%
<b>One Day</b>	1	14%	0	0%
<b>Seven Days or More</b>	0	0%	3	21%
<b>Factoring Short Duration Counts</b>				
<b>Using Factors to Adjust Counts</b>	2	17%	6	38%

### 2.2.5 Challenges of Pedestrian Volume Data Collection

Respondents were asked about challenges and lessons learned in pedestrian volume monitoring. The most common response (eight of the twenty respondents who answered this question) was that they lack the staff, volunteer, or financial resources needed to establish a traffic monitoring program. Seven respondents cited challenges installing or calibrating equipment to account for occlusion, five respondents stated that they need to conduct more counts, and four more felt that manual counts were inadequate at high volume locations due to the complexity of counting. Some respondents mentioned vandalism as a challenge, particularly with infrared counters. Other challenges included pedestrians

loitering in front of counters, the difficulty of obtaining consistent results, lack of established methodologies, and the difficulty of isolating pedestrian volumes from mixed traffic.

## **2.3 SUMMARY OF ENVIRONMENTAL SCAN**

The environmental scan highlighted the following findings:

- Pedestrian traffic monitoring is in its infancy and further research is needed in almost all areas.
- Correlates of non-motorized traffic include socio-demographic factors, the built environment, weather, and temporal factors.
- The basic non-motorized traffic monitoring program structure is to collect a combination of short duration and continuous counts in order to estimate pedestrian volumes throughout the network, typically represented as a measure of average daily traffic (FHWA, 2013).
- Of the jurisdictions who responded to the jurisdictional survey, 58% of Canadian jurisdictions and 88% of U.S. jurisdictions responded that they collect pedestrian data. Of these, over half indicate that they use automated counters for data collection; however, most continue to use manual data collection as well.
- For short duration counts, most jurisdictions use manual counts of less than one day (24 hours)
- Challenges of data collection include the lack of resources, and equipment installation and calibration issues.

This research contributes to the current body of knowledge in pedestrian traffic monitoring by developing a pedestrian counting system, examining weather and temporal correlates of non-motorized traffic, and evaluating ways of estimating AADT.

### **3 METHODOLOGY**

This chapter describes the methodology used to collect pedestrian volume data. It includes the selection of sites for pedestrian data collection and pedestrian count equipment, as well as the field set-up of the pedestrian count equipment. This chapter also addresses special issues encountered during the count process. One common methodology for active transportation data collection was developed as part of a larger non-motorized traffic monitoring project for the City of Winnipeg. The aspect of this methodology involving cyclists was originally described in Budowski (2015). The same general methodology was used in this research, with the exception of the use of additional counting equipment (Pyro Boxes). The following sections, which are also contained in Budowski (2015), summarize the methodology applied in this research.

#### **3.1 SELECTION OF COUNTING TECHNOLOGY FOR ANALYSIS**

Count technologies were selected based on their suitability for use on outdoor urban trails in Winnipeg. No pedestrian-only count technologies existed at the time of equipment selection; therefore, mixed-mode and cyclist-only count technologies were paired to isolate pedestrian volumes. The calculation method for determining pedestrian volume using paired technology is described at the end of this section. Eco-Counter's inductive loop sensors, known as Zelt counters were chosen to collect cyclist volumes, as described by Budowski (2015). Five additional technologies were considered to collect mixed-mode non-motorized traffic and are listed below:

- Passive infrared
- Active infrared
- Laser scanners
- Piezoelectric pads

- Video imaging

The researchers selected passive infrared technology based on its cost effectiveness, availability, ease of installation, and versatility in outdoor conditions. The passive infrared technology is readily available at a low cost relative to the alternatives, is convenient to install and able to collect counts at night and in adverse weather (Yang et al., 2010; Ryan & Lindsey, 2013). The Pyro Box Compact (Pyro counter) supplied by Eco-Counter was the counter selected for the research. It uses passive infrared technology to count non-motorized traffic. The Pyro counter has low power consumption, lasting for up to ten years on a single battery, and requires little maintenance. Its dual-sensor technology also enables the counter to record direction (Bu et al., 2007).

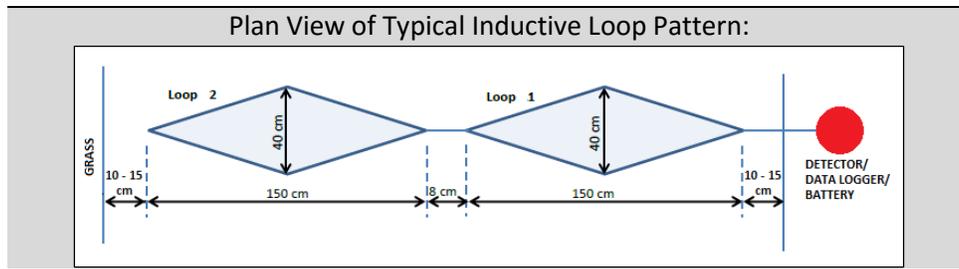
A disadvantage of using the Pyro counter is that it may become unreliable in extreme heat or cold (Nytepchuk, 2016). Extreme heat or cold conditions which could affect the counter are not common in Winnipeg, and this disadvantage was not considered to significantly hinder data collection. Research by Nytepchuk (2016) found that the performance of Pyro counters was significantly affected by site and seasonal conditions. Some inconsistencies were observed in results below 12°C, with one of the study sites in Winnipeg exhibiting occasional overcounting at these temperatures. The technology also systematically undercounts due to pedestrians walking side-by-side (occlusion); however, the effects of occlusion can be calibrated (NCHRP, 2014). Nytepchuk (2016) found that in Winnipeg, occlusion accounted for approximately 60% of the error observed. The Pyro counter counts both pedestrians and cyclists and does not distinguish between the two modes (Ozbay et al., 2010). The specifications for the Pyro and Zelt counter technologies are shown in Table 3-1 and Table 3-2 respectively.

**Table 3-1: Eco-Counter Pyro Box Compact technical specifications as provided by Eco-Counter (Poapst, 2015 – used with permission)**

<b>Dimensions</b>	23 x 10 x 18 cm (9 x 3.9 x 7 inch)
<b>Weight</b>	2.6 kg (5.9 lbs)
<b>Battery Life</b>	10 years
<b>Operating Temperature</b>	-40°C to 50°C (-40°F to 140°F)
<b>Sensitivity</b>	1°C difference between body and ambient temperature
<b>Waterproof</b>	IP 68
<b>Data collection</b>	GSM connection (Passive Remote)

**Table 3-2: Eco-Counter Zelt technical specifications as provided by Eco-Counter (Budowski, 2015 – used with permission)**

	<b>Asphalt</b>	<b>Gravel</b>
Dimensions	2 x 1.5 m (8 units)	2 x 1.5m (1 unit) 2 x 1.1m (1 unit)
Battery Life	2 years	
Operating Temperature	-40°C to 50°C (-40°F to 140°F)	
Data Collection Interval	15 minute	
Waterproof	IP 68	
Data Transmittal	GSM Connection	



The following equation describes how the pedestrian volumes were calculated.

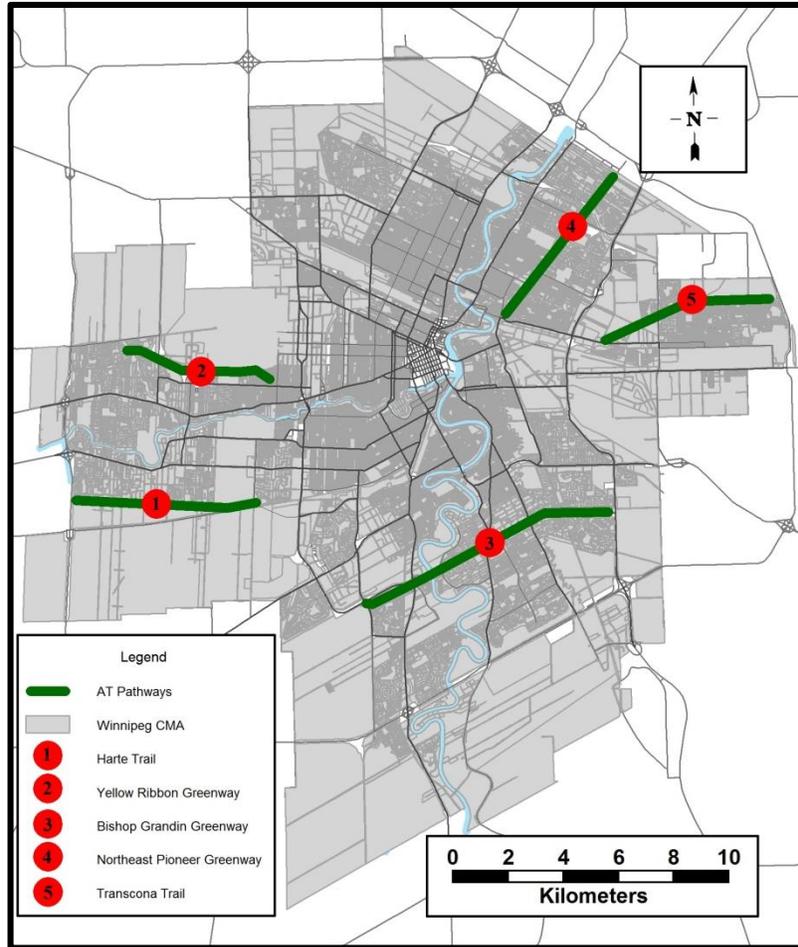
$$Pedestrian\ Volume = Pyro\ Volume - Zelt\ Volume$$

Pedestrian volumes were calculated by subtracting the number of bicycles collected by the Zelt counter from the total number of pedestrians and bicyclists collected by the Pyro counter.

## **3.2 INVESTIGATION OF COUNT SITES FOR DATA COLLECTION**

The following five multi-use trails were selected for data collection. The trails are shown graphically in Figure 3-1 and are listed below (Budowski, 2015):

- (1) Harte Trail;
- (2) Yellow Ribbon Greenway;
- (3) Bishop Grandin Greenway;
- (4) Northeast Pioneer's Greenway; and
- (5) Transcona Trail.



**Figure 3-1: Winnipeg multi-use trails selected for pedestrian and cyclist traffic monitoring (Budowski, 2015 – used with permission)**

As described by Budowski (2015), the pedestrian counting equipment was installed at ten count sites on five multi-use trails to continuously collect non-motorized traffic volumes for a minimum of one year. A full year of data captures hourly, daily, and seasonal variations in pedestrian volumes at each site.

Pre-screening site visits and counts enabled the researchers to select continuous count sites. According to the 2013 U.S. Traffic Monitoring Guide (TMG), optimal conditions for conducting counts occur on straight, level, sections of trail where people are unlikely to leave the trail. Areas with natural or artificial barriers adjacent to the trail, such as fences or trees, are helpful in funneling traffic past a specific point (FHWA, 2013). Ideally, the selected locations would represent typical non-motorized traffic patterns. Location selection also depends on the specific requirements of the non-motorized traffic count

technology being used (FHWA, 2013). For example, infrared sensors should not be installed facing a roadway, near water, or in direct sunlight because these could trigger false counts. Inductive loops should be located away from high-power utility lines, and on smooth pavement to avoid electrical interference or damage to the equipment caused by pavement cracking (FHWA, 2013). These recommendations from the TMG were applied in the site selection process.

As described by Budowski (2015), Pre-screening site visits consisted of several bicycle rides over the length of each trail to investigate optimal count site locations based on the TMG guidelines described above. Surrounding land-use was also incorporated into the selection process. Three or four potential count sites were identified per multi-use trail, with the exception of Transcona Trail, on which one site was chosen. In total, sixteen potential count sites were identified.

The researchers conducted manual pedestrian and cyclist pre-screening counts at each potential count site to inform the selection of ten continuous count sites. Both pedestrian and cyclist counts were required because as discussed, Pyro counters do not distinguish between cyclists and pedestrians and a cyclist counters needed to be installed at the same locations as the Pyro counters. The other reason cyclist volumes were included was because concurrent research by Budowski (2015) used the same data to analyse cyclist volumes. The selection details for each trail are described below.

### **3.2.1 Harte Trail**

Harte Trail is a gravel multi-use trail through a narrow swath of trees in the southwest part of Winnipeg. The trail extends west from Assiniboine Forest to the Perimeter Highway. A residential area borders the trail's north side and the proposed Ridgewood South neighborhood lies to the south. Figure 3-2 shows the four pre-screening count sites on Harte Trail.



Figure 3-2: Pre-screening count sites on Harte Trail (Budowski, 2015 – used with permission)

Budowski (2015) describes the pre-screening count sites and the schedule of pre-screening counts on Harte Trail. Site one is approximately 700m east of the Perimeter Highway and 400m west of Charleswood Road. Site two is accessible from the west end of Glenbush Street, between Community Row in the west and Harstone Road in the east. Site three is bordered on the south by Marj Edey Park and on the north by Ridgewood Avenue. Site four is just west of Assiniboine Forest, and south of Cathcart Street.

As described by Budowski (2015), Pre-screening counts for Harte Trail were undertaken at each site on Monday, August 19<sup>th</sup>, 2014 from 11:00AM to 1:00PM and 3:00PM to 5:00PM, and Tuesday, August 20<sup>th</sup>, 2014 from 1:00PM to 3:00PM and 5:00PM to 7:00PM. Eight hours of data were collected at each pre-screening count site. Figure 3-3 illustrates the results, which show bicycle and pedestrian volumes for each hour of data collection.

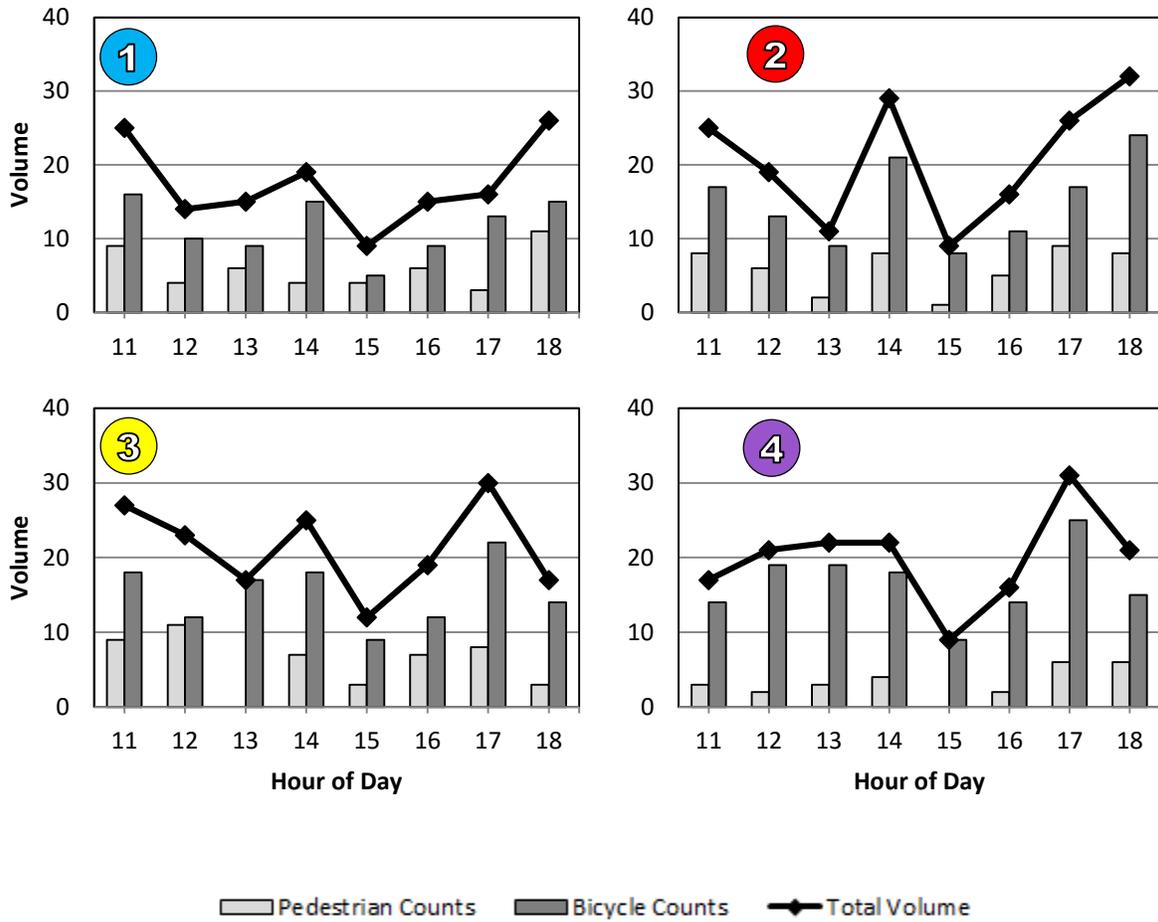


Figure 3-3: Pre-screening count results at sites one to four on Harte Trail

All sites appeared to have some degree of total volume peaking in the early afternoon, with sites two and three having the most distinct midday peak in total volume. A second, larger peak in total volume was observed at all sites in the evening. At sites one and two, the pm peak reached it's highest recorded total volume in the last hour of counting. At sites three and four, the highest volume was recorded between 5:00PM and 6:00PM (Budowski, 2015). Site two and site four were selected as continuous count sites because they had high total volumes, and distinct hourly patterns from each other. Sites two and four are hereafter referred to as HT1 and HT2, respectively.

### 3.2.2 Yellow Ribbon Greenway

Yellow Ribbon Greenway starts at Saskatchewan Avenue at Sturgeon Creek and terminates at the intersection of Ferry Road and Silver Avenue. The area is primarily residential and the trail accesses several parks. Figure 3-4 shows the three pre-screening count sites on Yellow Ribbon Greenway.



Figure 3-4: Pre-screening count sites on Yellow Ribbon Greenway (Budowski, 2015 – used with permission)

Budowski (2015) describes the count sites used in this research. Site one is north of the Living Prairie Museum and about 700m west of Moray Street. Site two is on the east side of Whytefold Road, and north of Jameswood Drive. The airport borders the trail on the north side, and a residential area is located to the south. Site three is near the corner of Silver Avenue and Winchester Street, at the northeast corner of the Assiniboine Golf Club.

As described by Budowski (2015), Pre-selection counts were conducted at each site on Wednesday, August 21<sup>st</sup>, 2014 from 8:00AM to 12:00PM and on Thursday, August 22<sup>nd</sup>, 2014 from 12:00PM to 4:00PM. Eight hours of data were collected at each site. Figure 3-5 illustrates the results for each hour of data collection.

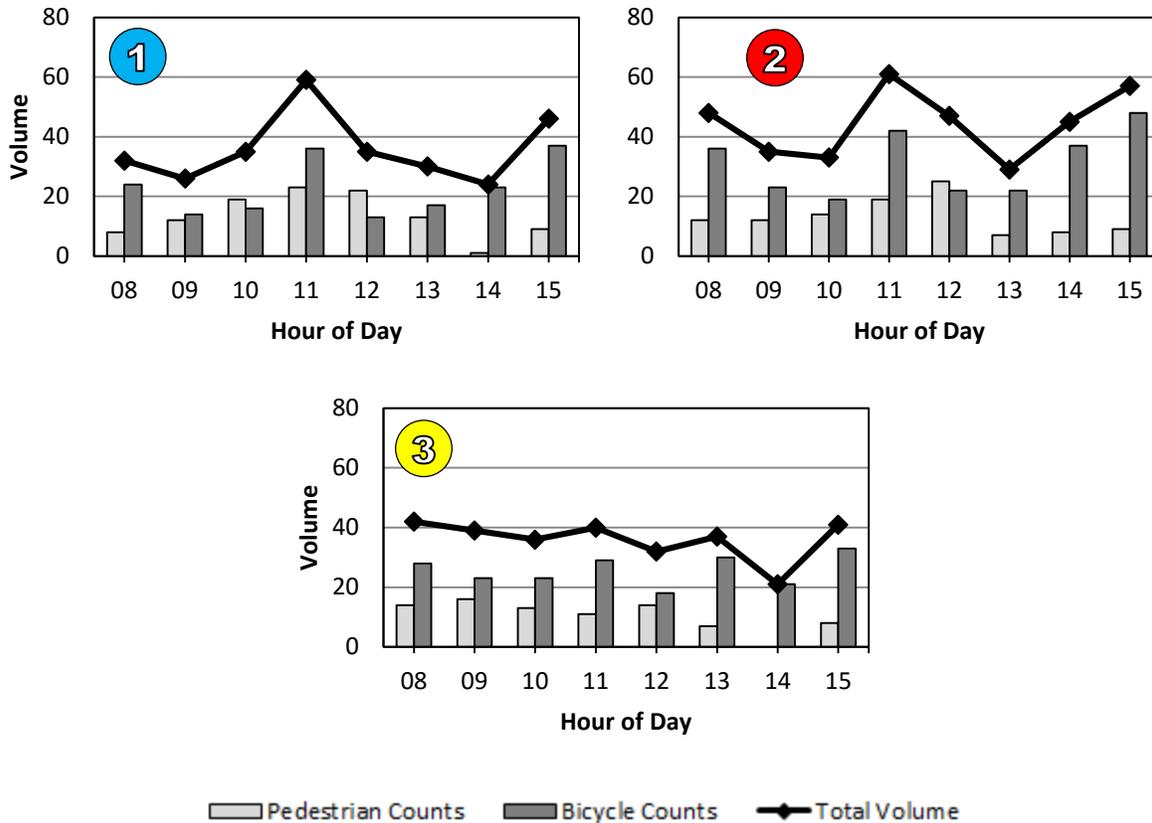


Figure 3-5: Pre-screening count results at sites one to three on Yellow Ribbon Greenway

Sites one and two had similar temporal distributions for total traffic, consisting of a midday peak and a PM peak (Budowski, 2015). The temporal distribution of cyclist volumes at sites one and two consisted of an AM, midday, and PM peak, while the temporal distribution for pedestrians exhibited a single midday peak. Site three had a relatively constant volume throughout the count period for both pedestrians and cyclists. Of these three locations, site two was selected as a continuous count site because it had distinct temporal patterns for both pedestrians and cyclists and had higher volumes than the other two sites. Site two is hereafter referred to as YRG.

### 3.2.3 Bishop Grandin Greenway

Bishop Grandin Greenway extends along the Bishop Grandin Boulevard, from Kenaston Boulevard in the west, to Lagimodière Boulevard in the east. Figure 3-6 shows the four pre-screening count sites identified on the Bishop Grandin Greenway.



Figure 3-6: Pre-screening count sites on Bishop Grandin Greenway (Budowski, 2015 – used with permission)

Budowski (2015) describes the pre-screening count sites used in this research. Site one is on the southwest side of the Fort Garry Bridge. Site two is located on the north side of Bishop Grandin Boulevard between River Road and St. Mary's Road. Site two is relatively isolated, approximately 700 m from the nearest public access point. Site three is on the north side of Bishop Grandin Boulevard between St. Mary's Road and Dakota Street to the east. Site four is on the south side of Bishop Grandin Boulevard near the Seine River.

As described by Budowski (2015), Pre-screening counts were conducted at each site on Monday, August 19<sup>th</sup>, 2014 from 11:00AM to 1:00PM and 3:00PM to 5:00PM, as well as on Tuesday, August 20<sup>th</sup>, 2014

from 9:00AM to 11:00AM and 1:00PM to 3:00PM. Eight hours of data were collected at each site. Figure 3-7 shows the results of the pre-screening counts.

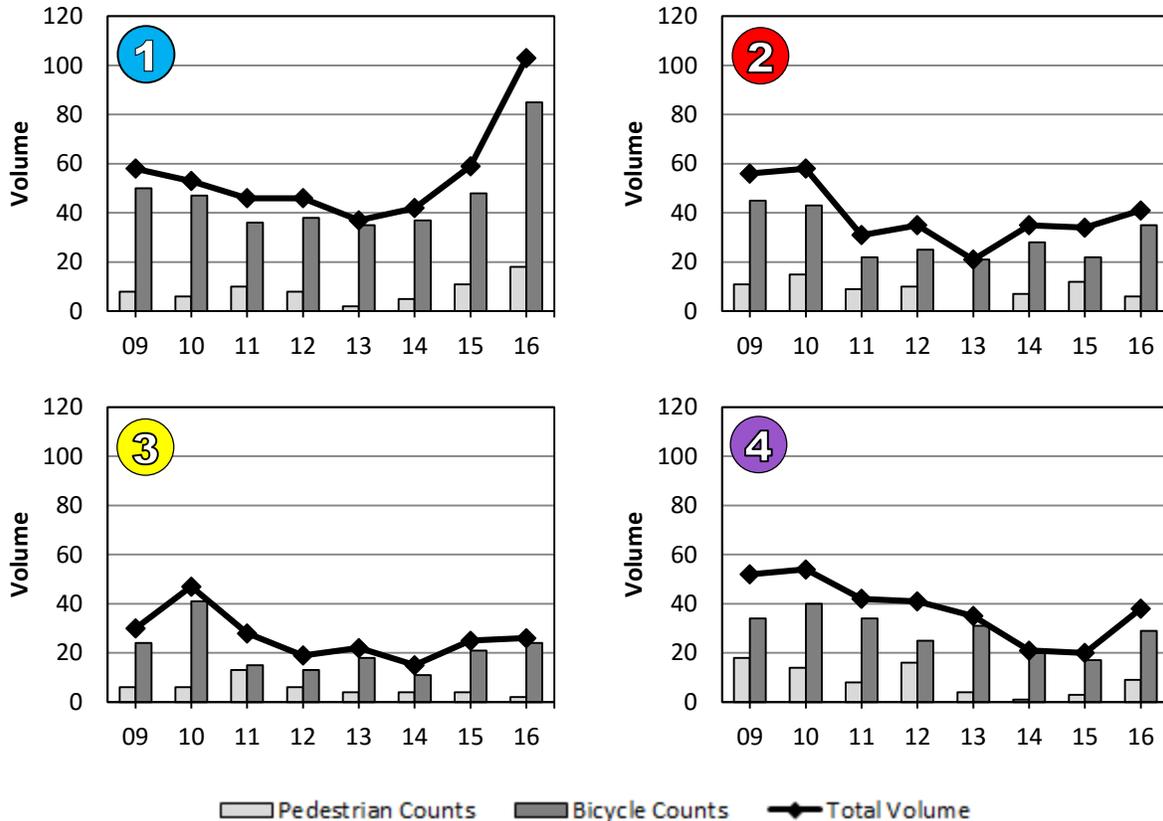


Figure 3-7: Pre-screening count results at sites one to four on Bishop Grandin Greenway

Site one was unique from sites two to four, with an initial decrease in total volume over the first five hours of data collection and an increase in volume during the last three hours of data collection (Budowski, 2015). The pedestrian volumes at site one had a peak at 11:00AM and a PM peak. In addition, the observed total volumes at site one are considerably higher than the other three locations on Bishop Grandin. Site one was therefore selected as a continuous count site. Sites two, three, and four all had an initial AM peak, and a slight increase in volume in the afternoon. Sites two and four had a more distinct PM increase in total volume than site three. The volumes at site two and four were also higher overall than the volumes at site 3 (Budowski, 2015). Sites two and four were also selected as

continuous count sites. Sites one, two, and four are hereafter referred to as BG1, BG2, and BG3 respectively.

### 3.2.4 Northeast Pioneers Greenway

Northeast Pioneers Greenway extends along a large grassy median, roughly halfway between Raleigh Street and Gateway Road in the northeast of Winnipeg. Both Raleigh Street and Gateway Road are approximated 20 m away from the multi-use trail. Northeast Pioneers Greenway spans approximately 6.5 km from Talbot Avenue at its south end to Glenway Avenue at its north end (Budowski, 2015). The Greenway is surrounded primarily by residential land and nearby parks. The Greenway provides a direct route downtown for bicycle commuters but is also easily accessible for recreational use by residents in the area. Figure 3-8 shows the four potential count sites on the Northeast Pioneers Greenway.

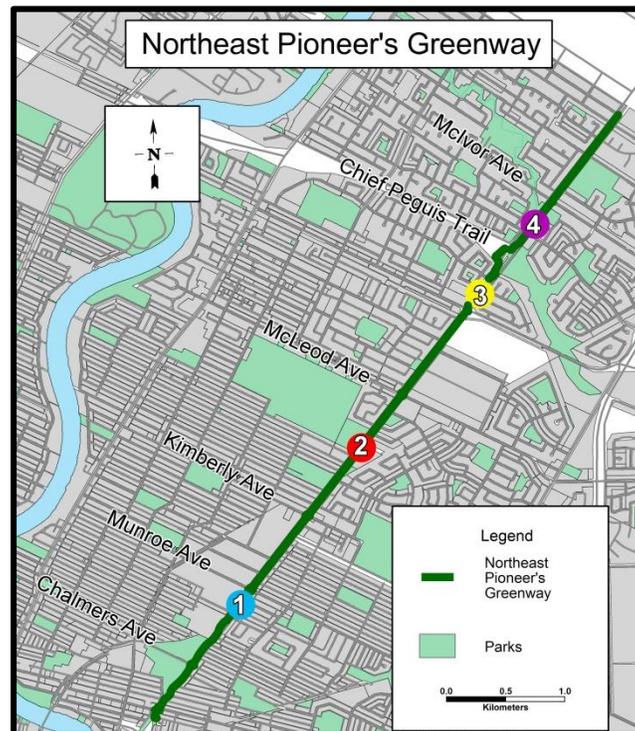


Figure 3-8: Pre-screening count sites on Northeast Pioneer's Greenway (Budowski, 2015 – used with permission)

Count site locations are described by Budowski (2015). Site one is south of Monroe Avenue. Site two is north of Kimberley Avenue near Anderson Park. Site three is immediately south of Chief Peguis Trail, near Donwood Drive. Site four is on the north side of Chief Peguis Trail and south of Sun Valley Drive.

As described by Budowski (2015), Pre-screening counts on Northeast Pioneers Greenway were conducted at four locations on Tuesday August 27<sup>th</sup>, 2014 from 8:00AM to 12:00PM and on Wednesday, August 28<sup>th</sup>, 2014 from 2:00PM to 5:00PM. Seven hours of data were collected at each site. The pedestrian counts for the last three hours of data collection were not available at Sites one and 3. The researchers used bicycle counts at these locations to select continuous count sites in the absence of pedestrian counts. Figure 3-9 shows the bicycle and pedestrian volumes recorded for each hour of data collection.

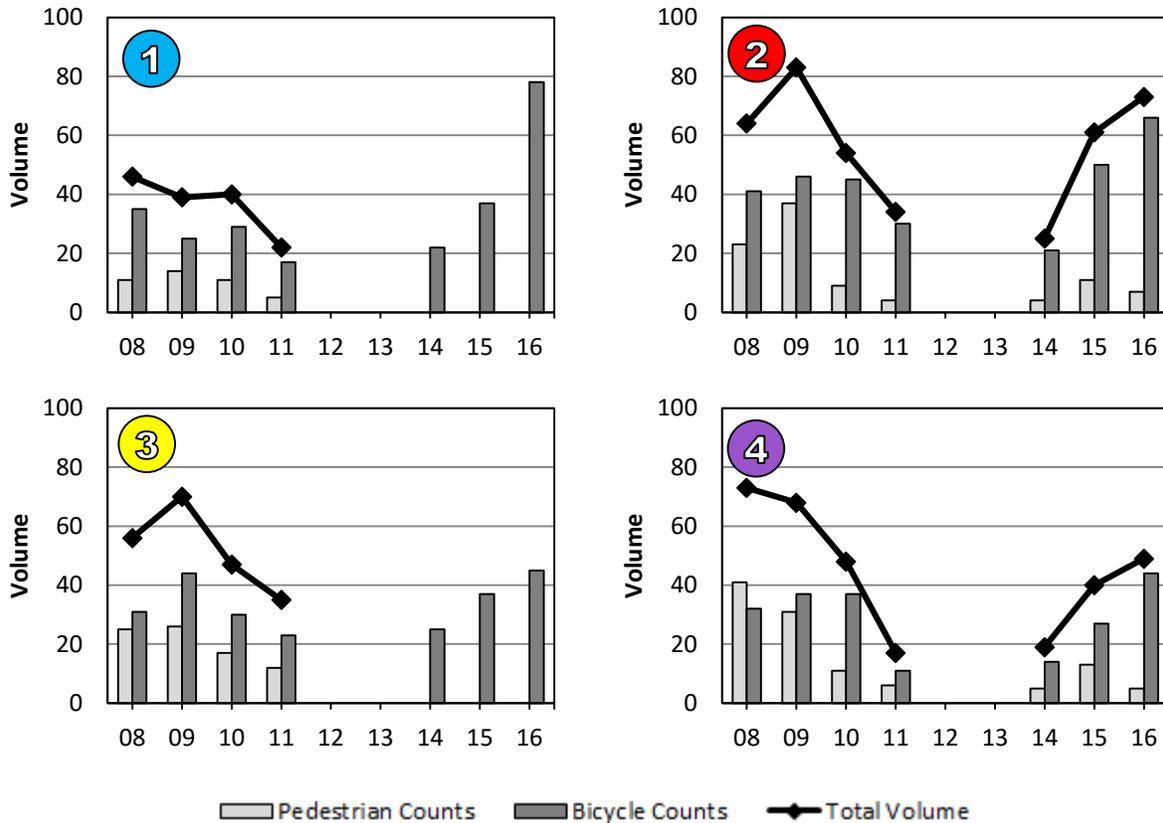


Figure 3-9: Pre-screening count results at sites one to four on Northeast Pioneers Greenway

All pre-screening locations exhibited morning and afternoon peaks for both pedestrians and cyclists (Budowski, 2015). Site one had a morning peak followed by an afternoon peak of approximately double the morning cyclist volume. Site one was selected as a continuous count site because it presented a pattern which was distinct from the other sites, with earlier AM peaking and a large PM peak relative to the AM peak (Budowski, 2015). Sites two and four had similar traffic patterns, and site two was selected as a continuous count site because it had higher overall volumes than site 4. Site three had a more distinct morning peak for bicycle traffic than the other three sites and was therefore selected as a continuous count site. The three continuous count sites on Northeast Pioneers Greenway were removed from the research due to inconsistencies in data collection. Section 3.5.1.2 discusses the removal of continuous count sites on Northeast Pioneers Greenway.

### 3.2.5 Transcona Trail

Transcona Trail is located beside a rail line in the Transcona neighborhood. The trail extends from the intersection of Regent Avenue and Peguis Street to the Perimeter Highway (Budowski, 2015). Transcona Bio reserve is a large park located near the midpoint of the trail, and the trail accesses several other parks in the neighborhood. Only one count site was identified as a potential continuous count site on Transcona Trail and no pre-screening counts were conducted following the site visit (Budowski, 2015). The continuous count site on Transcona Trail is shown in Figure 3-10.



Figure 3-10: Continuous count site on Transcona Trail (Budowski, 2015 – used with permission)

Site one, hereafter referred to as TT, is located east of Plessis Road, and adjacent to Kiwanis Park (Budowski, 2015). The site was selected because it captures both recreational and commuter bicycle and pedestrian traffic. Kiwanis Park and parkland farther east on this trail segment made the site an ideal location to capture recreational users entering the segment from the west and travelling toward the parkland, recreational users coming from the east to visit the park, and commuter traffic travelling to and from Regent Avenue.

### 3.3 DATA COLLECTION

This section describes the data collection process used for this research.

#### 3.3.1 Equipment Installation

Automated counters were operational at the count sites by January 1, 2014. Each automated counter included a battery, a sensor, and a transmitter (Budowski, 2015). The Zelt counters were buried below ground, and the Pyro counters were installed on permanent trail-side fixtures. Recall that both Zelt and Pyro counters were needed to calculate pedestrian volume, where the bicycle volume (Zelt counter) was subtracted from the total mixed-mode volume (Pyro counter) to obtain the number of pedestrians. Figure 3-11 shows an example of the Zelt counting equipment and the Pyro counting equipment.



Figure 3-11: Zelt (top) and Pyro (bottom) counting units. (Poapst, 2015 – used with permission)

### 3.3.1.1 *Installation of Zelt Counters*

This research uses the data collected by the Zelt counters installed by Budowski (2015), at the continuous count sites described in Section 0. Budowski (2015) describes the installation methodology for Zelt counters.

### 3.3.1.2 *Installation of Pyro Counters*

Installation of Pyro counters followed installation guidelines provided by Eco-Counter. According to the Eco-Counter guidelines, the Pyro counters were installed 75 cm – 100 cm above the pavement surface, to balance the range of pedestrian heights against over-counts due to double counting legs, bicyclists, and dogs. The Pyro counters were mounted using metal straps on a variety of trail-side objects, such as trees and way-finding signposts. Where no signpost or tree was available, counters were mounted on metal posts which were approved and installed by City of Winnipeg staff. Figure 3-12 shows an example of a Pyro counter installation on a metal post.



Figure 3-12: Example of Pyro counter installation at BG1

## 3.3.2 **Field Data Collection**

Field data collection procedures as they relate to bicycle counts (Zelt counters) are described in Budowski (2015) and as they relate to the total counts (Pyro counters) by Nytepchuk (2016). Field data

collection resources are provided by EcoCounter and the same for all users of the Pyro and Zelt counting technology. All counters collect pedestrian and bicycle data continuously. The counters store data internally in 15 minute intervals (or bins), and are accessed either on-site with a Bluetooth connection or through a remote access service.

Counters can be accessed on-site via Bluetooth with a program called Eco-Link PC, which is compatible with laptop computers. The Bluetooth capability is activated by holding a magnet against a magnetic sensor on the front of the counter. Eco-Link PC is used to manually connect with the counter. Once connected to a counter, the user can perform a number of functions, including downloading the data, resetting the time on the counter, and adjusting the counter sensing range. Users connected to a counter via Eco-Link can also observe real-time counts, which is useful for checking counter performance.

The count data can be accessed remotely using the Global System for Mobile Communication (GSM). GSM uses the existing digital cellular network, which connects the counter with a server to upload the count data. Eco-Counter provides the GSM access under a monthly license, in which count data is uploaded once per day. The counters in this research used the Rogers Wireless network, and each counter was assigned a cellular number. The uploaded data is accessible on the Eco-Visio website.

Eco-Visio provides information such as where the counter is located, estimated remaining battery life, and other technical specifications. Raw counts are also available for download or online display for various time intervals and output styles. The smallest possible time interval for raw counts is 15 minutes, but counts can also be aggregated into hourly, daily, weekly, or monthly volumes. Output styles include a variety of graphical and tabular formats.

### **3.3.3 Weather Data Collection**

Weather data was obtained from Environment Canada's historical weather archives (available at: [climate.weather.gc.ca](http://climate.weather.gc.ca)). Weather data was obtained from a weather station near the Winnipeg James Armstrong Richardson International Airport called 'Wpg A CS,' and was selected for this research because it has both hourly and daily weather data. Other nearby weather stations were also available but did not provide a sufficient level of detail.

## **3.4 CONTROLLED VALIDATION**

Validation is the process of measuring and evaluating the accuracy of automatically collected counts. Budowski (2015) found that for the count sites used in this research, user volumes on the trails were considered too low to conduct reliable field validation at the time of installation. Controlled validation was performed immediately after each counter installation, comprising 50 to 100 passes of a bicyclist across the counter sensing range (Budowski, 2015). All counting devices performed with high accuracy in the initial controlled validation. Section 2.1.6.1 in the literature review describes controlled and field validation techniques.

Field validation occurred between May 2014 and January 2015 and is originally described by Budowski (2015) and Nytepchuk (2016). Manual validation counts ranged in duration from two to four hours at each of the ten count sites and were conducted at varying times throughout the day and week (Budowski, 2015; Nytepchuk, 2016). An observer positioned at a count site recorded the number of pedestrians and cyclists passing the automated counters. Counts were collected in 15 minute intervals, corresponding to the smallest data unit provided by the Eco-Counters. The validation count sheet template is provided in Appendix A.

Budowski (2015) conducted validation counts at each count site in May, June, and September, 2014 and consisted of three weekday counts and one weekend count per site. Additional counts were conducted at BG3 by Nytepchuk (2016). In total, 173 hours of field validation counts were collected. The counts conducted at BG3 totalled 100 of the 173 hours of validation counts and were conducted between May 2014 and January 2015. Differences between count sites such as occlusion rates could make the validation dataset less robust because the majority of validation counts occurred at BG3. The decision to use the additional data from BG3 was based on the simplifying assumption that trail traffic composition is similar from one site to another.

Manual counts were compared to the pedestrian and bicyclist volumes collected by the automated counters to validate counter performance. The absolute percent error was calculated for each 15-minute interval, 30-minute interval, one-hour interval, and for the entire count interval. The absolute percent error represents the percent difference between automated and validation counts. The calibration analysis and results are described in Section 4.1. In addition to validation counts, the researchers monitored the data on Eco-Visio and investigated issues and anomalies as they occurred.

### **3.5 UNEXPECTED ISSUES**

This section describes the unexpected issues encountered during data collection. Some problems, such as interference from nearby power lines, occurred only with the Zelt counters and are discussed in further detail by Budowski (2015).

#### *3.5.1.1 Installation Issues*

As discussed in Section 3.3.1.2, Pyro counters were installed on a variety of trail-side fixtures. The Pyro counters at HT1 and YRG were attached to trees; however, the straps were not adjusted to accommodate tree growth and left indents on the trees to which they were attached. In addition to the

problems caused by tree growth, trees are flexible and may sway in a strong wind, which could trigger false counts. Attaching Pyro counters to trees is not recommended for future research.

### *3.5.1.2 Counter Malfunction*

All three Pyro counters on Northeast Pioneers Greenway showed evidence of overcounting due to motor vehicle traffic. Adjustments to the sensing range were not sufficient to eliminate overcounting. Northeast Pioneers Greenway is located between two roads with few barriers such as trees or other solid objects between the trail and the road. The sensing range selected for these counters was between zero and four meters; however, the approximately 20 m distance between the trail and the road was not sufficient to prevent overcounting due to large motorized vehicles such as trucks and buses. The Pyro counters were therefore removed from the three sites on Northeast Pioneers Greenway and the number of count sites was reduced to seven.

Some Pyro counters were affected by the excessive grass growth in summer months. Tall grass in front of the sensors caused overcounting in the tens of thousands. Interference due to grass growth led to the removal of data at YRG from June 3, 2014 through June 12, 2014 and at BG2 from June 30, 2014 through July 12, 2014. Site visits were conducted to investigate flagged counts, but the author stresses the importance of regularly monitoring raw counts so that high counts can be flagged and investigated on site.

The Pyro counter at BG1 began registering excessively high counts on February 14, 2014. Traffic returned to expected volumes on March 5, 2014 but the counter began registering high counts again on March 10, 2014. The counter was removed from the site on March 13, 2014 and sent to Eco-Counter for repair. Eco-Counter provided a temporary replacement which was installed at the site from March 22,

2014 until May 6, 2014 at which point the repaired counter was reinstalled at the site. Subsequent site visits confirmed that the repaired counter performed accurately.

Intermittent high counts were observed at the YRG Pyro counter. The high counts usually occurred between 10:00AM and 2:00PM with hourly counts up to approximately 300. The problem was caused by direct sunlight triggering the infrared sensor. The effects of sunlight on counter malfunction at YRG were identified using an approach proposed by Turner and Lasley (2013). This approach is based on the understanding that when the sunlight triggers a false count, the counter always associates that count with the same direction, thus making it possible to identify the problem based on high counts in which one direction has a much higher count than the other. The process for identification and removal of high counts due to sunlight is discussed further in Section 4.1.3.

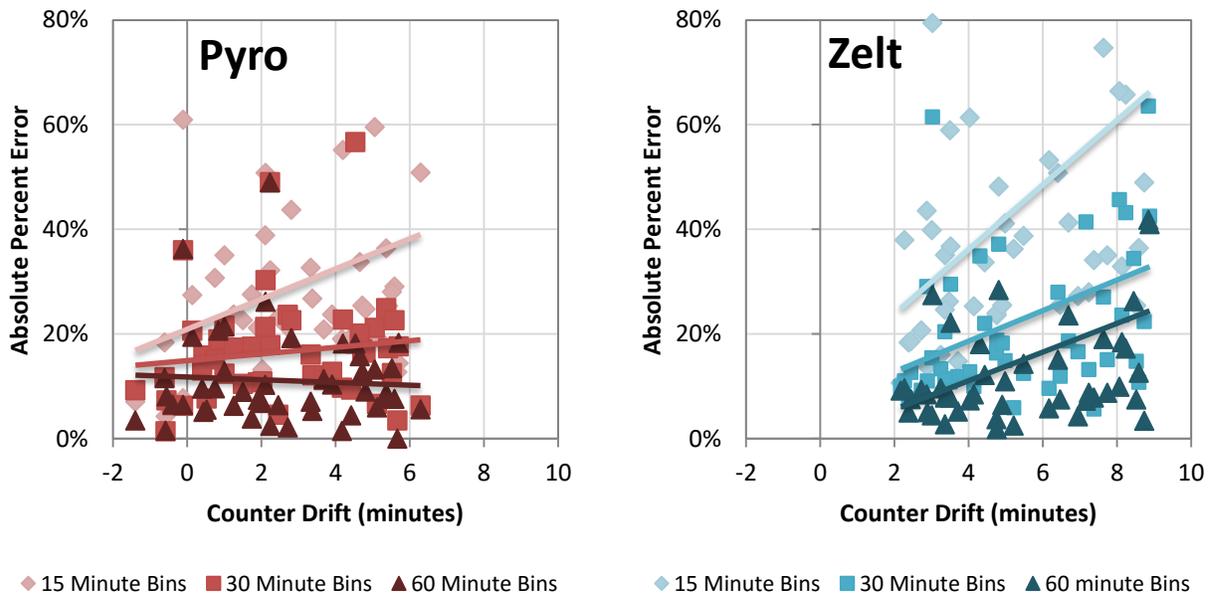
#### *3.5.1.3 Time Drift on Internal Clock*

Current generations of Pyro and Zelt counters synchronize their data logger time with the digital cellular network. The research team was incorrectly informed that the Pyro and Zelt counters used for this research also synchronized their internal clocks with cell phone towers; however, the Pyro and Zelt counters required manual synchronization of the internal clock. This discovery was made after approximately nine months of data collection, at which point the time drift of the internal clocks varied from zero to nine minutes.

The time drift was investigated to determine whether it would affect the integrity of the data. Eco-Counter provided the time drift data observed on the first day of each month from April to October, 2014. The drift over time for all counters is a linear increase of approximately one minute per month. At the time that the author discovered the internal clock drift, the author informed other researchers who were using the technology about the issue and the analysis that the author of this report had taken to

investigate the internal clock drift. As a result, this issue is also discussed in Budowski (2015) and Nytepchuk (2016).

Time drift data was compared to the validation counts described in Section 3.4. The time drift data was linearly interpolated to obtain an estimate for the counter time drift at the time of each validation count. The time drift was subsequently compared to the absolute percent error for each count. The analysis considered the effects of time drift on 15 minute, 30 minute, and 60 minute intervals. Figure 3-13 shows a scatterplot of the average absolute errors calculated for all days on which validation data was available from April to October, 2014.



**Figure 3-13: The effect of time drift on Pyro and Zelt counter error**

The trendlines in Figure 3-13 show that in general absolute percent error increases as the time drift increases for both Pyro and Zelt counters; however, this effect is stronger for 15 minute intervals than for 60 minute intervals. The drift of the Zelt counters was generally higher than the drift for the Pyro counters. The absolute percent error ranged up to approximately 60% to 80% for 15-minute intervals, 30% to 40% for 30-minute intervals, and 20% to 30% for 60-minute intervals. The drift analysis shows

that at 60-minute time intervals, the magnitude of counter drift does not strongly influence error. Using time intervals of less than 60 minutes leads to higher error due to counter drift and should be avoided. If both counters are synched to real time, then validation counts using smaller time intervals such as 15 minutes may be used with more confidence. Based on these findings, the internal clocks in the counters should be reset regularly, keeping in mind that the counters drift about one minute per month (Nytepchuk, 2016). It is critical that Pyro and Zelt counters have internal clocks that are set to the same time, in order to create accurate pedestrian estimates and that Pyro and Zelt counters have their clocks set to real time, in order to create accurate validation counts, particularly for validation count intervals of less than one hour.

## **4 ANALYSIS AND DISCUSSION**

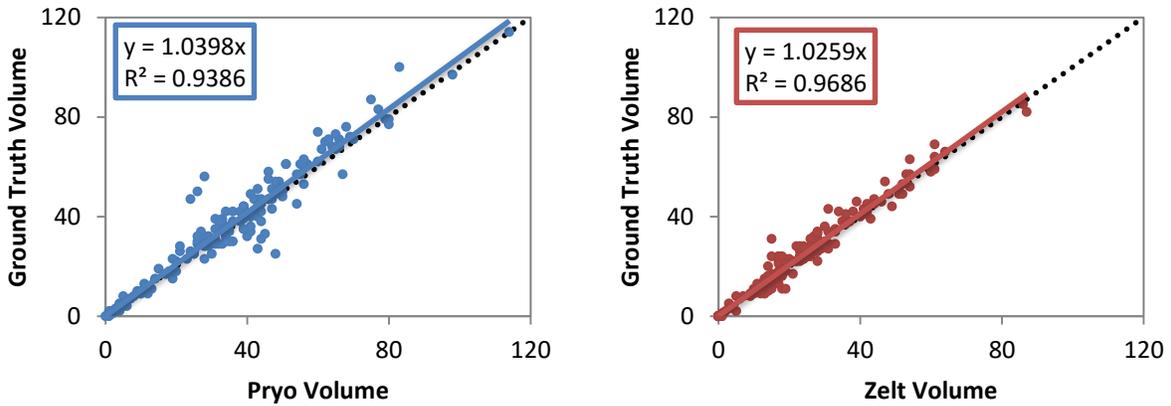
This chapter presents the analysis of pedestrian volumes on multi-use trails, and is intended to inform the future development and evaluation of methods to estimate average daily pedestrian traffic (ADPT) from short duration counts. This chapter reviews data quality control, recommends an ADPT calculation methodology on a monthly, seasonal, and annual basis, provides an overview of the temporal patterns of pedestrian volumes at the seven count sites used for data collection, and presents a qualitative analysis of the effects of weather on pedestrian volume.

### **4.1 QUALITY CONTROL**

Quality control ensures that the data adequately represent truth-in-data. This section describes the calibration and data cleaning processes applied to the continuous pedestrian count data used in this research.

#### **4.1.1 Field Validation**

Two types of equipment were used to estimate pedestrian volumes on multi-use trails throughout Winnipeg and are referred to as Pyro counters and Zelt counters. Recall from Section 3.4 of the methodology, that 173 hours of manual counts were collected as ground truth. Automated counts were compared to the manual ground truth counts to determine the accuracy of the count equipment. Figure 4-1 shows the validation results for both Pyro counters and Zelt counters based on hourly counts. The manual count data shown in this figure for Zelt counters was also used in analysis of bicycle volumes on the same multi-use trails by Budowski (2015).



**Figure 4-1: Validation results for Zelt and Pyro counters**

For both Zelt and Pyro counters, there is a strong linear correlation between the volume collected by the automated counter and the volume collected from manual observation. Slight undercounting was observed for both the Pyro and Zelt counters. Counter error was calculated as the percent difference between automated and ground truth volumes, expressed as a proportion following the guidance of Ryus et al. (2014). Table 4-1 shows a summary of the errors calculated from validation counts. Error could not be calculated for hours in which the ground truth count was zero; therefore, instances with a ground truth count of zero were excluded from results.

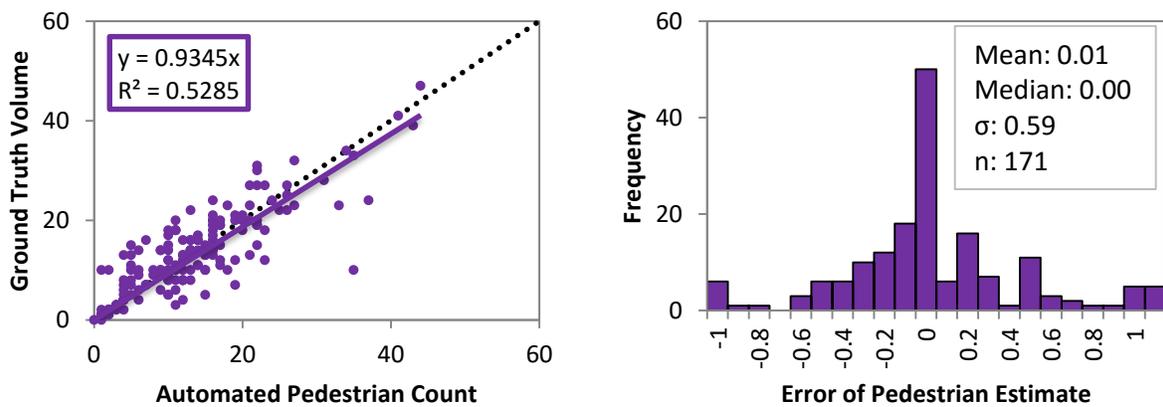
**Table 4-1: Validation results for Zelt and Pyro counters**

	<b>Pyro</b>	<b>Zelt</b>
<b>Hours of Ground Truth (n)</b>	171*	144*
<b>Mean Error</b>	-0.01	0.00
<b>Median Error</b>	0.00	0.00
<b>Standard Deviation of the Error (<math>\sigma</math>)</b>	0.20	0.21
<b>Linear Correlation (<math>R^2</math>)</b>	0.98	0.97

\*instances with a manual count of zero were not included.

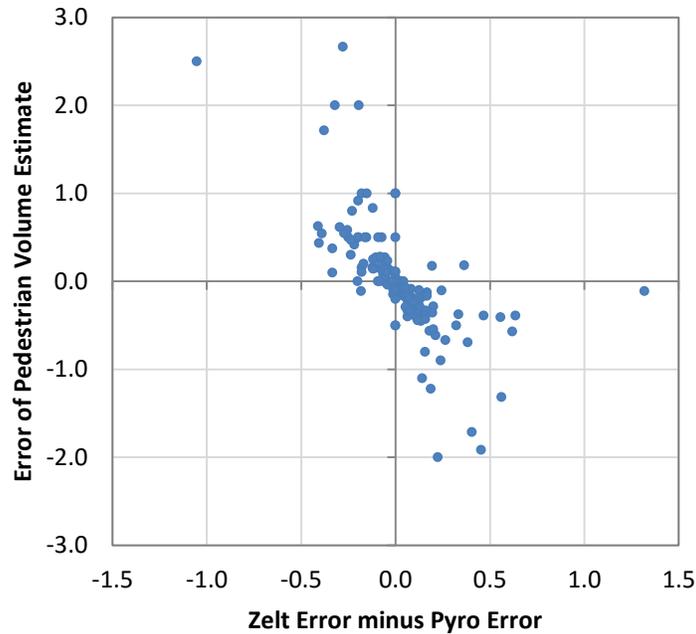
The mean and median errors are very close to zero for both counters, which indicates high accuracy. The standard deviation, which reflects counter precision, is 20% for Pyro counters and 21% for Zelt counters. Both counter types perform at a similar level of accuracy and precision and followed a normal distribution of errors.

As described in Section 3.1 of the methodology, Pyro counters record the total number of trail users and do not distinguish between bicyclists and pedestrians, while Zelt counters count only bicycles. The estimated number of pedestrians was calculated by subtracting the Zelt counter volume from the Pyro counter volume. This calculation step introduces new error into the pedestrian estimate because it compounds the error of the Pyro and Zelt counters. Figure 4-2 shows the validation results for the pedestrian estimates based on hourly volumes.



**Figure 4-2: Validation results for the pedestrian estimate**

As shown in Figure 4-2, the mean and median error of the pedestrian estimate are close to zero; however, the standard deviation is approximately three times higher for the pedestrian estimate. The standard deviation of the error for each type of counter individually was approximately 20%, while the standard deviation of the error of the pedestrian estimate was approximately 60%. In other words, while accuracy remains high, precision decreases. This occurs because the individual errors from Zelt and Pyro counters combine to increase the range of errors of the pedestrian estimates. This compounding effect is shown in Figure 4-3, which compares the difference between the errors of the Zelt and Pyro counters to the resulting error of the pedestrian volume estimate.



**Figure 4-3: Effect of Pyro and Zelt counter error on the pedestrian estimate**

Figure 4-3 shows the relationship between the error of the pedestrian estimate and the difference between Zelt counter error and Pyro counter error. The figure shows that the error of the pedestrian estimate tends to be higher when the difference in error between the counters is higher (for example, when one counter is overcounting and the other counter is undercounting). The error of the pedestrian estimate is closest to zero when the error of both counters is equal. This occurs because the smallest differences between the Pyro and Zelt counter error from calibration occurred when the errors of each individual counter were also small. Outliers would be expected when the errors of both counters were large, regardless of whether they were equal. The slope of the relationship in Figure 4-3 is approximately 1:3, which corresponds to the increase in the standard deviation from 20% for individual counter error to 60% for the error of the pedestrian estimate.

### 4.1.2 Calibration

The purpose of calibration is to correct systematic counter error due to occlusion. Budowski (2014) found that the Zelt counters installed on multi-use trails in Winnipeg did not require the application of correction factors. Correction factors were therefore not applied to the Zelt count data used in this research.

Recall from Section 2.1.4.2 that Pyro counters are known to systematically undercount mixed-mode traffic because of occlusion (Nytepchuk, 2016). Based on the results of validation, the Pyro counters used in this research were found to undercount slightly, and correction factors were developed as a result. Correction factors were calculated based on the methodology recommended by the NCHRP Guidebook on Pedestrian and Bicycle Volume Data Collection, requiring a minimum of 30 time units for analysis (Ryus, et al., 2014). A linear relationship was observed between ground truth data and automated counts; therefore, linear regression was used to calculate the correction factor based on the guidance provided by Ryus, et al. (2015) and research by Nytepchuck (2016). When the validation results are plotted with the automated count on the x-axis, and the ground truth count on the y-axis, the slope of the line represents the correction factor which can be applied to automated counts. The ground truth counts used to conduct calibration contained some of the counts which were also analysed by Nytepchuk (2016); however, it also included counts at additional sites which were not part of the research by Nytepchuk (2016).

The purpose of developing correction factors in this research is to mitigate the effects of undercounting due to occlusion. The simplifying assumption was made that the occlusion rate is consistent for all multi-use trails in Winnipeg, because there were not enough hours of ground truth data at each site to develop site-specific calibration factors. Future research could be enhanced by performing a minimum of 30 time-units of ground truth data collection at each site, as recommended by Ryus, et al. (2015). The

sites used to develop correction factors for the Pyro counters included BG1, BG2, BG3, and HT1. HT2, TT, and YRG were not included because they exhibited inconsistent errors (including overcounts), suggesting that site specific variables other than occlusion were influencing the results. Hourly counts were used as the base time interval because there was insufficient confidence in the synchronization between ground truth time and the internal clock on the Pyro counters to use a smaller time interval. Ryus, et al. (2014) recommends a minimum sample size of 30 units of time for the development of correction factors, and in this research, a total of 134 hours of counts were used to develop the correction factor. The slope of the regression line for calibration describing the relationship between Pyro counter volume and ground truth volume is 1.0472, as shown in Figure 4-4. This slope value was applied as a correction factor to all Pyro count data to correct the effects of undercounting.

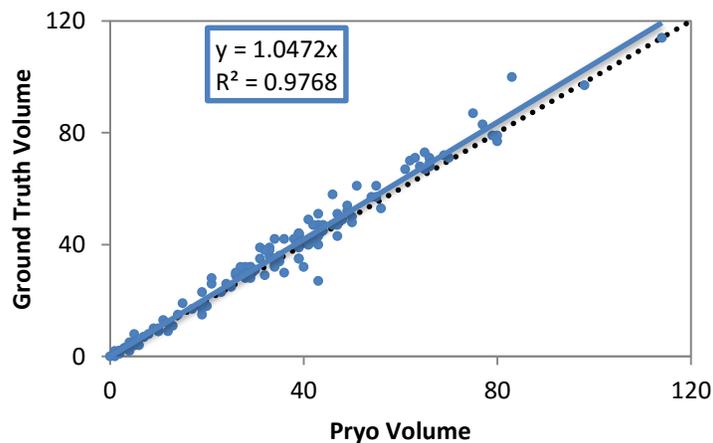


Figure 4-4: Calibration results for Pyro counters

### 4.1.3 Data Cleaning

Data cleaning involved the identification and removal of incorrect data. Incorrect data occurs for a number of reasons including counter malfunction, or people or objects triggering false counts. BG1 is located close to the Investor’s Group Field, which hosts about 10 to 15 events per year and causes high

volumes at BG1 on event days. A total of 13 events occurred at Investor’s Group Field in 2014 and the data from these days were not removed because high volumes due to events are typical of this location.

Visual review of the data was used for data cleaning and was conducted using conditional formatting of the raw hourly data, which flagged high or low volumes, missing volumes, and negative numbers. A seasonal average hour of day was calculated for weekend days and weekdays, and was used to develop a threshold for flagging high data. Based on guidance by Ryus, et al. (2014), hourly counts which were higher than two standard deviations above the seasonal average hour of day count were flagged. All negative counts were also flagged. Flagged data was investigated at both 60-minute and 15-minute intervals to determine the cause of the problem and make a decision about whether to accept or reject the counts.

Specific problems including the effects of direct sunlight, counter malfunction, and the effects of grass were encountered during data collection and are described in Section 3.5 of the methodology. These issues resulted in higher than expected volumes. Turner and Lasley (2013) developed an imputation methodology to identify and correct false counts triggered by the sun. The premise of the method is that when the sun triggers a false count, the counter always assigns the count to the same direction, creating much higher counts in one direction than the other. The method calculates the difference between the IN count and the OUT count for each hour, and uses the following equation to flag counts:

$$Flag = 2.5 * IQR + Q_3$$

where IQR refers to the interquartile range and  $Q_3$  is the 75<sup>th</sup> percentile difference between the IN and OUT count. The decision to impute data is controversial, and the imputation method was not applied to the data at YRG because there were other problems occurring at the site including negative numbers and grass waving in front of the counter, which could have affected the imputation calculations. As a

result, the method was only used to flag counts and counts which were determined to be due to sunlight were removed from the dataset. The effect of grass waving in front of the counter and general counter malfunction were verified on site if possible and removed from the data. In the case of grass, the grass was removed from in front of the counter. Recall from Section 3.5.1.2 that high counts due to grass occurred at YRG and BG2 and counter malfunction occurred at BG1. Flagged counts for which no removal justification could be found were kept in the dataset.

In some cases the Pyro counter recorded a lower volume than the Zelt counter, resulting in a negative value for the calculated number of pedestrians. Negative numbers occurred due to undercounting by the Pyro counter, overcounting by the Zelt counter, or a combination of the two conditions. An analysis of the negative counts revealed that the occurrence of negative pedestrian volumes varied by magnitude, by time of day, and by count site. The calibration analysis revealed that at all count sites, the standard deviation of errors was equivalent to a count of approximately +/- four pedestrians. The error of calculated pedestrian volumes was normally distributed. Assuming the same normal distribution of errors occurs at low volumes, calculated pedestrian counts between zero and negative four theoretically fall within a typical range of error and could plausibly represent pedestrian counts anywhere between about zero and positive four. With this concept in mind, Figure 4-5 presents the frequency at which negative pedestrian volumes occur by count site, hour of the day, and magnitude, both above and below the negative four threshold.

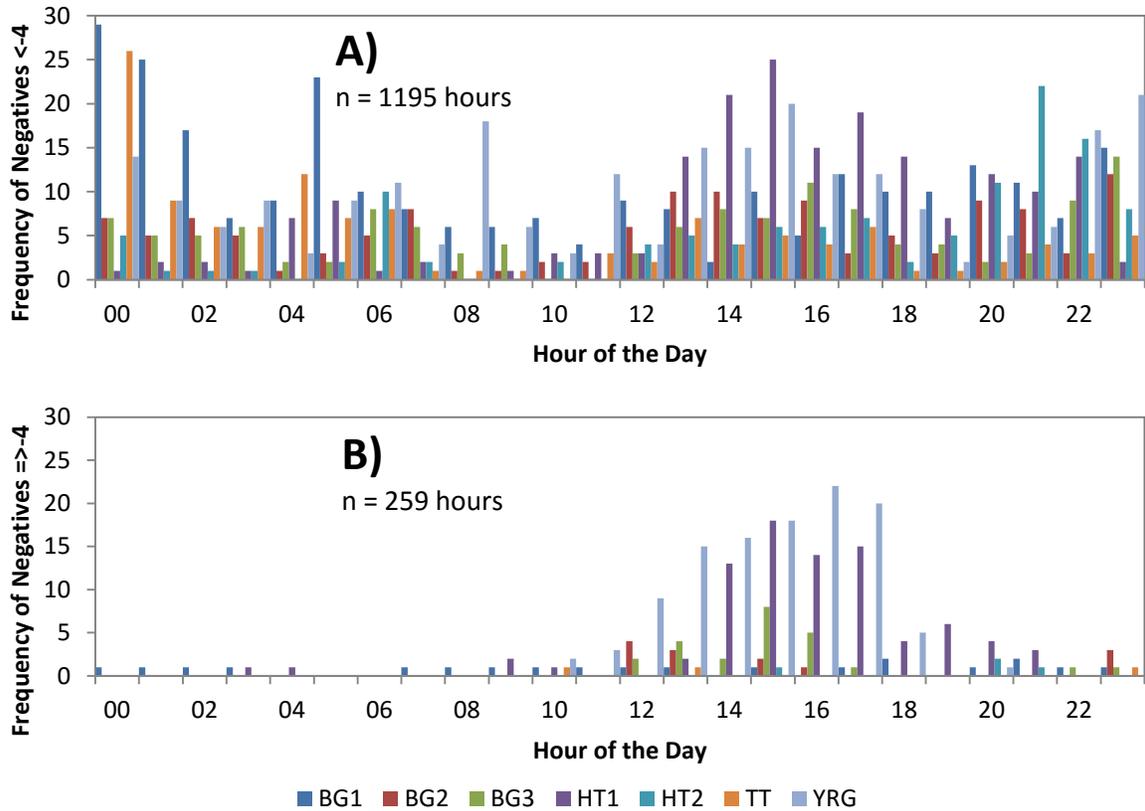


Figure 4-5: The occurrence of negative pedestrian counts by hour of day and count site given a magnitude of A) between zero and negative four, and B) lower than negative four.

For simplicity, negative counts between zero and negative four will be hereafter referred to as minor negative counts, whereas negative counts below the typical range of values (in this case, negative four) will be referred to as major negative counts. Figure 4-5 shows that minor negative counts are distributed throughout the hours of the day. These results are consistent with the possibility that minor negative counts reflect a typical range of errors, because minor negative counts would be expected to occur randomly during hours in which pedestrian volumes are typically low.

Major negative counts occur primarily at BG3, HT1, and YRG, between the hours of 12:00 and 17:00, suggesting that there are site specific issues affecting the data. Most of the major negative counts occur in late July and early August during hours with high cyclist volumes ranging from 20 to 40 cyclists per hour. The major negative counts may have been due to higher than average cyclist occlusion rates,

which caused the Pyro counter to underestimate the mixed-mode volume. Negative pedestrian counts are known to be impossible as ground truth, regardless of their magnitude. Therefore, all negative counts were removed from the dataset. This problem could be mitigated in future research by performing more extensive site-specific and season-specific calibration.

While hourly negative volumes must be removed for hourly analysis, changing the base unit of time to days (24 hours) may warrant a different approach. For example, if the assumption that minor negative counts are due to the typical range of errors exhibited by the Pyro and Zelt counters, their removal may not be necessary because the counts are aggregated to a daily volume and the minor negative counts would be expected to balance with overestimated pedestrian counts occurring during the day. This balancing of over- and under-estimates is expected because the mean and median errors of the pedestrian estimate from validation were very close to zero, even though the range of errors was high. In this way, only counts falling below a set threshold of typical values would need to be removed. The amount of rejected data would be vastly reduced without necessarily sacrificing the integrity of the data. This approach was not taken because not only is it counter-intuitive to accept obviously incorrect data and because further analysis is required to either support or reject this reasoning.

Table 4-2 shows a summary of hourly and daily data removed and the reason for data removal.

Table 4-2: Summary of data eliminated for each counter

	BG1	BG2	BG3	HT1	HT2	TT	YRG
<b>Days Removed</b>	<b>37</b>	<b>20</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>12</b>
Malfunction	37	0	0	0	0	0	0
Grass	0	20	0	0	0	0	12
<b>Hours Removed</b>	<b>296</b>	<b>146</b>	<b>155</b>	<b>277</b>	<b>129</b>	<b>156</b>	<b>498</b>
Missing Data	7	0	0	0	0	10	0
Maintenance	0	0	2	1	2	1	0
Sun	0	0	0	0	0	0	140
High Count	2	0	0	3	2	16	5
Negative Counts	286	145	152	272	124	128	352

## 4.2 CALCULATION OF AVERAGE DAILY PEDESTRIAN TRAFFIC

A measure of average pedestrian traffic is useful both for summarizing pedestrian volumes and providing a consistent basis for comparison between count sites. This section discusses several methods which were considered to calculate average pedestrian traffic.

### 4.2.1 Seasonal and Annual Average Pedestrian Traffic

Summary statistics such as Annual Average Daily Traffic (AADT) and Seasonal Average Daily Traffic (SADT) are recommended by the 2013 U.S. Traffic Monitoring Guide (TMG) for analysis of non-motorized traffic. Due to the extent of missing data, common ways of calculating a pedestrian AADT and SADT were not possible; however, average daily pedestrian traffic was estimated using an alternative approach based on annual, seasonal, and monthly time periods, and are referred to as AADPT, SADPT, and MADPT respectively. The calculation and application of average daily traffic is well established in motor vehicle traffic monitoring; however, a similar approach has not yet been developed for pedestrian traffic.

Both AADPT and SADPT are useful tools to quantify pedestrian traffic. Recall from Section 2.1.2 of the literature review that a seasonal average is commonly used for non-motorized traffic monitoring in

regions which experience seasonal peaking due to changes in climate. Winnipeg undergoes large seasonal changes in temperature; therefore, SADPT was investigated as a candidate to quantify pedestrian volumes in this research.

One of the benefits of using a seasonal average is that it reduces the effects of seasonal variations on pedestrian volumes by eliminating low volume months. A seasonal average also increases the consistency of pedestrian data from year-to-year. In climates with large seasonal variation in temperature, the time of year and the rate at which the temperature transitions from colder to warmer (or vice versa), can vary. As a result, years with a mild winter, an early spring, or a late fall may have higher than normal annual average pedestrian volumes. A seasonal average reduces these differences by only using months with consistently higher pedestrian volumes.

As discussed in Section 2.1.1, temperature has been found to have an influence on pedestrian volumes. Temperature is therefore instrumental in selecting the range of months over which to apply SADPT. Figure 4-6 shows a summary of the maximum daily temperatures in Winnipeg between 2004 and 2014, in order to identify the best months for SADPT calculation.

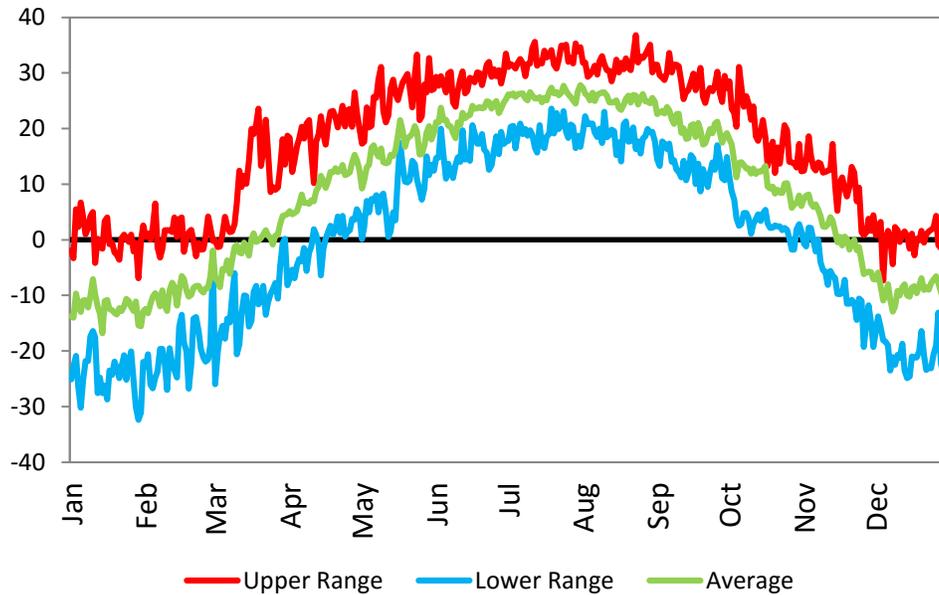


Figure 4-6: Summary of maximum daily temperatures between 2004-2014

The effect of weather factors on pedestrian volume is presented in Section 4.4 of this chapter. As might be expected, the months of the year with temperatures consistently above 0°C yield higher and more consistent pedestrian volumes than colder months. The point at which the daily maximum temperature rises and stays above 0°C varies from year to year; however, Figure 4-6 shows that the months of May through October consistently have maximum daily temperatures above 0°C.

A rule of thumb recommended by the TMG is that SADT be used for non-motorized traffic over a period of months containing at least 80% of annual traffic. Table 4-3 shows the percentage of the total annual pedestrians counted in different ranges of months. Percentages which do not include the minimum 80% of total annual pedestrian volume are shown in red.

Table 4-3: Percentage of annual pedestrian volume occurring in each range of months

	BG1	BG2	BG3	HT1	HT2	TT	YRG
<b>May – October</b>	<b>71%</b>	<b>77%</b>	<b>73%</b>	<b>68%</b>	<b>64%</b>	<b>76%</b>	<b>72%</b>
<b>April – November</b>	87%	92%	87%	80%	<b>78%</b>	91%	88%
<b>March - November</b>	89%	94%	91%	85%	85%	94%	91%

Following the TMG recommendation, an SADPT reflecting at least 80% of annual traffic could be applied to a minimum of nine months of the year, from March through November, 2014. A time period of March through November includes potentially variable transition months in which the temperatures from year to year are not consistent. However, SADPT is still a valuable measure of pedestrian activity because it represents the higher pedestrian volumes occurring during the summer. The months of May through October were used to calculate the SADPT for this research, acknowledging that the May through October volume does not meet the target 80% of annual volume at any count site. This decision was made because the May through October range increases year-to-year consistency by eliminating some of the annual variation in climate. AADPT was also calculated and used in analysis because it represents a more complete set of data than SADPT and is helpful for looking at pedestrian volumes over the entire year.

#### **4.2.2 Calculation Methods for Average Daily Pedestrian Traffic**

Traditional methods of calculating and applying AADT do not necessarily apply for pedestrians. For example, one method of calculating AADT is called the Simple Average method, and involves taking the average of each day's traffic volume in a given one-year period (FHWA, 2013). This approach requires a full 365 days of volume data (or 366 for a leap year) and is less effective in the instance of missing or incomplete data. Missing data could skew the average, depending on the season or day of week in which the missing data occurs. In the case of the pedestrian volumes on trails in Winnipeg, a simple average would not be practical because of the amount of missing data discussed in Section 4.1.3 would introduce error.

A second method to calculate average daily traffic, described by the American Association of State Highway Transportation Officials (AASHTO), attempts to account for the effects of missing data by averaging data temporally based on day of the week and month of the year (FHWA, 2013). This method

requires 84 complete days of data, representing one complete day of data for every day of the week in every month of the year. The equation, found in FHWA (2013), is as follows:

$$AADT = \frac{1}{7} * \sum_{i=1}^7 \left[ \frac{1}{12} * \sum_{j=1}^{12} \left( \frac{1}{n} * \sum_{k=1}^n VOL_{ijk} \right) \right]$$

Where:

$VOL$  = daily traffic for day  $k$ , of day-of-week  $i$ , and month  $j$

$i$  = day of the week

$j$  = month of year

$k$  = each occurrence of a given day of the week during a given month

$n$  = the number of occurrences of a given day of the week during a given month (FHWA, 2013)

The AASHTO formula is based on the assumption that traffic varies consistently between each day of the week and each month of the year. The truth of these assumptions has not been verified for pedestrian traffic and the AASHTO formula may not be appropriate for calculating average daily pedestrian traffic if the assumptions are not met. Section 4.3 addresses these assumptions by examining the temporal variability of pedestrian traffic. The AASHTO method was not attempted for this research because the extent of data removal reduced the number of days of data below the acceptable criteria for calculation.

A third method was used to calculate average pedestrian volumes. The method uses hourly, rather than daily data to estimate average daily volume for a given transportation mode. The FHWA has recently investigated the use of hourly volumes rather than daily volumes as way of calculating AADT for motor vehicle traffic as well (Krile, Feng, & Schroeder, 2014). The use of hourly rather than daily volumes is advantageous because it does not require complete days of data and the hours used in the calculation of AADT need not be from the same day.

The approach used to calculate average pedestrian traffic for this research involved calculating an average daily pedestrian volume for weekdays and weekend days in each month using hourly volumes rather than daily volumes. Monthly volumes were calculated using a weighted average based on the number of weekdays and weekend days in each month. This approach requires at least 48 hours of data per month, equivalent to at least one weekday and one weekend day. The equation used to calculate the monthly average pedestrian traffic (MADPT) and annual average pedestrian traffic (AADPT) is as follows.

$$MADPT_m = \frac{a * \sum_{h=1}^{24} (\frac{\sum_{i=1}^n v_{hi}}{n}) + b * \sum_{h=1}^{24} (\frac{\sum_{j=1}^n v_{hj}}{n})}{a + b}$$

$$AADPT = \frac{\sum_{m=1}^{12} MADPT_m}{12}$$

Where,

$MADPT_m$  = the average daily pedestrian traffic volume occurring in a given month  $m$

$V_{hi}$  =The volume occurring in hour  $h$  on a weekday in a given month, where  $n$  indicates the number of times that hourly volume is found on a weekday in a given month.

$V_{hj}$  = The volume occurring in hour  $h$  on a weekend day in a given month.

$a$  = the number of weekdays occurring in a given month  $m$

$b$  = the number of weekend days occurring in a given month  $m$

The seasonal average daily pedestrian traffic volume (SADPT) was calculated similarly, except averaged over the months of May through October, rather than the whole year. This approach has not been tested in other research and should be used cautiously and with the application of judgement. While the acronym AADPT was used to represent the average calculated in the above formula, it should be noted that this is a new approach and distinct from the AASHTO method of calculating AADT. It attempts to

account for the missing data specific to this research while still representing a value approximating the true average daily pedestrian traffic occurring at each site. Table 4-4 shows a summary of the average monthly pedestrian volumes at each count site as well as the annual (AADPT) and seasonal (SADPT) averages calculated using this approach.

**Table 4-4: Average daily pedestrian volumes by month, AADPT, and SADPT at each count site in 2014**

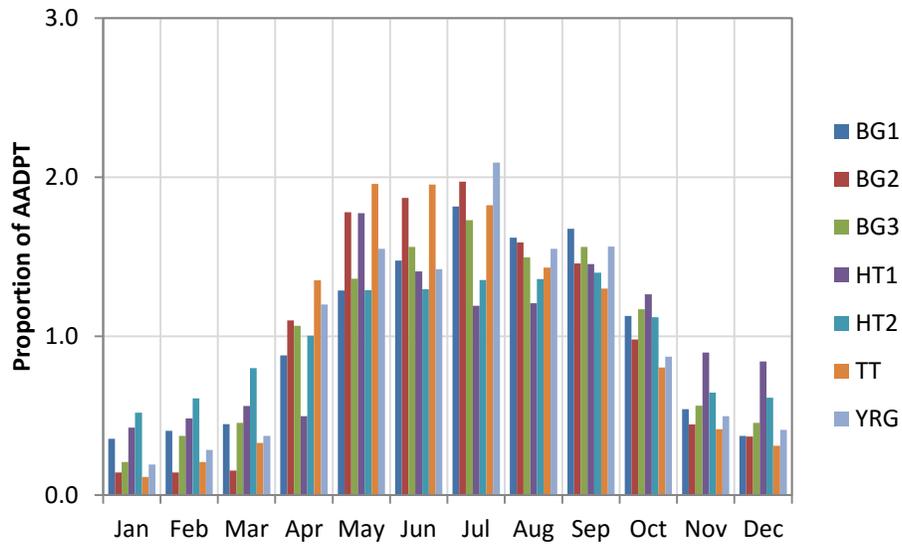
	<b>BG1</b>	<b>BG2</b>	<b>BG3</b>	<b>HT1</b>	<b>HT2</b>	<b>TT</b>	<b>YRG</b>
<b>Jan</b>	50	20	32	57	62	18	27
<b>Feb</b>	57	20	56	64	73	32	40
<b>Mar</b>	63	22	69	75	95	50	53
<b>Apr</b>	124	156	160	66	120	208	170
<b>May</b>	182	253	205	236	154	302	220
<b>Jun</b>	208	266	235	188	155	301	202
<b>Jul</b>	256	281	261	159	162	281	297
<b>Aug</b>	228	226	225	161	163	221	220
<b>Sep</b>	236	207	235	194	167	200	222
<b>Oct</b>	159	139	176	168	134	124	124
<b>Nov</b>	76	63	85	119	77	64	70
<b>Dec</b>	53	52	68	112	73	48	58
<b>AADPT</b>	141	142	151	133	120	154	142
<b>SADPT</b>	212	229	223	184	156	238	214

This research uses the proposed measures of AADPT and SADPT to perform temporal and weather analysis of pedestrian volumes on multi-use trails in Winnipeg. These values provide a consistent basis from which to compare variation over time and differences between count sites.

### **4.3 VARIABILITY OF PEDESTRIAN VOLUMES DUE TO TEMPORAL FACTORS**

Pedestrian volumes in Winnipeg were found to vary by month, day of the week, and time of day. The monthly variation in pedestrian volumes corresponded to seasonal changes, with lower volumes in winter and higher volumes in summer. This trend is demonstrated in Figure 4-7, which shows the

average pedestrian volume in each month at each count site, relative to AADPT. The volumes are shown as a proportion of AADPT to provide a consistent basis for comparison between sites.



Sample Sizes	BG1	BG2	BG3	HT1	HT2	TT	YRG
# Hours	7577	8134	8605	8483	8631	8605	7966
Equivalent # Days	316	339	359	353	360	359	332

Figure 4-7: Monthly variation of pedestrian volumes relative to AADPT

Figure 4-7 shows that there is a strong relationship between month-of-year and pedestrian volume at all count sites, with higher volumes in summer than winter. Some count sites exhibit more distinct summer peaking than others. For example, the volumes at BG1 and HT2 increase during the summer; however, they appear to have more steady volumes throughout the year relative to other count sites. Conversely, count sites such as TT and BG2 have higher peaking in summer and lower volumes in winter compared to other count sites.

The monthly variation in pedestrian traffic was also analysed for weekdays and weekend days separately. Figure 4-8 shows the monthly variation in average daily pedestrian traffic for weekdays only and weekend days only.

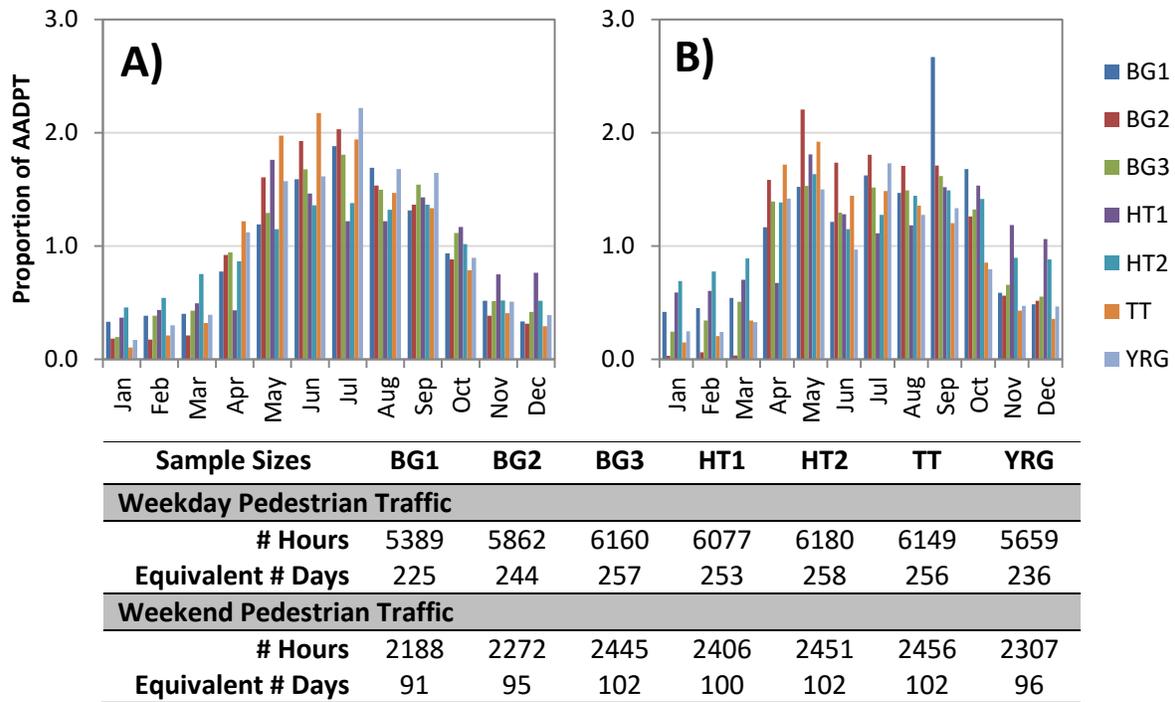


Figure 4-8: Average daily pedestrian traffic by month for A) weekdays only, and B) weekend days only, expressed as a proportion of AADPT

Figure 4-8 shows that when the averages are split up by weekdays and weekend days, the ratio of daily pedestrian traffic to AADPT varies differently by month. Winter months have low volumes for both weekdays and weekend days; however, summer months reveal different characteristics between weekdays and weekend days. Weekdays appear to exhibit an increase in average pedestrian volume up to a maximum occurring in June and July, followed by a decrease in average pedestrian volume. Weekend days exhibit a sudden increase in pedestrian volume occurring around April or May, followed by relatively steady volumes throughout the summer and another sudden decrease in volumes between October and November. This difference indicates that weekdays and weekend days have different temporal patterns and should be considered separately when making pedestrian volume estimates.

In addition to AADPT, average daily pedestrian volumes were also compared to SADPT. The relationship shown in Figure 4-9 shows the average pedestrian daily volume for weekdays and weekend days, as a proportion of SADPT.

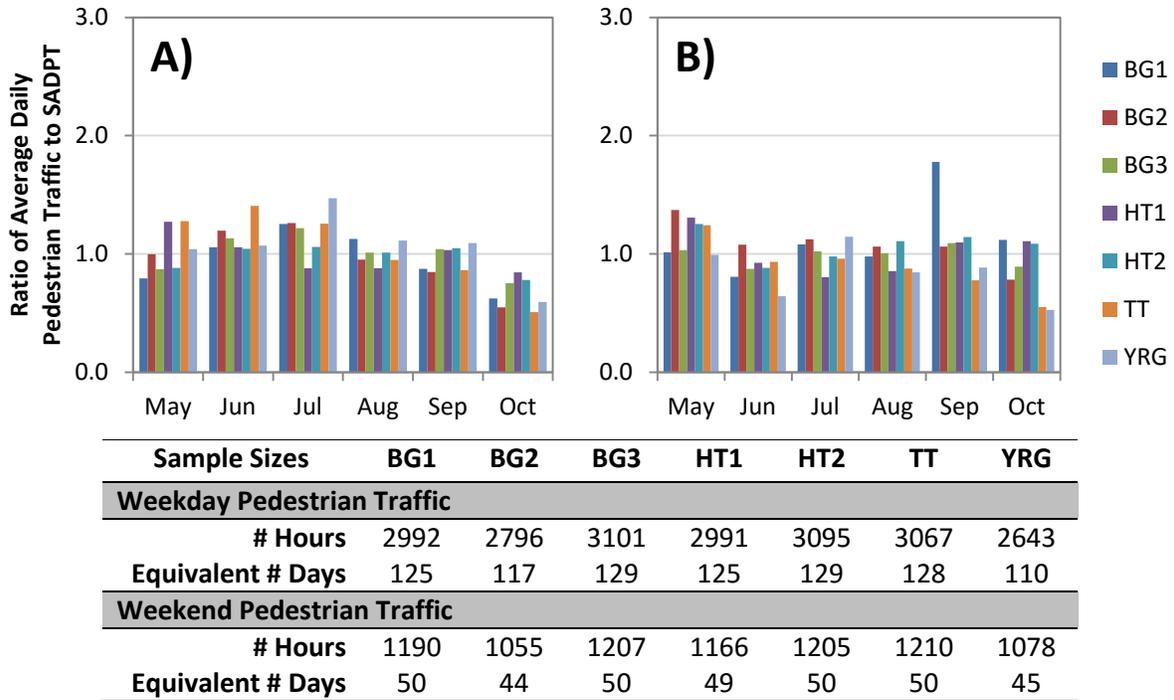


Figure 4-9: Average daily pedestrian traffic by month for A) weekdays only, and B) weekend days only, expressed as a proportion of SADPT

The pedestrian volumes relative to the average are much more consistent between May and October compared to winter months. This finding supports the use of SADPT in pedestrian analysis as a representation of average pedestrian, because seasonal monthly volumes appear to be consistent.

Recall that current methods used to calculate average pedestrian volumes both monthly, seasonally, and annually require data from each day of the week. The relationship between pedestrian volume and day-of-week was considered to investigate this assumption. Figure 4-10 shows the day of week variation in pedestrian volumes for each month of the year at each count site. Insufficient data were available to calculate the day-of-week volumes relative to weekly traffic; therefore, the volume on each day of the week is shown as a proportion of monthly average daily pedestrian traffic (MADPT).

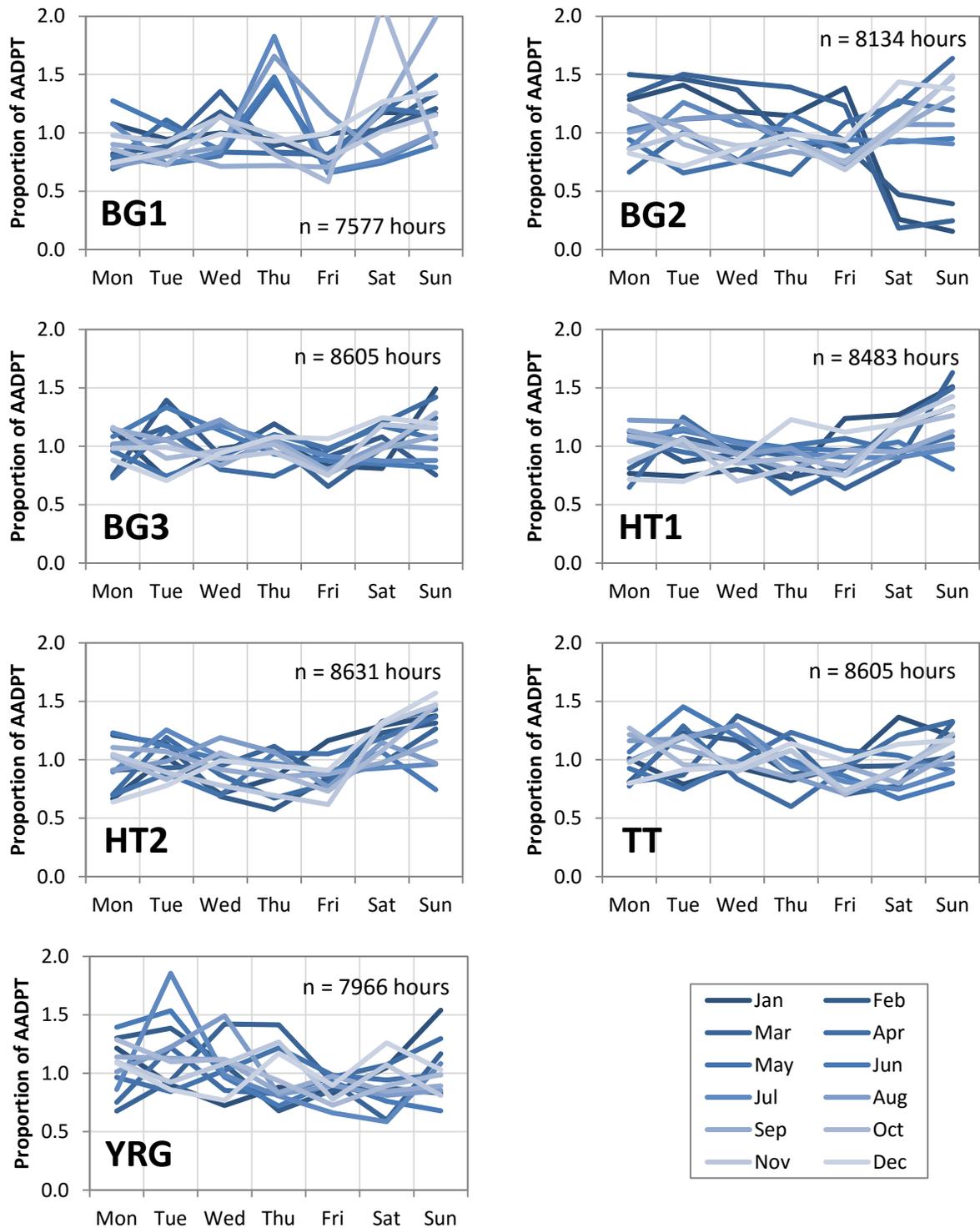


Figure 4-10: Day-of-week variation of pedestrian traffic at each count site, expressed as a ratio of average day-of-week pedestrian volume to MADPT

These results indicate a high degree of variability in the month-to-month proportion of pedestrian traffic on any given day of the week, although some count sites appear to have less month-to-month variation in day-of-week traffic than others. In general, there appears to be an increase in month-to-month consistency in day-of-week patterns in higher volume months; however, the day-of-week patterns are still highly variable at most sites. These results challenge the assumption in the AASHTO AADPT calculation method and the traditional factor method that day-of-week patterns are consistent throughout the year. Given the high variability of day-of-week proportions, removing day-of-week from the pedestrian AADPT calculation be warranted for multi-use trails in Winnipeg. This hypothesis corresponds with the finding by Budowski (2015) that the link between bicycle volumes and day-of-week is unnecessary for AADPT calculation. Further investigation is needed to determine the most appropriate way(s) of calculating average pedestrian volumes in the future.

Finally, the temporal analysis considered hour-of-day pedestrian volumes. Both weekday and weekend hourly volume distributions were plotted for each month and count site in order to better understand the variability of pedestrian traffic volumes. Figure 4-11 shows an example of hourly distributions of pedestrian traffic in January, March, and July at BG3.

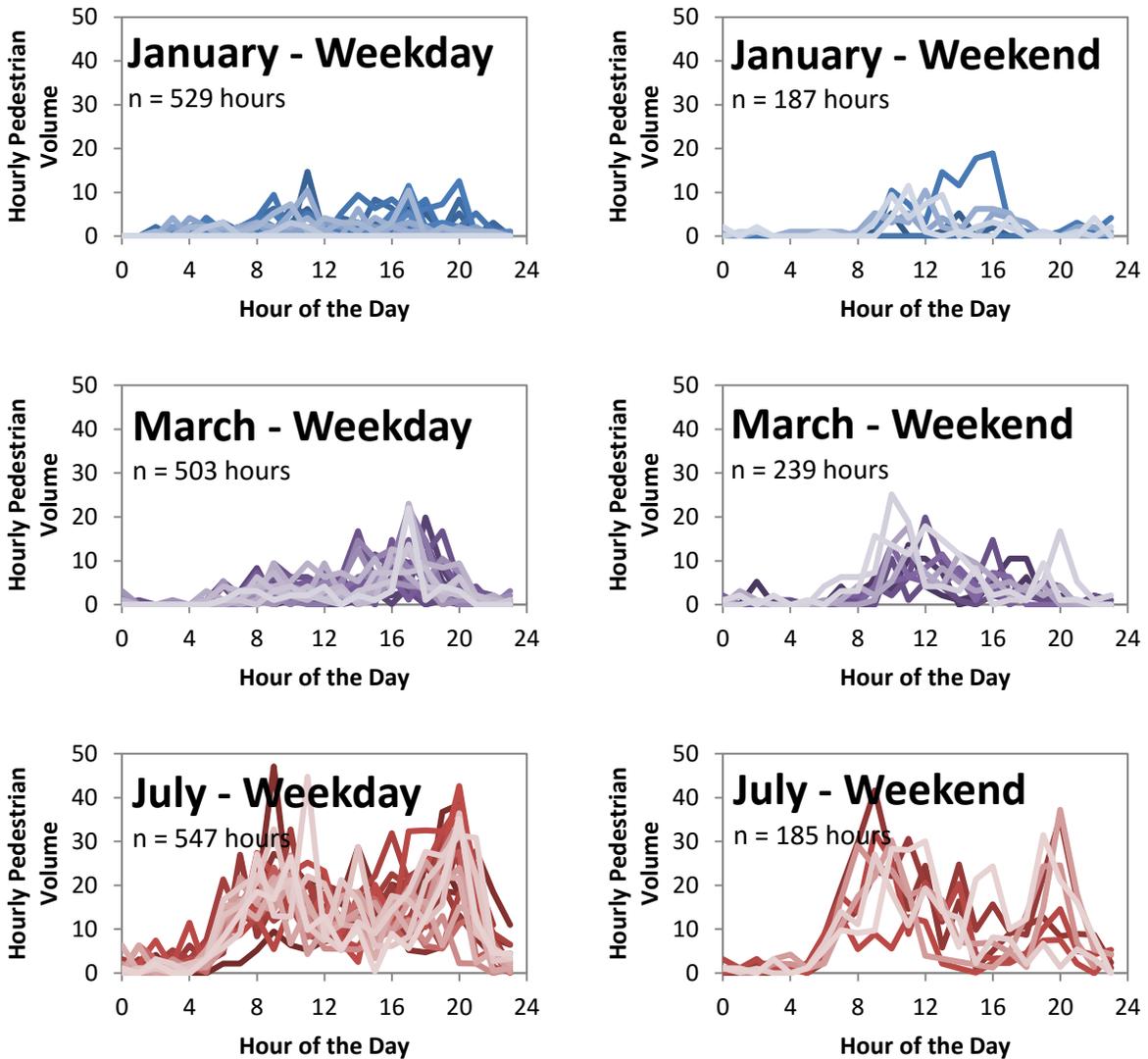


Figure 4-11: Hour-of-day variation for weekend and weekday pedestrian traffic at BG3

Figure 4-11 shows the difference between summer and winter counts, as well as the difference between weekday and weekend hourly distributions. At all count sites, there was lower volume and higher variability in the hourly distributions of pedestrian volumes between December and March, and higher and more consistent patterns between April and November. The hourly distributions observed between June and September were the most consistent for all count sites. One of the reasons for the variability observed in winter months is that during low volume months, even one or two pedestrians could make up a large proportion of that day's pedestrian volume. When considering the difference between

weekday and weekend hourly distributions, all count sites exhibited a higher AM peak and a lower or sometimes nonexistent PM peak on weekends and a smaller AM peak and larger PM peak on weekdays. AM and PM peaking exhibited by weekday traffic may be related to the time before or after work at which pedestrians use the trails. Weekday PM peaking usually occurs around 19:00 or 20:00, which corresponds to the time after a typical workday in which people might choose to go for a walk.

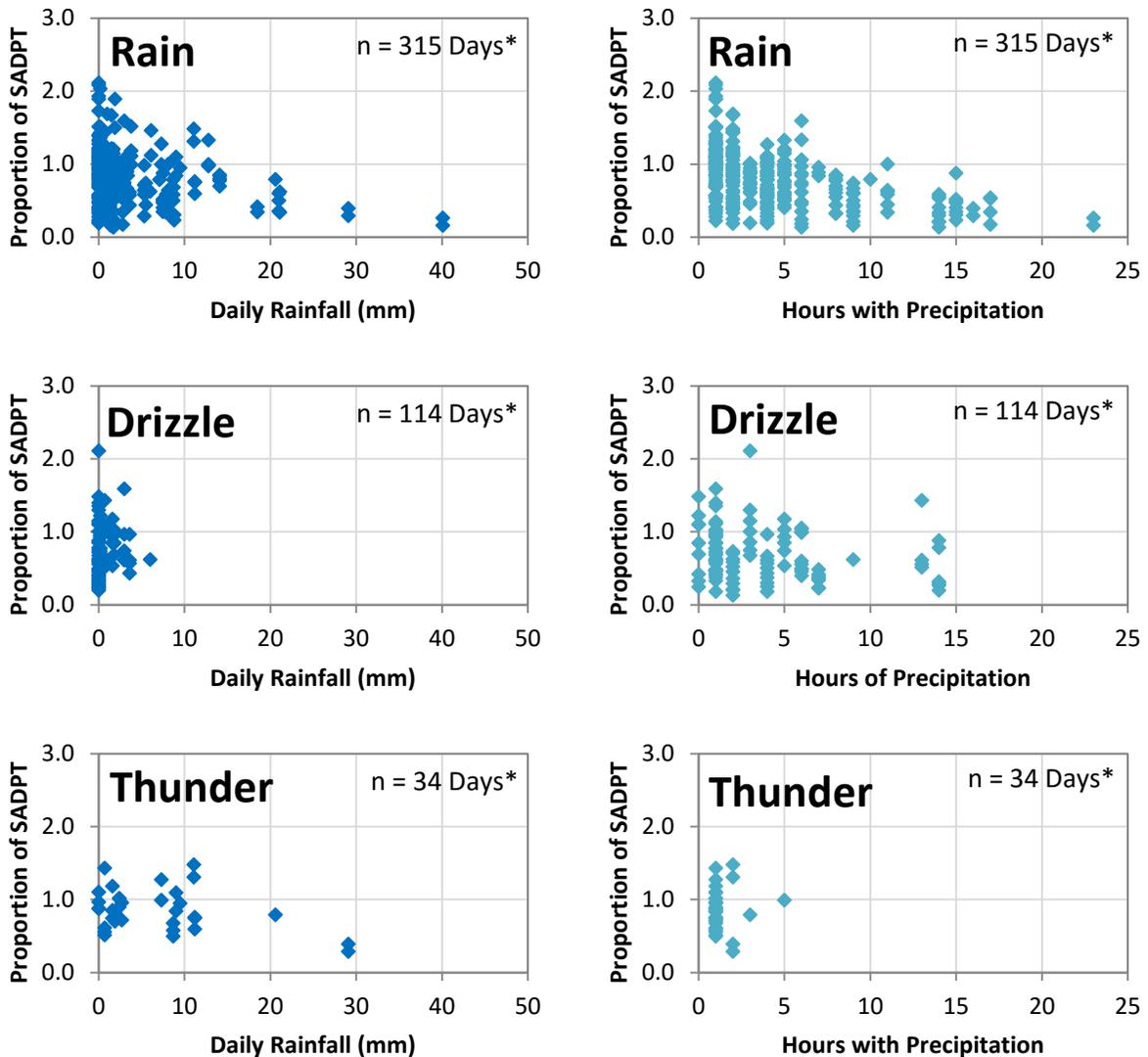
In summary, variability is inherent in pedestrian volumes at the hourly, daily, and monthly levels. Based on the pedestrian volumes collected, several conclusions are drawn. First, the variability in hour-of-day and day-of-week traffic is highest during the coldest months of the year (November – April) and lowest during the warmest months of the year (May – October). Therefore, the most consistent time of year to use for analysis would be in summer when the variability of pedestrian traffic volumes is the lowest. Second, weekend and weekday traffic behaves differently at hourly, weekly, and monthly levels. This finding supports the decision to include a weekday and weekend day component in analysis of pedestrian volumes. Third, day-of-week variation is not consistent from month-to-month, which supports the decision to simplify analysis to only weekdays and weekend days rather than using each day of the week. This finding only applies to pedestrian volumes on multi-use paths, as other facility or user types may follow more consistent day-of-week patterns.

#### **4.4 VARIABILITY OF PEDESTRIAN VOLUMES DUE TO WEATHER**

A qualitative analysis was conducted to determine the effect of weather variables on pedestrian volumes on multi-use trails in Winnipeg. These variables are rain, snow, wind, and daily maximum temperature. Pedestrian volumes for each variable were presented as proportions of AADPT in order to make more uniform comparisons between sites.

#### 4.4.1 The Effect of Rain on Pedestrian Volume

The amount of daily rain precipitation and the number of hours per day of reported precipitation were compared to daily pedestrian volumes at all count sites. Figure 4-12 shows the relationship between daily rainfall and daily pedestrian volume, expressed as a proportion of SADPT.



\*n = the number of daily volumes calculated in which a rain event occurred

Figure 4-12: Effect of total daily rainfall and hours of reported precipitation on pedestrian volume at all count sites

The relationship between pedestrian volume and non-freezing precipitation has a negative correlation for both total daily rainfall and the number of recorded hours of precipitation. As the daily volume of rain increases, the daily number of pedestrians tends to decrease. Similarly, as the amount of hours in which precipitation is recorded increases, the daily number of pedestrians tends to decrease. Most daily rainfall totals between zero and ten millimetres and there is a notable amount of variation in pedestrian volume within this range. Precipitation recorded as rain occurred the most frequently, and both volume of rain and hours of rain had a negative correlation with pedestrian volume. Precipitation recorded as drizzle was more sensitive to the number of hours of drizzle than the accumulated volume, because drizzle typically signifies low rainfall volumes. Thunderstorms are typically associated with heavier rainfall volume and shorter time periods; therefore, precipitation recorded as a thunderstorm was more sensitive to the total precipitation volume rather than the number of hours of thunderstorms.

#### **4.4.2 The Effect of Snow on Pedestrian Volume**

The relationship between the amount of daily precipitation as snow and daily pedestrian volumes is summarized in Figure 4-13. The months used in the analysis of the effects of snowfall on pedestrian volume are November through April, which correspond to the period in which precipitation was observed as snow and not as rain. Snowfall is measured as the water equivalent of snowfall, in millimetres.

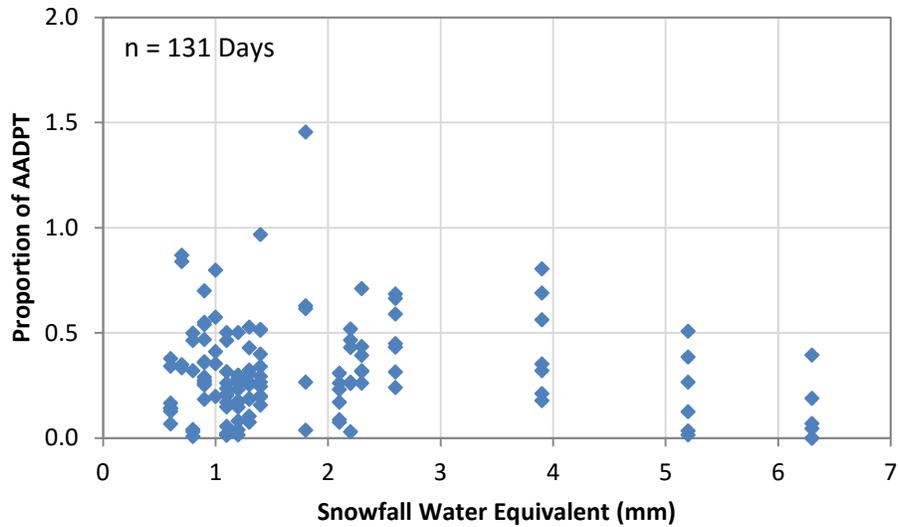
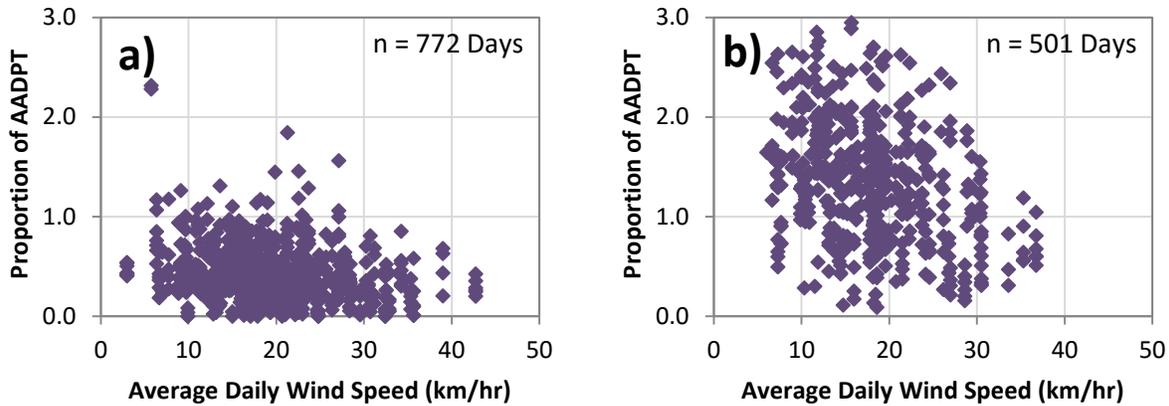


Figure 4-13: The effect of snowfall on daily pedestrian volume

Based on the results shown in Figure 4-13, a slight negative correlation was observed between daily pedestrian volumes and the amount of snow precipitation. Although slight variation in pedestrian volumes did occur, the presence and magnitude of snow precipitation was not found to correlate strongly with pedestrian volumes on the multi-use trails studied in this research.

#### 4.4.3 The Effect of Wind on Pedestrian Volume

Average wind speed was also compared to daily pedestrian volumes. The entire year was considered in the analysis, because variable wind speeds occur throughout the year. Figure 4-14 shows the relationship between average daily wind speed and daily pedestrian volumes at each count site.

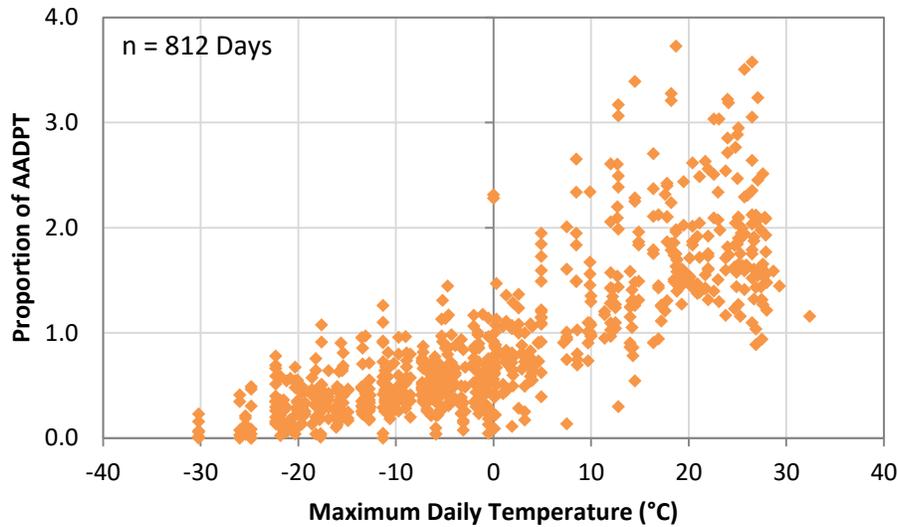


**Figure 4-14: The effect of average wind speed on daily pedestrian volumes excluding days with rain for a) temperatures below 0°C and b) temperatures above 0°C**

As average wind speed increases, pedestrian volume tends to decrease; however, the correlation between wind speed and pedestrian volume does not appear strong, and is highly sensitive to temperature. A wide range of pedestrian volumes was found to occur for any given wind speed. Wind speeds above approximately 30 km/hr resulted in a smaller (and lower) range of pedestrian daily volumes. Low pedestrian volumes appear to occur for all wind speeds; however, the average daily wind speed appears to affect the upper range of pedestrian volumes such that the upper range of pedestrian volumes appears to decrease as wind speed increases. This trend is more noticeable when the maximum daily temperature exceeds 0°C, because of generally higher pedestrian volumes.

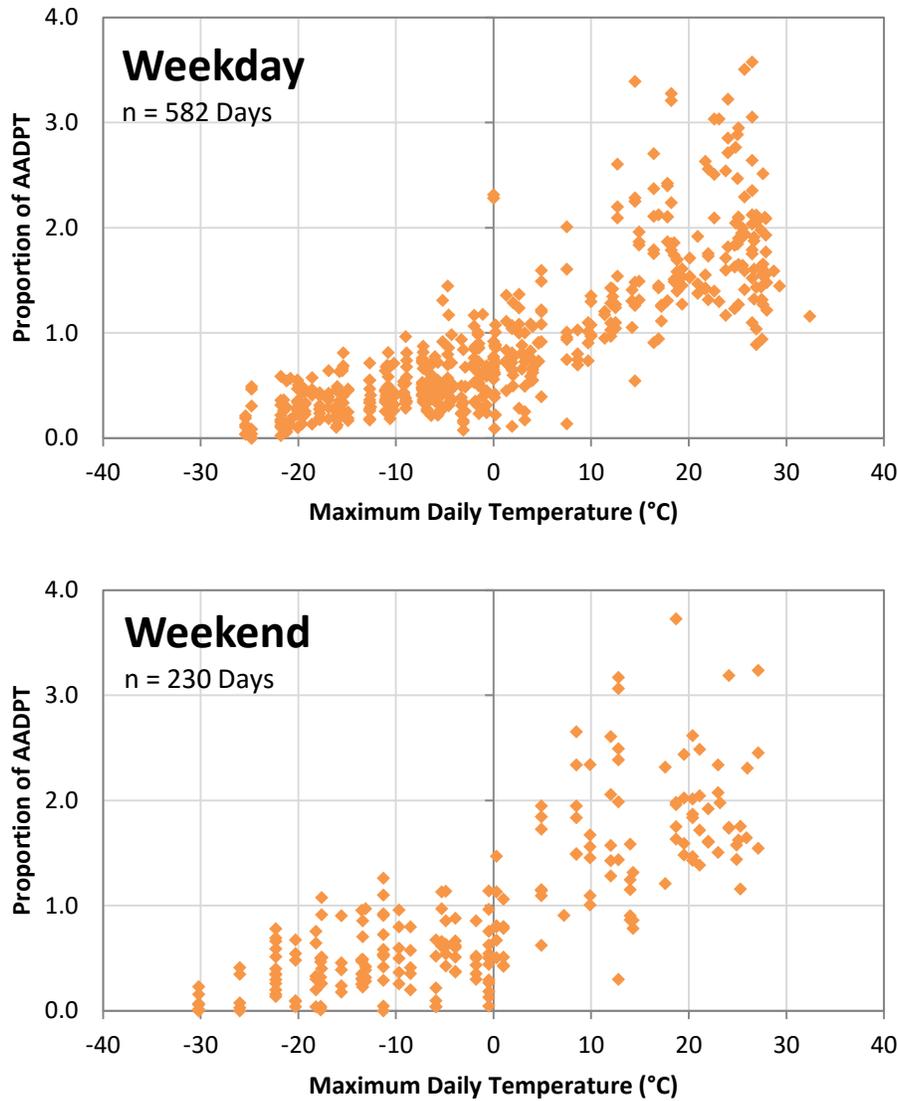
#### **4.4.4 The Effect of Temperature on Pedestrian Volume**

The effect of daily maximum temperature on daily pedestrian volume was the final variable examined. Figure 4-15 shows the relationship between daily maximum temperature and pedestrian volumes at all count sites, excluding days with rain and high wind (> 25 km/h).



**Figure 4-15: The effect of daily maximum temperature on daily pedestrian volumes**

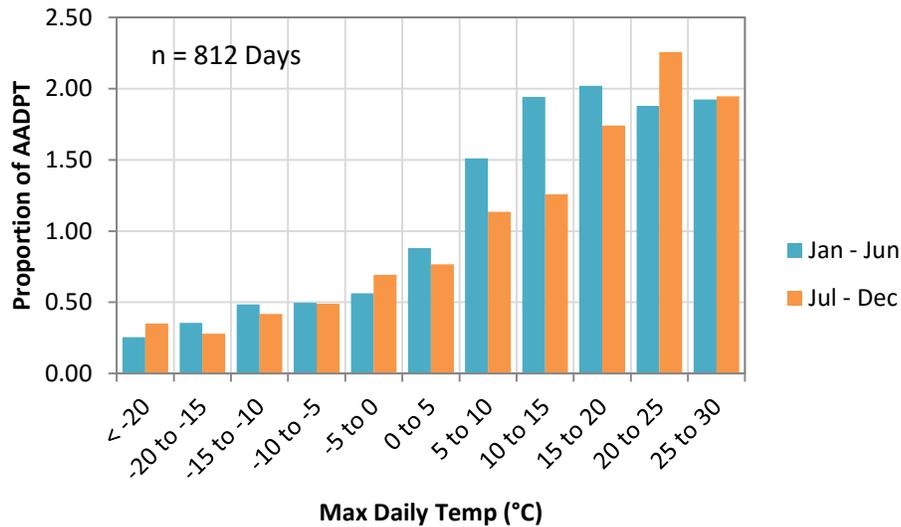
The relationship between temperature and pedestrian volume is non-linear. In general, as temperature increases, pedestrian volume tends to increase. The rate of increase in pedestrian volume with temperature is higher at temperatures above 0°C and lower at temperatures below 0°C. At temperatures below 0°C, the pedestrian volumes are consistently low, with less variable pedestrian volumes relative to temperature. At temperatures above 0°C, the range of the possible pedestrian volumes increases. Recall that days with rain or high wind are not included. Weekends and weekdays exhibit different pedestrian volume patterns and may affect the variability of the above results. Figure 4-16 shows the relationship between temperature and pedestrian volume after disaggregating the data into weekdays and weekend days.



**Figure 4-16: Effect of daily maximum temperature on pedestrian volume on weekdays and weekends at all count sites after removing days with rain, strong wind (>25km/h)**

The relationship between temperature and pedestrian volume appears more consistent on weekdays than on weekend days. This may be due in part to fewer data points being available for weekend days. The relationship between temperature and pedestrian volume appears to be stronger than those for wind and rain; however, variability persists. Moreover, the amount of variability in the data appears higher at temperatures above approximately 15°C. Some of the variation may be due to differences between count sites, as well as the variation in average wind speed.

The time of year was another interesting variable which was found to affect results. Figure 4-17 shows average pedestrian volumes for a series of temperature intervals, expressed as a proportion of AADPT. The data has been divided into the first and second halves of the year.



**Figure 4-17: Relationship between pedestrian volume and temperature for the first and second halves of the year**

For the most part, pedestrian volumes in spring were found to be higher than pedestrian volumes in fall at the same temperatures. This trend is most evident between the temperatures of 5°C and 20°C. While the cause of this difference has not been established, it may be due to the perception of the weather experienced by pedestrians choosing to use the multi-use trails. Perhaps the warming temperatures in spring are perceived as warmer than the same cooling temperatures in fall, because spring temperatures are preceded by colder winter temperatures and fall temperatures are preceded by warmer summer temperatures. Below 0°C, the results show that volumes are low regardless of time of year.

## **4.5 IMPLICATIONS FOR TRANSPORTATION ENGINEERING AND PLANNING**

This research is one piece of the pedestrian traffic monitoring puzzle. The ability to understand pedestrian traffic can inform planning, design, operation and maintenance decisions regarding the pedestrian network. Pedestrian data is important because it provides decision makers with the information necessary to plan and design for pedestrians in real-world applications. Information about pedestrian volume contributes to proper design and management of pedestrian facilities. An understanding of how many pedestrians are using a certain facility and under what conditions they choose to travel, can impact many decisions from the planning and design of new facilities to the prioritization of snow removal or the provision of lighting. In terms of engineering, knowledge of pedestrian volumes also has implications in traffic safety as well as traffic signal timing and design.

Knowledge of pedestrian traffic and the patterns in which they occur has broad applications in transportation planning and engineering, both in the short term, and over the long term. If the patterns of pedestrian traffic are well understood, pedestrian volume data can be used in the short term to more readily extrapolate short duration counts and possibly even react to changes due to real-time events which influence traffic. In the long term, knowledge of pedestrian volumes can influence planning decisions in terms of filling in gaps in the network, making policy changes, and addressing factors such as access to pedestrian facilities in terms of socio-economic status, and demographics.

While this research was conducted on multi-use trails in Winnipeg, the findings are applicable to other recreational pedestrian facilities across Canada and other North American cities with cold winters. As a winter city, the weather factors examined in this research were not found to vary from site to site, which suggests that similar patterns may occur in other winter city contexts with similar conditions. In particular, the variation between summer and winter as well as the response to changing temperature

are expected to translate into other monitoring contexts. In addition, the method of calculating average daily pedestrian traffic based on hourly volumes may be useful to other jurisdictions dealing with how to quantify pedestrian traffic.

When looking more specifically at the technical implications of this research within the traffic monitoring context, this research found that pedestrian traffic is characterized by different patterns than motor-vehicle traffic monitoring. Non-motorized traffic monitoring borrows from motor-vehicle traffic monitoring concepts; however, this research has shown that in terms of temporal variation and the effects of weather, pedestrian volumes behave differently than motor vehicles. The findings from this research suggest that the analysis of pedestrian volumes requires a different approach than the one used for motor vehicle traffic monitoring. This need for a new approach has implications for transportation professionals across North America as they seek to monitor and analyse pedestrian traffic in their jurisdiction.

In terms of temporal factors, pedestrian volumes on multi-use trails in Winnipeg undergo a high degree of seasonal peaking, and do not exhibit clear day-of-week patterns. This finding suggests that calculating average volumes in the case of missing data may not require that each day of the week be represented, as suggested by the AASHTO method. More data is needed to determine whether the lack of clear day-of-week patterns is symptomatic of all pedestrian traffic, or only of pedestrian traffic on multi-use trails.

Pedestrian traffic on multi-use trails was found to be sensitive to rain, wind, and temperature, which is not commonly incorporated into analysis of motor vehicle traffic. Weather factors have not yet been applied extensively in pedestrian traffic monitoring; however, they may be an appropriate tool to use in certain analysis. For example, weather may be useful to incorporate into the development of methods to estimate annual average pedestrian traffic from short duration counts, including the development of factor groups.

## **5 CONCLUSIONS AND RECOMMENDATIONS**

This chapter summarizes conclusions of the research, and discusses for future research opportunities.

### **5.1 CONCLUSIONS**

This research examines patterns of pedestrian volumes on multi-use trails in Winnipeg, from the perspective of temporal and weather related variation. It includes an environmental scan, a description of the methodology used to conduct pedestrian counts, and analysis of pedestrian volumes to (1) determine an approach to calibration and quality control, (2) calculate average daily pedestrian traffic on both an annual (AADPT), and seasonal (SADPT) basis from continuous counts, and (3) examine the variability of pedestrian volumes with respect to both temporal and weather factors.

The results presented in this research relate to the context of multi-use trails in Winnipeg; however, the concepts addressed can be used by both practitioners and researchers in other pedestrian monitoring contexts. The research can be used by practitioners developing pedestrian traffic monitoring programs in their jurisdictions and by researchers to inform the development of standardized best practices in pedestrian traffic monitoring. Specifically, this research provides a basis of understanding from which to develop further analysis tools, such as the development of techniques for estimating AADPT and SADPT from short duration counts. The following sections describe the key research findings.

#### **5.1.1 Data Quality Control**

Raw data can be improved by performing field validation, calibration, and data cleaning. A minimal level of quality control is essential to ensure that data adequately represents reality. Calibration and data cleaning can also reduce the amount of data which is available for analysis. Regular maintenance, field

checks, and data checks should occur to ensure that equipment is functioning and to avoid the need to remove data in the data cleaning process.

### **5.1.2 Calculating Average Pedestrian Traffic from Continuous Count Data**

Both AADPT and SADPT were selected to represent pedestrian volumes on multi-use trails in Winnipeg. These measures of average daily pedestrian traffic were calculated based on hourly volumes grouped by weekdays, weekend days, and by month. Daily volumes could not be used due to the extent of missing data present at each station.

### **5.1.3 Understanding the Variability of Pedestrian Traffic**

Pedestrian volumes were found to vary both spatially, temporally, and based on weather factors. Pedestrian volume was collected at seven count sites, and each exhibited varying daily volumes of pedestrians, with AADPTs ranging from 120 to 150 pedestrians per day and SADPTs ranging from 150 to 240 pedestrians per day. Spatial variation was not further accounted for in analysis because of the limited number of count sites.

Temporal factors, including time-of-day, day-of-week, and month-of-year were found to correlate with pedestrian volume. Time-of-day patterns were observed at all sites, with differences between time-of-day patterns on weekends compared to weekdays. Aside from the weekday-weekend distinction, day-of-week was not found to meaningfully correlate with pedestrian volume, which challenges the assumption used in the AASHTO formula for calculating AADT as it would relate to pedestrians. Pedestrian volumes were found to be higher in summer months and lower in winter months. Weekday volumes exhibited a relatively constant increase in pedestrian volume in the first half of the year and a similarly constant decrease in volume during the second half of the year. Weekend volumes exhibited a

more sudden increase in volumes around April and May, with a similar drop off in volumes around October and November.

Weather factors were found to have a relationship with pedestrian volumes at all count sites. Rainfall, average wind speed, and temperature were found to correlate with pedestrian volume, while only a slight correlation was found for the amount of snow precipitation. Rainfall and wind speed were found to have a negative correlation with pedestrian volumes, while temperature was found to have a positive correlation. Temperature was found to account for the most variability in pedestrian volumes, compared to the other variables considered. There was less variability in the relationship between temperature and pedestrian volume than for the relationships between pedestrian volume and wind or rain. Controlling for wind and rain in the temperature analysis appeared to strengthen the correlation between maximum daily temperature and pedestrian volume.

## **5.2 OPPORTUNITIES FOR FUTURE RESEARCH**

The following opportunities are identified for future research:

- Some research has conducted thorough quantitative evaluation of the effects of weather on bicycle traffic volumes. There is opportunity for future research to (1) conduct a quantitative analysis of the effects of weather specifically on pedestrians, and (2) link the quantitative weather analysis with pedestrian volumes in order to improve the accuracy of pedestrian AADPT predictions based on weather.
- Qualitative research to further understand the trail users from a planning perspective would be helpful. Such an approach would provide more of a basis for understanding pedestrian's motivations and human factors behind the decision to use the trails.

- The collection of more than one year of data would strengthen the results found in this research by (1) assessing whether the effects of weather found in this research are consistent from year to year, and (2) comparing annual data to study long-term trends in pedestrian volumes and the effects of infrastructure development on pedestrian volumes.
- One of the limitations of this research was missing data. A further investigation of the effects of missing data on pedestrian traffic analysis would strengthen the results of this research and extend to the development of methods to estimate average pedestrian volumes from short duration counts.
- Further research would be beneficial at different pedestrian facilities and in different urban contexts, in order to understand how traffic patterns change throughout the urban environment and whether the characterization of pedestrian traffic should take a different approach for different types of facilities and land-uses.
- Along with the development of methods to estimate average pedestrian traffic from short duration counts comes the need to investigate about the role of traffic pattern groups. This investigation should consider which patterns to look at, and whether traffic pattern groups are the most appropriate way of aggregating pedestrian volume data. Research into pedestrian traffic patterns should not only include temporal factors, but also other correlates of pedestrian traffic, such as weather, the built environment, and socio-demographic factors.
  - If traffic pattern groups can be successfully adapted for pedestrian traffic monitoring, further research is needed to determine how to link short duration count sites to continuous count sites based on traffic patterns. An investigation of which patterns to look for and the necessary proximity of each short duration count site to a continuous count site would be helpful.

- Further research is needed to determine whether AADT and SADT are appropriate ways of quantifying pedestrian traffic. If they are, further analysis is needed to develop an equation which most accurately reduces the effects of missing data. Analysis should also examine which summary statistics other than AADT would be most helpful to jurisdictions and other professionals working in active transportation.

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# APPENDIX A VALIDATION COUNT SHEET

## AT Counting Sheet

Counter: \_\_\_\_\_  
 Date: \_\_\_\_\_  
 Location: \_\_\_\_\_

* Cyclist in centre	S Stroller
W Wheelchair	K Skateboard
D Dog (bigger)	C Child Scooter
Circle cyclists that travel in the wrong lane	

<b>Bishop Grandin Greenway</b>					
<b>PEDESTRIANS</b>					
Time	Eastbound	Total	Westbound	Total	Comments
:00					
:15					
:30					
:45					
:00					
:15					
:30					
:45					
<b>BICYCLISTS</b>					
:00					
:15					
:30					
:45					
:00					
:15					
:30					
:45					