Analysis and Evaluation of Methods for Adjusting Pedestrian Counts

By

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ABSTRACT

Traffic monitoring efforts to date have focussed primarily on motorized travel. As more jurisdictions prioritize active transportation, addressing the need for network-level pedestrian data through system-wide traffic monitoring programs is essential to optimize engineering decisions. The purpose of this research was to evaluate methods to better leverage pedestrian count data for cities to estimate annual pedestrian traffic statistics. Using data from eight automated pedestrian counters, this research validated previously established traffic pattern groups in downtown Winnipeg while analyzing and evaluating adjustment methods to estimate annual statistics from short-duration counts.

Pedestrian traffic data was collected throughout 2016. Using this continuous dataset, two traffic pattern groups initially developed using short-duration count data were updated. Results indicate that in Winnipeg's downtown area, the day-of-year factor method for adjusting short-duration counts produces the most precise estimates of annual average daily pedestrian traffic (AADPT), with mean absolute percent error ranging from 19% to 16% for single day and two week counts respectively. Also that adjustment methods using partial day counts produce approximately twice as much error on average than multi-day counts. Additionally, counts beyond three days in duration do not significantly improve the precision of any multiday adjustment method's estimate of AADPT. Finally, this research highlighted the presence of two additional pedestrian traffic peak periods often ignored by traditional pedestrian traffic data collection methods, these being the noon peak (11:00-13:00) and the evening event peak (21:00-23:00).

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1. INTRODUCTION

1.1. THE RESEARCH

This research evaluated the performance of four methods for adjusting mid-block short-duration pedestrian counts to estimate annual average daily pedestrian traffic (AADPT). The research defines performance in terms of expected error in estimating AADPT. Eight automated pedestrian counters (APCs) were installed on sidewalks throughout downtown Winnipeg and continuously collected pedestrian traffic volumes throughout 2016. These data were used to validate previously defined pedestrian traffic pattern groups (TPGs) within the study area using continuous data as current monitoring efforts make use of groups defined by short-duration counts. Traffic data were also used to evaluate the expected error of four different adjustment methods under varying implementation parameters.

This research develops adjustment factors for each of the adjustment methods for the year 2016 to produce annual pedestrian traffic statistics. The adjustment methods investigated are: the Hourly Factor Method, Separated Factor Method, the Combined Factor Method, and the Day-of-Year Factor Method.

1.2. BACKGROUND AND NEED

Sustainable modes of transportation, such as walking, are among the most important elements for a city in providing healthy and livable communities (Hussein, Sayed, Reyad, & Kim, 2015). Reduced congestion, energy consumption, and air pollution are reasons why an increasing number of North American jurisdictions are prioritizing the accommodation of these modes. While this shift provides many benefits, there is a growing concern regarding transportation network safety. Active travellers, particularly pedestrians, are considered the most vulnerable road users. To provide safe and equitable accommodation to all users of the transportation system, cities require accurate and accessible data to best inform the design and implementation of network improvements.

Understanding pedestrian movement and data availability to inform decision making is in its infancy compared to motorized traffic. While funding for increased frequency and quality of pedestrian traffic data is growing, many cities have begun implementing non-motorized traffic monitoring programs in an ad-hoc fashion in the absence of adequate guidance. Many jurisdictions have identified the need for more systematic approaches to develop non-motorized traffic monitoring programs (TAC, 2017, p. 194). Considering the emerging needs for cities looking to improve sustainability, livability, and accessibility for their residents, this gap in understanding must be addressed to strategically implement a safe and equitable transportation network.

In 2015, the City of Winnipeg published the *Winnipeg Pedestrian and Cycling Strategies* (City of Winnipeg, 2015). This document outlined goals and objectives to improve active transportation accommodation in Winnipeg. An increase in pedestrian traffic volumes was outlined as a “measure of success” for the strategies. Developing a formal pedestrian monitoring program throughout the city was an action item linked to this measure to produce annual pedestrian traffic statistics. This will be used to evaluate progress made towards the goal of increasing pedestrian traffic.

There are two fundamental components of a formal traffic monitoring program. The first is a modest number of continuous count sites which collect traffic data at a single location over the course of a year. These continuous data provide insight into the temporal variation of pedestrian traffic throughout an entire year at a particular location. The second is comprised of many, spatially diverse coverage counts (usually much less than one year in duration). These counts provide insight into the spatial variation of pedestrian activity throughout the transportation network. By assigning similarly behaving continuous and coverage counts to traffic pattern groups (TPGs), adjustment factors can be used to estimate annual statistics at sites where coverage counts were conducted. This is a more economical way of using sensor technology as compared to conducting continuous counts wherever annual traffic statistics are required. While general guidance exists for implementing pedestrian traffic monitoring programs, the local characteristics of a city result in a gap in knowledge for how different adjustment methods will perform (TAC, 2017, p. 193).

This research addresses the gap in knowledge by evaluating the performance of different adjustment methods under varying implementation parameters. These parameters are related to the duration of coverage counts and the time of year they are conducted. This is the next step for the City of Winnipeg to develop a formal pedestrian traffic monitoring program.

1.3. OBJECTIVES AND SCOPE

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

1) What were the hourly, daily, monthly, and seasonal distributions of pedestrian traffic in downtown Winnipeg throughout 2016?

2) Does previous research describing pedestrian traffic pattern groups (TPGs) in the study area, based on short-duration counts, align with the pedestrian behaviour observed at continuous count sites in 2016?

3) How do different coverage count adjustment methods compare to each other under varying implementation parameters (i.e., duration of count, time of year)?

These questions will be answered by meeting the following specific research tasks:

1) Produce annual statistics summarizing the hourly, daily, monthly, and seasonal distributions of pedestrian traffic for the eight continuous count sites.

2) Evaluate the hourly pedestrian traffic distributions on which the original pedestrian TPGs in the study area were created (Olfert, 2015).

3) Determine whether the continuous data collected adequately reflect the TPGs which they were initially assigned to.

4) Compare the mean absolute percent error (MAPE) of adjusted short-duration counts sampled from the continuous count sites for each of the four adjustment methods under varying adjustment parameters (duration of count, time of year).

This research was conducted in the downtown area of Winnipeg, Manitoba over a twelve-month study period beginning January 1, 2016 and concluding December 31, 2016. Data collection was limited to sidewalks in the area bounded by Main Street, Portage Avenue, Memorial Boulevard, and Broadway (Figure 1). Winnipeg has a population of 811,900 (City of Winnipeg, 2017) and has a downtown area with many office spaces, event centres, restaurants, and parking lots. Within the study period, outdoor temperatures ranged from -28°C to 35°C and there were 24 days with more than 10 millimetres of recorded precipitation (Government of Canada, 2017).

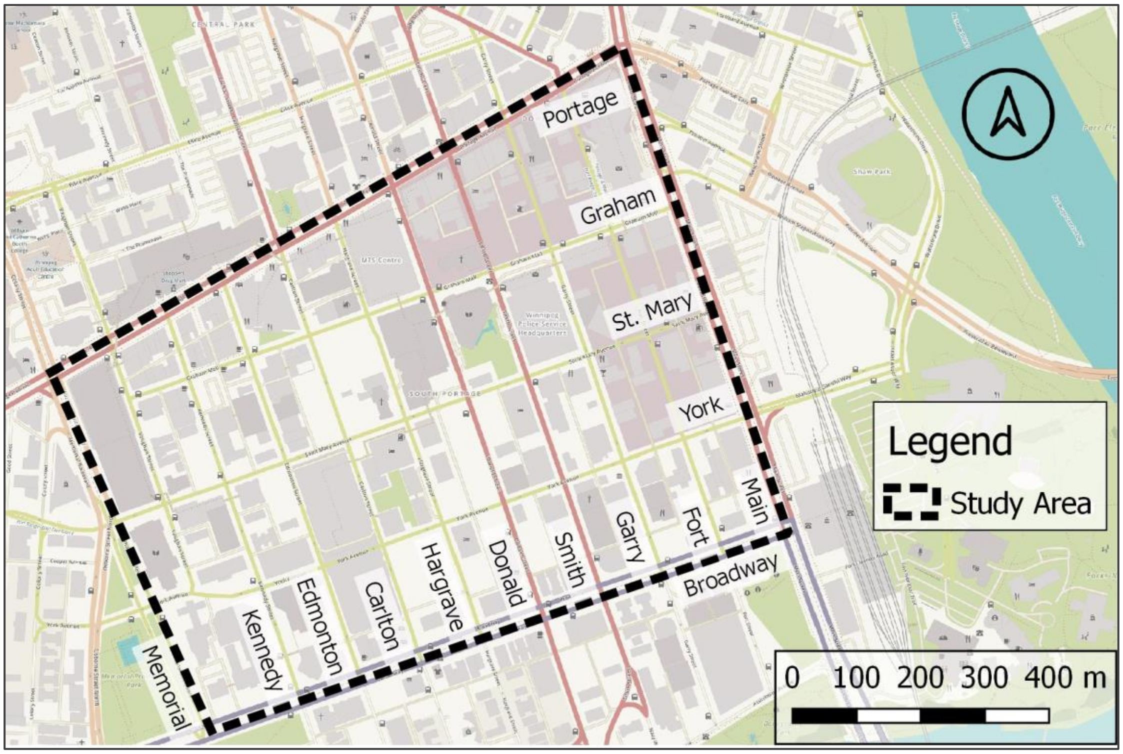


Figure 1: Study Area Map - Downtown Winnipeg

1.4. THESIS ORGANIZATION

This thesis is organized into six chapters.

Chapter 2 summarizes a literature review concerning current practices and research for the development of pedestrian traffic monitoring programs. The literature review addresses the following: system-wide pedestrian monitoring program considerations, the characteristics of pedestrian traffic variability, and the data methods used for analyzing non-motorized traffic.

Chapter 3 outlines the methodology developed to collect and analyze pedestrian traffic data. The methodology discusses (1) automated counting technologies selection; (2) selecting continuous count sites; (3) an overview of the data collection system; and (4) data processing and analysis methods.

Chapter 4 characterizes pedestrian activity within the study area resulting from a year of data collection at eight continuous count locations. This chapter illustrates average hour-of-day, day-of-week, month-of-year, and seasonal trends for each continuous count site. The adequacy of historically established traffic pattern groups (TPGs) within the study area is also validated. These historical TPGs were developed from short-duration counts conducted in fall 2015 and are compared to the behaviour of the continuous counts conducted throughout the 2016 study period.

Chapter 5 presents the analysis and results for the statistical comparison of four coverage count adjustment methods. These include the Hourly, Separated, Combined, and Day-of-Year factor methods. In addition to a summary and analysis, a discussion is presented to highlight the strengths and weaknesses of each adjustment method. Finally, this chapter provides an analysis of each adjustment method under varying coverage count durations and analyzes the expected error of AADPT estimates resulting from coverage counts conducted at different times of year.

Chapter 6 discusses research findings, implications for practitioners, conclusions, and opportunities for future research.

1.5. TERMINOLOGY

The following terms are used throughout the thesis.

AADPT – annual average daily pedestrian traffic.

Adjustment Method – the statistical method by which a coverage count value is adjusted to estimate the annual average daily traffic at that site. This is done by referencing the temporal variation of a continuous count site within the same traffic pattern group.

Automated Pedestrian Counter (APC) – refers to an automated device used for counting the passage of a pedestrian along a sidewalk remotely.

Continuous Count Station – a site where pedestrian traffic data is collected continuously for a duration of at least one year.

Coverage Count Station – a type of short duration count used to evaluate the spatial variation of pedestrian traffic throughout a transportation network.

Evening Traffic – Pedestrian traffic occurring between the hours of 18:00 and 23:59. This traffic is used to evaluate the influence of events hosted at the downtown arena in this research.

Pedestrian – those who navigate infrastructure on foot or with the use of an aid device such as a wheelchair.

Short Duration Count – pedestrian traffic data which is collected for a period less than one year.

Traffic Pattern Group (TPG) – A set of continuous count sites known to exhibit similar temporal variations.

Traffic Monitoring Program – a systematically designed program used to produce network wide traffic statistics based on the spatial and temporal variation observed from coverage count sites and continuous count sites.

MAPE – The Mean Absolute Percent Error. This metric is the absolute difference between an estimate and ground truth value divided by the ground truth value. MAPE is a measure of prediction accuracy of a forecasting method in statistics

HOD – Hour-of Day. Used to indicate the hour of day pedestrian traffic being analysed. Ranges from 0 to 23.

DOW - Day-of Week. Used to indicate the day of week pedestrian traffic being analysed. Ranges from 1 to 7 (Monday = 1, Tuesday = 2, … , Sunday = 7).

MOY - Month-of Year. Used to indicate the month of year pedestrian traffic being analysed. Ranges from 1 to 12 (January = 1, February = 2, … December = 12).

DOY - Day-of Year. Used to indicate the day of year pedestrian traffic being analysed. Ranges from 1 to 366. (Jan 1, 2016 = 1, December 31, 2016 = 366).

WWI – Weekend to Weekday Index. Compares traffic of average weekends to average weekdays to indicate utilitarian or recreational patterns.

AMI – Morning to Midday Index. Compares traffic of average morning hours (7:00 a.m. to 9:00 a.m.) to average midday hours (11:00 a.m. to 1:00 p.m.) to indicate utilitarian or recreational patterns.

2. LITERATURE REVIEW

This chapter summarizes a literature review concerning current practices and research for the development of pedestrian traffic monitoring programs. The literature review addresses the following: system-wide pedestrian monitoring program considerations, the characteristics of pedestrian traffic variability, and data methods used for analyzing non-motorized traffic.

As active transportation data collection is relatively novel compared to motorized traffic, the literature reviewed often attributes results from bicycle or pedestrian specific research to describe "active transportation" in general. While these pedestrian and cyclist activity exhibit similar characteristics, there are differences which should limit the degree to which research findings for the two respective modes are interchangeable. One key distinguishing feature is trip length between these modes. While origin and destination for cyclists may be several kilometres, in a downtown area pedestrian trips are often limited to a couple of city blocks. Also, pedestrians are limited to the sidewalk network while cyclists often share the road with vehicles. Furthermore, much of pedestrian traffic only represents the "last-mile" rather than a full trip. For instance, most of a commute type trip may have been made in a personal vehicle or transit bus, while the remaining distance between a parking lot or bus stop is made as a pedestrian. These differences in trip type are expected to limit the applicability of research findings between the two modes.

In light of differences between pedestrian and cyclist traffic characteristics, an effort was made in the literature review to focus specifically on pedestrian research first for each of the topics. In absence of this, research reporting findings for general active transportation was used. If both these were not available for a topic required in the literature review, bicycle specific research findings were reported.

2.1. SYSTEM-WIDE PEDESTRIAN MONITORING CONSIDERATIONS

The most important function of a jurisdiction's traffic monitoring program is to provide system-wide estimates of traffic statistics which relies on well-designed continuous and coverage count programs (TAC, 2017, p. 54). The process of developing a system-wide traffic monitoring program includes developing traffic pattern groups (TPGs), determining the number of continuous count sites, selecting continuous count sites, assigning short duration counts to the appropriate TPG, and determining the location, frequency, time of year, and duration of coverage counts.

2.1.1. Developing Pedestrian Traffic Pattern Groups

A TPG is composed of a set of continuous count sites which are known to behave similarly with respect to their temporal variation. Given the known temporal variation in activity observed at these sites, spatially diverse coverage counts may be assigned to a similarly behaving traffic pattern groups. Given that the temporal variation of coverage count sites are typically not available, this assignment process is often based on presumed similarities such as land use type, facility type, or local knowledge. This relationship enables the estimation of annual traffic statistics at coverage count sites.

- The Federal Highway Administration (2016, pp. 4-26) states that the best way to analyze traffic patterns to be monitored is to compare hour-of-day (HOD) variation, day-of-week (DOW) variation, and month-of-year (MOY) variation observed at continuous count sites.
- Miranda-Moreno, et al. (2013, p. 19) developed a classification scheme to characterize non-motorized count sites into one of four different TPGs. These include utilitarian, mixed-utilitarian, mixed-recreational, and recreational. These

were produced by analyzing the difference between many short-duration count sites in terms of their HOD and DOW variation.

- TAC (2017, p. 214) outlines three approaches for developing TPGs. The first is the traditional method, which relies extensively on qualitative information and local knowledge of the transportation network that is used to group sites based on similar characteristics. Examples of such traits may include surrounding land use types or nearby network origins and destinations. The second is through clustering procedures, which make statistical comparisons between data collected at different sites. The third is a hybrid approach, which starts with a statistical clustering procedure to identify unique pattern groups, then each group is characterized in terms of the variables which are expected to cause them. For clustering methods, the best approach is to use continuous count data, however short-duration count data is acceptable in the absence of continuous data.
- Olfert (2015) developed pedestrian TPGs in downtown Winnipeg based on the degree to which many short-duration counts were influenced by frequently occurring special events hosted at the downtown arena.

2.1.2. Determining the Number of Continuous Count Sites

The number of continuous count sites assigned to a traffic pattern group has a direct impact on the strength of annual estimates produced by adjusting short-duration counts. The statistical strength of annual estimates increases with the number of continuous count sites within a TPG. For pedestrian traffic monitoring programs, the appropriate number of continuous counters to include in each TPG has not yet been determined in research. Many jurisdictions have replicated practices from motorized traffic monitoring, or have attempted to spread out available resources in a strategic manner.

- The FHWA Traffic Monitoring Guide (FHWA, 2016, pp. 3-27) recommends reliability levels of 10 percent precision with a 95 percent confidence interval for short duration count adjustment using TPGs. The equation used to estimate precision is shown below:

$$\boldsymbol{D} = \boldsymbol{T}_{\mathbf{1}-\frac{\boldsymbol{d}}{\mathbf{2}},\boldsymbol{n}-\mathbf{1}}\left(\frac{\boldsymbol{\mu}/\boldsymbol{s}}{\sqrt{\boldsymbol{n}}}\right)$$

Where:	$\boldsymbol{D}$	relative precision interval [%]	
	$\boldsymbol{T}$	value of student's t-distribution	
		with:	1-d/2 level of confidence
			n-1 degrees of freedom
	$\boldsymbol{\mu}$	mean traffic ratio	
	$\boldsymbol{s}$	standard deviation of traffic ratio	
	$\boldsymbol{n}$	number of continuous count sites	

  For motorized traffic, five to eight continuous count sites are typically needed to achieve a 10 percent precision interval with a 95 percent confidence interval depending on the TPG.

- Ryus et al. (2014, p. 67) state that since research has not developed an appropriate recommendation for reliability levels of precision and confidence in adjusting short-duration counts for pedestrian traffic, jurisdictions should aim to have between three and five continuous count sites in each traffic pattern group.

- TAC (2017, p. 215), recognizes that jurisdictions typically have a limited budget and supply of automated pedestrian counters (APCs), and recommends that the number of continuous count sites be divided equally between the TPGs to be monitored. While potentially decreasing precision, this maximizes the number of coverage counts which can benefit from the application of temporal adjustment factors.

2.1.3. Selecting Continuous Count Locations

The specific locations where continuous counts are conducted will have a significant impact on the results of the pedestrian traffic monitoring program. The purpose of a monitoring program should dictate the methodology in selecting these locations.

- The National Bicycle and Pedestrian Documentation Project (Alta Planning & Design, 2010, p. 5) outlines multiple criteria by which count locations may be selected. These include designated pedestrian and bicycle corridors, representative locations in urban areas, key corridors to gauge the impacts of future improvements, gaps or pinch points in the walking network, or locations where pedestrian incidents are known to be high.

- Jackson, Stolz, and Cunningham (2014, p. 4) initiated a 24-month continuous non-motorized data collection program and documented the site selection process. The goal of the method was to create a prioritized list of recommended continuous count sites which could be used to guide further program investments. This pilot project recommends distributing continuous count sites evenly across distinct TPGs rather than saturating a single group.

- Ryus, et al. (2014, p. 26) recommend using one of four approaches for determining specific continuous count locations within TPGs. These include a random or stratified random sampling method, selecting representative locations to balance resource availability with spatial coverage, targeted locations associated with specific projects, or control locations to assess the changes in traffic volumes over time at sites affected and unaffected by network changes.

2.1.4. Assigning Coverage Counts to Traffic Pattern Groups

Assigning coverage counts to pedestrian traffic pattern groups enables the application of appropriate adjustment factors. Since coverage counts are only conducted for limited periods of time, referencing the temporal variation of a similarly behaving traffic pattern group is done to estimate annual pedestrian traffic statistics.

- Beitel and Miranda-Moreno (2016), recommend that short-duration counts should be assigned to TPGs by assessing the day-of-week and hour-of-day patterns simultaneously. The short duration traffic periodicities should exhibit similar behaviour to the continuous count sites of the TPG to which they are assigned. Without a full year of data at short duration count sites however, these periodicities may not reflect the true behaviour of a site throughout the year.
- TAC (2017, p. 217) recommends the use of a decision algorithm or expert system to systematically assign coverage count TPGs in parallel with an assessment of site specific traffic behaviour. This includes a series of ‘yes or no’ questions to guide the assignment process. Examples of such questions may include: “Is the coverage count site located on the same facility as a continuous counter in a known TPG?”, “Is there a major destination nearby?”, or “Is the coverage count site located on a route that serves recreational/commuter/utilitarian trips?”.
- Miranda-Moreno, et al. (2013) made use of cluster analyses based on the weekend-to-weekday index (WWI) and morning-to-midday index (AMI) to assign

short-duration counts to traffic pattern groups. The WWI and AMI are described mathematically below.

$$WWI = \frac{V_{we}}{V_{wd}}$$

Where:	V_{we}	Mean daily weekend pedestrian traffic
	V_{wd}	Mean daily weekday pedestrian traffic

$$AMI = \frac{V_{am}}{V_{mid}}$$

Where:	V_{am}	Mean morning (7:00 a.m. to 9:00 a.m.) pedestrian traffic
	V_{wd}	Mean midday (11:00 a.m. to 1:00 p.m.) pedestrian traffic

Based on the values resulting from these indices (Miranda-Moreno, Nosal, Schneider, & Proulx, 2013), sites were assigned to utilitarian, mixed utilitarian, mixed recreational, or recreational TPGs. Assignment based on the AMI-WWI coordinates is summarized graphically in Figure 2.

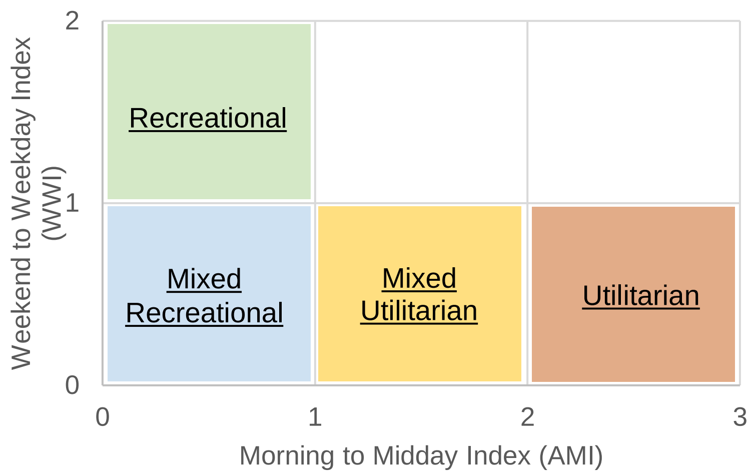


Figure 2: AMI-WWI TPG Classification

2.1.5. Determining the Location, Frequency, and Duration of Coverage Counts

Determining location, frequency and duration are the three fundamental components to developing a coverage count program. The purpose of a coverage count program is to collect spatially diverse pedestrian traffic data across a transportation network.

- Hankey, Lindsey and Marshall (2014, p. 6), tested the accuracy of coverage counts with different adjustment methods and implementation parameters. They concluded that adjustment error decreases with short-duration count length, with only minimal gains in accuracy for counts longer than one week. They also determined that the impact of sampling consecutive days vs. non-consecutive days on AADT estimation was minimal but consecutive days does reduce labour requirements.
- TAC (2017, p. 218) recommends that jurisdictions begin pedestrian traffic monitoring programs within a targeted area (e.g., downtown or commercial zones) then sample all segments within that area on a rotating schedule based on equipment availability. For example, if a downtown area had 100 sidewalk segments and enough resources to conduct 20 coverage counts each year, each segment should be sampled once every five years. This is the minimum frequency in coverage counts recommended by the guide. The guide also recommends at least seven days of continuous data for coverage counts. However, the Guide recommends that this duration should be extended if an abnormal number of non-recurring events occur during the initial seven-day period.
- Jackson, Stolz, and Cunningham (2014) recommend coverage counts for non-motorized traffic to be seven days in length but indicate that the minimum duration should be 24 consecutive hours.

- Figliozzi, et al. (2014) suggest that pedestrian count locations should represent high crash areas, future smart growth zones, locations near transit stops, and recently completed active transportation facilities.

2.2. PEDESTRIAN TRAFFIC VARIABILITY

Pedestrian traffic is characterized by the effects of recurring and non-recurring variation. Understanding the influence of each of these effects at specific locations within a network is essential to produce traffic statistics for informed engineering decisions.

2.2.1. Recurring Variability

Recurring variability is the variation in pedestrian traffic that is attributed to schedule-based factors. The consistency and predictability of these factors are what TPGs and adjustment factors are typically founded on. Recurring variability is normally assessed in terms of hour-of-day, day-of-week, month-of-year, or season.

2.2.1.1. Hour-of-Day

- Poapst (2015, p. 61) found that pedestrian traffic is highly volatile between 00:00 and 06:00 due to low volumes. For this reason, analysis and automated data flagging methods were not used as part of their analysis between these times.
- Miranda-Moreno, et al. (2013) characterized short-duration bicycle count sites by comparing selective hours of day in their analysis. If midday traffic represents a greater proportion of total daily traffic, it was described as exhibiting recreational characteristics. If the morning period represented a greater proportion of daily traffic than midday, it was described as exhibiting utilitarian/commuter characteristics.

2.2.1.2. Day-of-Week

- Poapst (2015, p. 95) conducted short duration counts in commercial zones in Winnipeg to characterize pedestrian traffic. The study indicates that to produce the greatest consistency in data possible, the analysis of "weekday" traffic volumes should be limited to Tuesdays, Wednesdays, and Thursdays. This is because Mondays and Fridays, on average, do not behave as other weekdays or weekends due to periodically occurring holidays throughout the year.

- Miranda-Moreno, et al. (2013) characterized short-duration bicycle count sites by comparing weekdays to weekends in their analysis. If average weekend traffic was higher than average weekday traffic, it was said it display recreational characteristics. If average weekday traffic was greater than average weekend traffic, it was said to display utilitarian/commuter characteristics.

2.2.1.3. Month-of-Year and Seasonal Variability

- Klassen (2016, p. 86) conducted continuous pedestrian counts on multi-use paths in Winnipeg which experiences warm summers and cold winters. The study found a high degree of seasonal peaking in pedestrian volumes. The study recommended that estimates of annual average daily pedestrian traffic should be based on counts conducted in the summer months (May – September). This is because summer months are less prone to the volatility of relatively low pedestrian traffic.

- The FHWA Traffic Monitoring Guide (2016, pp. 4-27) states that the seasonal average daily traffic (SADT) is a measure used for non-motorized count sites which experience a large degree of seasonal peaking. It defines SADT as the average daily traffic which occurs over the months which contain 80% of annual traffic.

2.2.2. Non-Recurring Variability

Pedestrian activity is highly susceptible to the effects of non-recurring variation as compared to motorized modes of traffic. Non-recurring traffic is the result of atypical traffic conditions which may be the result of severe weather, special events, construction or traffic incidents.

2.2.2.1. Environmental Effects

- Aultman-Hall, Lane, and Lambert (2009) collected continuous pedestrian volumes over a full year period at a single location and analyzed the effect of varying weather and seasonal conditions. They concluded that these factors have a significant effect on downtown pedestrian traffic where precipitation reduced average hourly volumes by 13%. It was also observed that winter months experienced 16% less average hourly traffic. They conclude that week-of-year and hour-of-day adjustment factors may be used to develop adjustment factors, but that they are highly site specific.

- El Esawey, et al. (2013, p. 81) found a strong correlation between non-motorized traffic and precipitation. For this study, precipitation of 5 millimeters or more was considered to be “wet weather” and all other days “dry weather”. This value was selected arbitrarily based on local knowledge and engineering judgement.

- In conducting 2-hour counts at 50 intersections across a 13-week study period, Schneider, Arnold, and Ragland (2009, p. 4) observed lower pedestrian volumes on days with abnormally cool or hot temperatures.

- Hankey, Lindsey, and Marshall (2014, p. 8), conducted continuous pedestrian data collection for one year. They concluded that the error in estimating AADT was greater when short duration counts were conducted during times of year when weather was most variable (early spring and late fall).

- The FHWA Traffic Monitoring Guide (2016, pp. 4-35) recommends that weather conditions should be recorded in a non-motorized traffic monitoring program as they have shown to be a significant factor in the level and variability of traffic volumes. Specifically, a record of precipitation (yes/no), daily high temperature, and daily low temperature are recommended to help explain atypical traffic variation from automatically collected pedestrian data.
- Klassen (2016, p. 89) found that pedestrian activity is significantly influenced by rainfall, average wind speed, and temperature, while only a slight correlation was found for the amount of snowfall. Of the environmental factors considered, temperature was found to account for the most variability in pedestrian volumes.
- Glasgow (2016, p. 54) found that evening pedestrian traffic specifically is strongly correlated with warmer weather conditions.

2.2.2.2. Special Events

- For the National Bicycle Documentation Project, Alta Planning & Design (2010) recommended that short-duration counts occasionally target special events to document abnormally high, but expected, pedestrian and cyclist volumes.
- Hankey, Lindsey, and Marshall (2014, p. 5) suggest that the best way to adjust pedestrian coverage counts, which are highly susceptible to special events, is by using a day-of-year scaling factor. Rather than a two-step procedure which uses weekly and monthly factors, 365 unique ratios are developed to capture non-recurring variation for sites of the same TPG.

- Nordback, Marshall, and Janson (2013, p. 127) state that since special events can produce atypical traffic volumes, these time periods should be excluded from the calculation of annual average daily pedestrian/bicyclist traffic.
- TAC (2017, p. 207) states that the influence of special events on pedestrian traffic depends on the size of the event and the proximity of the count site to the venue. The magnitude of influence also depends on the background traffic during other hours of day relative to the size of the event.
- Olfert (2015) characterized pedestrian activity in the downtown area based on the degree to which short-duration counts sites were influenced by events hosted at the downtown arena. The change in average hourly pedestrian traffic in the evening period on event days compared to non-event days was significant and was moderately correlated with proximity to the arena.

2.2.2.3. Local Effects

Due to the relatively short length of trips taken by foot as compared to motorized vehicles or bicycles, the measurement of pedestrian traffic is highly influenced by the local context of a count site. Before initiating a pedestrian traffic monitoring program, these local effects should be identified to contextualize the observed activity.

- In San Fransisco, Schneider, et al. (2012, p. 2) found that pedestrian traffic is significantly affected by varying land use types. They identified a need for models to better quantify pedestrian activity around “attractors” such as large parks, waterfronts, and sporting arenas.

- Wang et al. (2014) found that the built environment has a significant impact on pedestrian traffic. Specifically, pedestrian activity is affected by location, population density, infrastructure, and land-use.
- Glasgow (2016, p. 91) found that pedestrian activity varies significantly from block to block in commercial zones. The study correlates this with the presence of destinations along street segments such as restaurants. It also recommends that the traffic homogeneity assumption for pedestrians is invalid for segments greater than three city blocks.
- Poapst (2015, p. 95) concluded from a study of pedestrian traffic in commercial zones in Winnipeg that the sidewalk traffic on one side of the street may not be assumed to be the same as the opposite side of the street.

2.3. TRAFFIC DATA COLLECTION AND PROCESSING METHODS

A fundamental aspect of a pedestrian traffic monitoring program is its ability to collect the desired traffic data and produce useful metrics for planning decisions. Traffic data collection and processing methods are processes which improve or are used by a traffic monitoring program. This section summarizes literature findings regarding pedestrian data quality assurance, continuous data summarization methods, adjusting short-duration counts, applying traffic ratios, and estimating adjustment error.

2.3.1. Quality Assurance for Pedestrian Data

Assuring data quality is critical for a pedestrian traffic monitoring program. Typically, quality assurance is performed in three phases including equipment installation, data cleaning, and data correction.

2.3.1.1. Equipment Installation Methods

Proper equipment installation ensures that the automated pedestrian counter (APC) being used is able to accurately measure the traffic along the segment or screen-line it is recording. This is typically the simplest factor to control and has the largest effect on data quality.

- The FHWA Traffic Monitoring Guide (2016, pp. 4-13) states that passive infrared sensors perform best when pointed toward a wall, building face, dense vegetation, or any other non-reflective background. It should be ensured that the travel area is constrained and the detection area is well defined so that pedestrians can not bypass the sensor's field of vision.
- The Eco-Counter PYRO-Box installation Guide (Eco-Counter, 2016) provides technical installation specifications to ensure accurate pedestrian detection. It states that the sensor should not be pointed towards a path where motor vehicles may pass, a surface directly exposed to sunlight, objects that are likely to move, reflective surfaces, or doors. Additionally the sensor should not be installed behind a window, at a location where pedestrians are likely to linger, or near devices that generate rapid fluctuations in temperature. The specification recommends installing at sites reserved for pedestrians where movement is fluid, where the sensor can be installed on the border of a path, and where there is sufficient cellular network coverage.

2.3.1.2. Data Screening Methods

It is often the case that while sensing equipment accurately captures what takes place within its field of vision, its measure does not depict the true pedestrian activity. Data cleaning methods are used to ensure that the pedestrian traffic recorded by the monitoring equipment is representative of the traffic which occurred during the count period.

- Ryus, et al. (2014, p. 53) identify potential reasons for why APCs may report incorrect counts even if they are properly installed. Examples may include sensor blockages or multiple counts of the same person (loitering).
- Turner, Qu, and Lasley (2012, p. 13) identified several automated quality control methods to flag abnormal pedestrian traffic volumes reported by APCs. These include rules based on directional split, maximum hourly percent deviation from average weekday/weekend values, ratio of peak hour to total daily volume, number of consecutive zeros, number of consecutive identical values, and percent difference in consecutive hourly volumes. The interquartile range was used to set thresholds to flag hourly volumes based on the above rules.
- Beitel and Miranda-Moreno (2016, p. 4) used multiple continuous count sites as reference to propose a method for automatically identifying atypical traffic volumes for sites within the same TPG. For each continuous count site, 365 day of year factors were calculated. Then, for each day of the year, a vector was produced with each possible day-of-year factor quotient for the continuous count sites. If any of the elements from any of the day-of-year quotient vectors exceeded a defined threshold, that day's data for the atypical count site was flagged.
- TAC (2017, p. 241) states that data should only be rejected if the analyst can prove or knows for certain that the data irregularity is not the result of atypical conditions, but of sensor malfunction or misrepresentative measurement.

2.3.1.3. Data Correction Methods

Data correction methods are used to account for systematic errors inherent to specific automated pedestrian counting equipment. These methods typically involve producing and applying correction factors based on mathematical curves to adjust clean pedestrian data.

- Yang, Ozbay, and Bartin (2010, p. 9) found that over four days of pedestrian traffic data collection using a passive infrared automated pedestrian counter, there is a significant difference between ground-truth counts and counts reported by the APC due to occlusion. In some cases this was as great as 20%. This study developed a non-parametric correction factor as a function of reported pedestrian volumes to estimate the true pedestrian volume. This study used a single correction factor for multiple sites.
- In developing APC correction factors Ryus, et al. (2014, p. 65) recommend a minimum of 30 time periods worth of ground truth data with a minimum time period of 15 minutes. These time periods should include a range of volumes including when peak volumes occur. Once the ground truth data have been collected, they can be plotted against the automated counter's counts to develop a correction curve.
- Nytepchuck (2015, p. 72) found that the Eco-Counter PYRO-Box was not significantly affected by varying weather conditions. The study did however recommend unique correction factors be developed for each count site. This is because occlusion is the most common reason for sensor undercounting which is a function of site specific characteristics.

2.3.2. Continuous Data Summarization Methods

Continuous data collection is the foundation for traffic monitoring programs and enables the development of temporal traffic statistics. TAC (2017, p. 244) outlines several statistics to summarize pedestrian data.

Table 1 lists each traffic statistic and how many unique possible values are produced in a given year.

Table 1: Pedestrian Average Traffic Statistics from Continuous Counts

Statistic	**Description**	**Count/Year**
MAHWPT	**M**onthly **A**verage **H**our-of-**W**eek **P**edestrian **T**raffic	2016
MAHDPT	**M**onthly **A**verage **H**ourly week**D**ay **P**edestrian **T**raffic	288
MAHEPT	**M**onthly **A**verage Hourly week**E**nd **P**edestrian **T**raffic	288
MAHPT	**M**onthly **A**verage **H**ourly **P**edestrian **T**raffic	288
MADWPT	**M**onthly **A**verage **D**ay-of-**W**eek **P**edestrian **T**raffic	84
MAWDPT	**M**onthly **A**verage **W**eek**D**ay **P**edestrian **T**raffic	12
MAWEPT	**M**onthly **A**verage **W**eek**E**nd **P**edestrian **T**raffic	12
MADPT	**M**onthly **A**verage **P**edestrian **T**raffic	12
SADPT	**S**easonal **A**verage **D**aily **P**edestrian **T**raffic	1
AAHWPT	**A**nnual **A**verage **H**our-of-**W**eek **P**edestrian **T**raffic	168
AAHDPT	**A**nnual **A**verage **H**ourly week**D**ay **P**edestrian **T**raffic	24
AAHEPT	**A**nnual **A**verage **H**ourly week**E**nd **P**edestrian **T**raffic	24
AAHPT	**A**nnual **A**verage **H**ourly **P**edestrian **T**raffic	24
AADWPT	**A**nnual **A**verage **D**ay-of-**W**eek **P**edestrian **T**raffic	7
AAWDPT	**A**nnual **A**verage **W**eek**D**ay **P**edestrian **T**raffic	1
AAWEPT	**A**nnual **A**verage **W**eek**E**nd **P**edestrian **T**raffic	1
AADPT	**A**nnual **A**verage **D**aily **P**edestrian **T**raffic	1

The guide also recommends using the hourly AASHTO method for estimating AADPT rather than the traditional AASHTO method. The hourly method enables the use of more good data than the traditional method, as hourly volumes are not rejected from incomplete days. This is particularly beneficial when working with pedestrian data as it is common that single hourly volumes are rejected in the data cleaning process. The Hourly AASHTO Method for estimating AADPT is shown below.

$$AADPT = \frac{1}{7}\sum_{d=1}^{7}\left[\frac{1}{12}\sum_{m=1}^{12}\left(\sum_{h=1}^{24}\left\{\frac{1}{n_{hdm}}\sum_{i=1}^{n_{hdm}} VOL_{ihdm}\right\}\right)\right]$$

Where:

VOL_{ihdm}	the hourly traffic volume for the *ith* occurrence of the *hth* hour-of-day within the *dth* day-of-week of the *mth* month-of-year
i	Index of the *ith* hour-of-day within the *dth* day-of-week of the *mth* month-of-year (i=1,2,…n_{hdm})
h	The *hth* hour of day (h=1,2,…24)
d	The *dth* day-of-week (d=1,2,…7)
m	The *mth* month-of-year (m=1,2,…12)
n_{hdm}	A count of hours with available data for the *hth* hour-of-day within the *dth* day-of-week for the *mth* month-of-year (n_{hdm} ranges from 1 to 5)

2.3.3. Adjustment of Short-Duration Traffic Counts

Continuous counts give an understanding of temporal variation of traffic throughout the year and are used to produce traffic ratios. Once average traffic statistics have been produced, traffic ratios may be used to adjust short term counts to estimate annual average statistics. Traffic ratios are calculated for each continuous count site and averaged within each TPG to be applied to coverage counts (TAC, 2017, p. 249). This thesis identified three adjustment ratios for short duration counts based on daily volumes including the Separated, Combined, and Day-of-Year factor methods. Additionally, the hourly factor method is reviewed to adjust partial day counts.

2.3.3.1. Separated Factor Method

The separated method is a two-step process that separately applies traffic ratios to represent monthly and daily variation. This method requires 19 traffic ratios: 12 month-of-year ratios, and 7 day-of-week ratios. This method does not recognize that day-of-week variation may change throughout the year, but assumes it is constant. Additionally, the separated method does not account for non-recurring variation. This method is the simplest to understand and employ as it requires the least number of unique traffic ratios (TAC, 2017, p. 250). The monthly and daily traffic ratio equations are shown below in] [Eq. 1] and [Eq. 2] respectively.

[Eq. 1]
$$TR_m = \frac{MADPT_m}{AADPT}$$

Where:		
	TR_m	Month-of-year traffic ratio
	$MADPT_m$	The monthly average daily pedestrian traffic
	$AADPT$	The annual average daily pedestrian traffic
	m	The month-of-year (1-12)

[Eq. 2]
$$TR_d = \frac{AADWPT_d}{AADPT}$$

Where:		
	TR_d	Day-of-week traffic ratio
	$AADWPT_d$	The annual average day-of-week pedestrian traffic
	$AADPT$	The annual average daily pedestrian traffic
	d	The day-of-week (1-7)

2.3.3.2. Combined Method

The combined method requires 84 MADWPT values to produce traffic ratios at a continuous count site. This method recognizes that sites may experience a change in day-of-week patterns by month and only requires the application of a single traffic ratio, but does not recognize the effects of non-recurring variation on pedestrian traffic (TAC, 2017, p. 250). The combined method traffic ratio equation is shown below in [Eq. 3].

[Eq. 3] $$TR_{md} = \frac{MADWPT_{md}}{AADPT}$$

Where:

$MADWPT_{md}$	The monthly average day-of-week pedestrian traffic
$AADPT$	The annual average daily pedestrian traffic
m	The month-of-year (1-12)
d	The day-of-week (1-7)
TR_{md}	Weekday-by month-traffic ratio

2.3.3.3. Day-of-Year Method

Day-of-year traffic ratios are calculated for each day of the year rather than aggregated by day-of-week or month-of-year. This method implicitly accounts for non-recurring variation at a short-duration count site under the assumption that the continuous count sites within the same TPG are effected to the same degree. For example if a precipitation event results in low pedestrian traffic volumes throughout a TPG, the non-recurring variation experienced by continuous count sites will be imposed on the coverage counts as it is adjusted by that day-of-year factor. This method recognizes that pedestrian count sites may experience day-to-day variation throughout the year due to non-recurring events (Hankey, Lindsey, & Marshall, 2014, p. 5). The day-of-year traffic ratio equation is shown below in [Eq. 4].

[Eq. 4] $$TR_{DOY,i} = \frac{DailyVol_i}{AADPT}$$

Where: $DailyVol_i$ The total pedestrian volume observed on the *ith* day-of-year

$AADPT$ The annual average daily pedestrian traffic

i The day-of-year (i=1-365,366)

$TR_{DOY,i}$ Day-of-year traffic ratio

In the study performed by Hankey, Lindsey, and Marshall (2014, p. 5), the Separated, Combined, and Day-of-Year factor methods were each evaluated for cyclist traffic in Minneapolis. The study demonstrated that the day-of-year factor method was most accurately able to estimate annual average daily bicycle traffic (AADBT) compared to the other methods.

2.3.3.4. Hourly Method

The hourly method is the only method which allows for partial day counts to be adjusted to annual averages. Many jurisdictions collect pedestrian data as part of an existing turning movement count program for motorized traffic. The hourly method can be used to leverage pedestrian counts which are conducted in this way (Nordback, Marshall, Janson, & Stolz, 2013, p. 8). The hourly method traffic ratio equation is shown in [Eq. 5].

[Eq. 5] $$TR_h = \frac{AAHDPT_h}{\sum_{h=1}^{24} AAHDPT_h}$$

Where: $AAHDPT_h$ The annual average hourly weekday pedestrian traffic

h The hour-of-day (h=1-24)

TR_h Hour-of-day traffic ratio

Nordback, et al. (2013) tested a modified version of the hourly method which includes the three peak, 2-hour periods starting at 8 a.m., 12 p.m., and 5 p.m.. This method performed better than 24-hour counts and worse than a 12-hour count between 7 a.m. and 7 p.m.. This approach also leverages a count practice commonly used by jurisdictions for turning movement counts which collects three hourly time periods beginning at 8:00 am, 12:00 pm, and 5:00 pm.

2.3.4. Application of Traffic Ratios

The Traffic Monitoring Practices Guide for Canadian Provinces and Municipalities outlines a three step process for adjusting short duration counts based on traffic ratios developed from continuous count sites (2017, p. 251). These steps are as follows:

1. Summarize all pedestrian traffic data from the short duration count into daily volumes.
2. Estimate AADPT for each individual daily traffic volume by dividing all daily traffic volumes by their appropriate daily traffic ratio(s).
3. Average the resulting AADPT values from each day of the short duration count to produce an estimate of AADPT.

This process is described below in [Eq. 6].

[Eq. 6] $$AADPT_{SDC} = \frac{1}{n}\sum_{1}^{n}\frac{VOL_i}{TR}$$

Where:	$AADPT_{SDC}$	The annual average daily pedestrian traffic estimated from a coverage count
	VOL_i	The total pedestrian volume observed on the *ith* day-of-year
	TR	Product of the appropriate traffic ratio(s)
	i	The day of the short-duration count (I = 1, ... , n)
	n	The number of full days in short-duration count

2.3.5. Adjustment Error Estimation Methods

Several researchers have performed analyses to estimate the accuracy of differing adjustment methods using continuous count data. Estimating the error produced while developing annual traffic statistics is useful when considering how to implement a short duration count program.

- Nordback, et al. (2013, p. 10) compared the performance of two methods for using partial day counts to estimate annual average daily bicycle traffic (AADBT). In this study, continuous count sites were used to develop an estimate of AADBT. Once an AADBT value was determined for the year, partial day counts were artificially extracted to simulate short-duration counts. These adjusted values were then compared by computing the error as a percent difference and error as absolute percent difference. These equations are shown below in [Eq. 7] and [Eq. 8].

[Eq. 7] $$Error\ as\ percent\ difference = \frac{(AADBT_e - AADBT)}{AADBT}$$

[Eq. 8] $$Error\ as\ percent\ absolute\ difference = \frac{|(AADBT_e - AADBT)|}{AADBT}$$

Where: $AADBT_e$ Adjusted value of AADBT from a short duration count

$AADBT$ Actual estimate of AADBT from a continuous count site

The standard deviation of the average percent difference error between the actual AADBT and that predicted for each method was also used to assess each adjustment method.

- El Esawey (2014, p. 6) evaluated the error in adjustment methods by calculating the mean absolute percent error (MAPE) for the separated method’s daily and monthly factors individually. This allowed the study to quantify the degree to which error is introduced at each step of the adjustment process. The MAPE values for daily and monthly factors are described below in [Eq. 9] and [Eq. 10] respectively.

[Eq. 9] $$MAPE_{df} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{(MADB - MADB_e)}{MADB}\right|$$

[Eq. 10] $$MAPE_{mf} = \frac{1}{M}\sum_{i=1}^{M}\left|\frac{(AADB - AADB_e)}{AADB}\right|$$

Where:

$MAPE_{df}$	Mean absolute percent error introduced by weekday adjustment factors
$MAPE_{mf}$	Mean absolute percent error introduced by monthly adjustment factors
$MADB$	Actual monthly average of daily bicycles
$MADB_e$	Estimated monthly average of daily bicycles
$AADB$	Actual annual average of daily bicycles
$AADB_e$	Estimated annual average of daily bicycles
N	Number of validation days for MADT estimation
M	Number of validation months for AADB estimation

2.4. SUMMARY

This chapter summarizes a literature review on current practices and research for developing pedestrian traffic monitoring programs. The literature review identified several key findings relevant to this thesis. Current practices related to system-wide pedestrian traffic monitoring, pedestrian traffic variability, and data collection and processing methods were each considered for developing the methodology and analysis for this research.

The literature review provided insight into current pedestrian traffic monitoring practices. Miranda-Moreno, et al., (2013) outline an approach for classifying pedestrian count sites based on recurring traffic patterns. Using this approach, activity may be assigned to recreational, mixed-recreational, mixed-utilitarian, or utilitarian pattern groups. The review also provided a summary of common short-duration count practices. Full-day counts are typically conducted between 1 and 14 days with minimal adjustment error improvement observed beyond seven days of data collection (Jackson, Stolz, & Cunningham, 2014).

Pedestrian traffic behaves differently from motorized traffic. While pedestrian traffic is strongly dictated by recurring, scheduled based factors, it is highly susceptible to the effects of non-recurring events. The literature review states that seasonal traffic should be considered separately if there is large variation between summer and winter traffic. Pedestrian activity is also prone to atypical events such as precipitation and special events. Current literature recommends removing these events in an effort to report typical pedestrian traffic.

The literature review identified data processing methods which formed the methodology and analysis for this research. The hourly AASHTO method was identified to estimate annual average pedestrian traffic (AADPT) from incomplete continuous data sets. Also, the Separated, Combined, Day-of-Year, and Hourly factor methods were identified to adjust short duration counts. Finally, the mean absolute percent error was identified as an effective way to compare the performance of adjustment methods to produce an estimate of annual average daily pedestrian traffic.

3. RESEARCH METHODOLOGY

This chapter discusses the methodology developed and used for data collection, automated pedestrian counter calibration, and the analysis of downtown pedestrian traffic characteristics. This chapter presents the following: (1) counting technology selection; (2) site selection for continuous counts; (3) an overview of the data collection system; and (4) methods for data processing and analysis.

3.1. SELECTION OF COUNTING TECHNOLOGY FOR ANALYSIS

Count technology selection was based on previous work performed at the University of Manitoba related to pedestrian and cyclist traffic monitoring. Poapst (2015), Nytepchuck (2015), Klassen (2016), and Glasgow (2016) each conducted thorough literature reviews comparing various counter technologies and confirmed the Eco-Counter PYRO-Box passive infrared detector (Figure 3) to be the most appropriate considering cost, seasonal performance, and usability.

Figure 3: Eco-Counter PYRO-Box Installation

Passive infrared devices for non-motorized traffic operate similarly to passive infrared vehicle detectors except that they are tailored to measure the passage of pedestrians or cyclists over a screen line. NCHRP Report 797 (2014) states that passive infrared devices detect pedestrians and cyclists by comparing the temperatures of the background surface to the infrared radiation patterns emitted by persons passing in front of the sensor (Ryus, et al., 2014). This technology was selected because it is capable of directional observation, is easily installed at midblock locations, performs well in low-light conditions, and does not require a permanent power supply (Poapst, 2015, p. 38).

The Eco-Counter PYRO-Box was selected for a variety of reasons. These include the relative ease of installation compared to other passive infrared devices, data storage capabilities, ease of mobility, wireless connectivity for uploading data, and long battery life. Additionally, research performed by Greene-Roesel, et al. (2008) found higher accuracy while using this counter as compared to other devices and technologies. Table 2 provides a summary of the Eco-Counter PYRO-Box technical specifications.

Table 2: Eco-Counter PYRO-Box Technical Specifications

Counting System General Characteristics	
Installation	PYRO-Box fixed to a flat surface using a metal plate or fixed to an existing post using tightening collars
Data Backup	60-minute or 15-minute data recording interval
Memory	15-minute data recording interval: 11 months 60-minute data recording interval: 21 months
Data Collection	Global system for mobile communication (passive remote)
Sensitivity	1°C difference between body and ambient temperature
Counting System Physical Characteristics	
Waterproofness	IP 66
Temperature Resistance	-40°C to +50°C
Weight	2.6 kg
Material	Shockproof polyurethane
Dimensions	23 x 10 x 18 cm
Range	400 cm

3.2. SITE SELECTION FOR CONTINUOUS PEDESTRIAN DATA COLLECTION

Previous research conducted in Winnipeg determined the location for eight continuous count sites to monitor pedestrian traffic (Olfert, 2015). Sites were selected by evenly distributing available automated pedestrian counters (APCs) between two pedestrian traffic pattern groups (TPGs) defined in the downtown area. These TPGs were based on the degree to which pedestrian traffic is influenced by events hosted at the downtown arena. Four APCs were placed in the “Urban Utilitarian” TPG while the remaining four APCs were placed in the “Urban Utilitarian-Event” TPG. Within each TPG, specific sites were selected based on a stratified random sampling method as recommended by Ryus, et al. (2014, p. 26). As a result, the final TPGs comprise the continuous count locations summarized in Table 3.

Table 3: Downtown Traffic Pattern Groups

TPG 1 – Urban Utilitarian		**TPG 2 – Urban Utilitarian-Event**	
Location	*Counter ID*	*Location*	*Counter ID*
Broadway	APC 55	Carlton St.	APC 49
Kennedy St.	APC 54	Donald St.	APC 52
Portage Ave.	APC50	Garry St.	APC 47
York Ave.	APC 46	St. Mary Ave.	APC 48

These eight APC units monitored pedestrian activity at the specified count sites continuously throughout 2016. Appendix A provides summaries for each continuous count site.

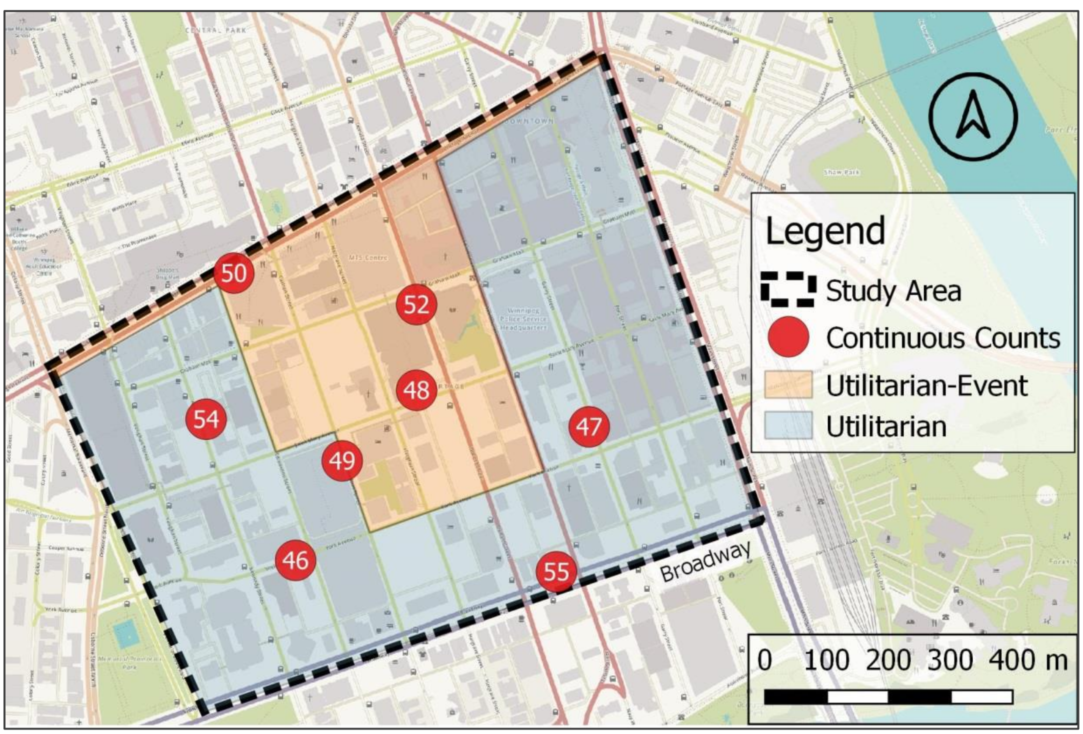


Figure 4: Continuous Count Site Map

3.3. DATA COLLECTION

The data collection system comprises the field equipment setup, field data collection, and weather data collection.

3.3.1. Field Equipment Setup

Automated pedestrian counters (APCs) were installed according to the Eco-Counter PYRO-Box Installation Guide (Integrated Traffic Solutions, 2017).

Automated pedestrian counter units were mounted to a metal post or tree as close to the curb as possible on each sidewalk segment that was specified for a continuous count site. This was done to minimize the likelihood of pedestrians bypassing the counter between the sensor and roadway. Sensors were installed perpendicular to the flow of pedestrian traffic between 70 cm and 100 cm above the ground, as per EcoCounter installation specifications. Specific mounting points were prioritized that were opposite from non-reflective surfaces and far from building entrances or bus stops. Figure 5 shows a typical APC installation.

Figure 5: Typical APC Installation – York Avenue at Garry Street

EcoCounter recommends that each continuous count site be calibrated shortly after installation. Adjustment factor for calibration are discussed in 2.3.1.3 Data Correction Methods.

3.3.2. Field Data Collection

Pedestrian traffic data was collected from two types of counts. The first were automatically collected data at eight sites in downtown Winnipeg. The second were eight short duration manual counts used to develop factors to correct for systematic undercounting by each sensor. The manual counts are discussed further in section 3.4.4.

3.3.3. Non-Recurring Event Data Collection

Non-recurring events have a significant effect on pedestrian traffic and were recorded as part of this research. Environmental effects and events hosted at the downtown arena were observed to influence how pedestrians behave in downtown Winnipeg. Weather data and event information at the arena were collected to contextualize pedestrian activity within the study area. The non-recurring event database produced from this data was used to validate and analyse recorded pedestrian traffic.

Climate data corresponding to conditions at the *Winnipeg International Airport* and *The Forks* meteorological stations were collected from the Environment Canada website (Government of Canada, 2017). Climatic data is reported at the international airport station on an hourly basis while the Forks reports data on a daily basis. The primary database used was daily weather data from *The Forks* as it is closer to the study area. The airport weather database was only used in the quality control process to investigate the influence of weather on atypical pedestrian traffic on an hourly basis. Table 4 summarizes data gathered from the Environment Canada database.

Table 4: Weather Data Collection Summary

Winnipeg International Airport (Hourly Climatic Data)	Winnipeg – The Forks (Daily Climatic Data)
• *Date-Time*	• *Date*
• *Temperature (^{0}C)*	• *Max Temp (^{0}C)*
• *Wind Chill (^{0}C)*	• *Min Temp (^{0}C)*
• *Humidity (^{0}C)*	• *Mean Temp (^{0}C)*
• *Weather (e.g., "Rain showers")*	• *Total Precipitation (mm)*

The event schedule of the downtown arena was appended to the collected climatic information to produce a non-recurring event database. Attribute data collected for each event included the date, event name, type of event, and scheduled start time.

3.4. DATA PROCESSING METHODS

Raw traffic records from automated pedestrian counters (APCs) often contain data that misrepresents true pedestrian activity. Data was processed through proper organization, quality control checks, and correction factors to ensure that anomalies were removed. A more representative dataset for analysis was produced by following a quality control process for each hour of pedestrian data collected at each continuous count site.

The quality control process is as follows. First, a variety of automated flagging methods scanned the dataset to identify atypical count data. If a manual review of these data determined that value was misrepresentative of traffic, it was discarded. Otherwise, it would remain in the dataset. Once the automated and manual review was complete, a correction factor was applied to each hourly pedestrian volume to account for the sensor's systematic error. Each corrected volume was then added to the cleaned and corrected hourly volume table. This process is illustrated in Figure 6.

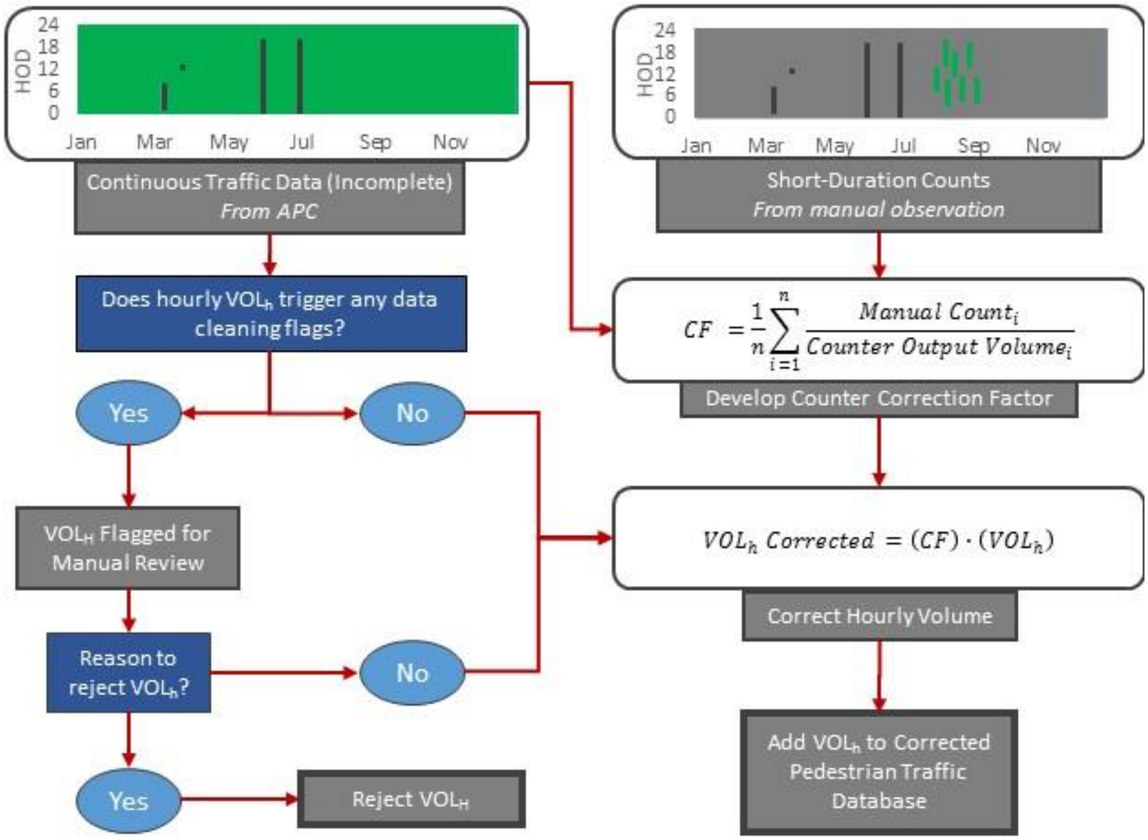


Figure 6: Data Processing Flow Chart

3.4.1. Raw Data Organization

Raw data collected by each APC unit was exported to a comma separated value format from the Eco-Visio web portal on a monthly basis throughout 2016. Pedestrian traffic records were automatically aggregated into 15 minute time bins by direction before being wirelessly uploaded to the Eco-Visio server. Each record in the raw data table represents a single 15 minute bin and is comprised of multiple fields. These include a field for date-time and three fields for each APC unit. The three fields represent a total count for the 15 minute bin as well as two directional fields which sum to the total count. For the eight APCs used in this research for 2016, this format resulted in 25 fields and 35,136 records. Downloaded files were accessed using Microsoft Excel and appeared in a format shown in Table 5. The “IN” and “OUT” columns represent opposite directions of traffic and are dependent on the sensor installation configuration. In this case for example, APC 46IN represents westbound traffic, while APC 46OUT represents eastbound traffic.

Table 5: Raw Count Table

Date Time	APC 46	APC 46IN	APC 46OUT	APC 47	APC 47IN	APC47 OUT	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
Mon 6 Jun 2016 12:00	26	20	6	6	3	3	…
Mon 6 Jun 2016 12:15	16	14	2	4	1	3	…
Mon 6 Jun 2016 12:30	11	2	9	6	4	2	…
Mon 6 Jun 2016 12:45	24	10	14	13	9	3	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	

The raw count table was aggregated into hourly bins, producing an hourly volume table for further analysis. For simplicity, directional segregation of counts was not included in the hourly volume table, only total hourly volumes. The raw count table was kept as reference to inspect atypical values and large differences between directional volumes. To analyze trends in recurring variation, the date, day-of-week, and hour-of-day fields were inserted into the hourly volume table. To analyse trends in non-recurring traffic variation, a weather description, and event field were appended. These fields were populated by sourcing information from *The Forks* meteorological station table and the downtown event arena schedule table. The resulting hourly volume table had 14 fields and 8,784 records with a format shown in Table 6.

Table 6: Hourly Volume Table Example

Date Time	Date	DOW	HOD	Weather	Event	APC 46	APC 47	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
6 Jun 2016 12:00	6/6/2016	1	12	Clear	No	77	29	…
6 Jun 2016 13:00	6/6/2016	1	13	Clear	No	65	25	…
6 Jun 2016 14:00	6/6/2016	1	14	Clear	No	45	20	…
6 Jun 2016 15:00	6/6/2016	1	15	Drizzle	No	40	20	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

3.4.2. Data Quality Methods

Proven data quality methods were used to ensure that data used for analysis was representative of the pedestrian activity recorded by APC devices. Data cleaning and data correction comprise the two components of data quality.

3.4.2.1. Data Cleaning

Data cleaning methods were performed to validate atypical data reported in the hourly volume table. Atypical data was highlighted using automated data flagging techniques then manually inspected. Based on the inspection, a decision would be made to either keep the abnormal value, or remove it from the hourly volume table. Hourly units of time were considered individually for the data cleaning process.

Reasons for atypical data reports by APCs can be classified in one of two ways: sensor errors or misrepresentative counts. Sensor errors are defined as cases where the APC records a count without the passage of a pedestrian through its field of vision or failing to count a passing pedestrian. For example gusts of warm wind from a passing bus or direct sunlight hitting the sensor have been observed to produce false counts (Turner, Qu, & Lasley, 2012). Misrepresentative counts occur when APC devices correctly record what happens within their field of vision but do not accurately portray the true volume of pedestrian traffic. For instance, a single loitering pedestrian near a building access may cross an APC screen line multiple times, resulting in an overestimation of true pedestrian traffic.

Automated data flagging techniques were developed in this research to scan the Hourly Volumes Table and highlight atypical records. This process was used to reduce the amount of manual effort by only requiring manual inspection for extreme values. The goal of the automated flagging process was to highlight the most atypical 5% of all records for manual review. Table 7 summarizes the automated flagging rules used for data cleaning that were applied to each record of the Hourly Volumes Table. These rules are based on procedures developed by Turner, Qu, and Lasley (2012).

Table 7: Automated Quality Control Flags

No.	Flag Name	Description
1	Consecutive Zeros	If three consecutive records at a station are zero, the first occurrence of zero is flagged.
2	Consecutive Count	If three consecutive records at a station are the same, the first occurrence of that value is flagged.
3	Average Hourly	If the record is 70% greater or lesser than its corresponding AAWDPT or AAWEPT, the record is flagged.
4	Preceding Count	If a record is 70% greater than the previous record, that hourly volume is flagged.

The rules listed in Table 7 were applied to all records falling between 06:00 and 24:00 for each day. Hours between 00:00 and 06:00 were excluded as they are typically volatile due to low volumes. Based on procedures by Schneider, et al. (2009), flagged hourly volumes were subjected to a manual review that consisted of:

- Referencing the raw data in 15-minute bins to see if there were any abnormally high volumes or large directional discrepancies. Any extreme value within the hourly bin may indicate a counter malfunction or obstruction.
- Checking if there was any inclement weather during the count period.
- Checking if there were any events at the downtown arena or elsewhere within the study area during the count period.

Atypical data was not automatically rejected due to non-recurring events. Data was only removed from the hourly volume table if the atypical value could be confidently attributed to a counter malfunction or misrepresentative observation Also, despite Nordback, Marshall, and Janson's recommendation (2013), special event days were not considered to be "atypical" due to their frequency and thus were not removed from the dataset. Throughout 2016, 143 large events occurred at the downtown arena.

In total 7,044 of 70,272 hours of collected data were removed, 10.0% of all data collected. Following recommendations from by El Esawy (2014), days with large precipitation events were removed from the dataset. These were considered to be entire days where over 10 mm of precipitation was recorded. This resulted in the removal of 4,140 hours of data, comprising 5.8% of all possible hours of data collection in 2016. The manual review process described earlier removed an additional 2,904 hourly volumes of traffic data corresponding to the remaining 4.2% of all possible hours of that were removed. Traffic data that was rejected through the manual review process or due to precipitation events were not considered in the analysis. The hourly bins in the final dataset for analysis where data was removed was assigned a null value. Section 3.4.3 provides an in-depth summary of data rejection by count site.

The clean and corrected hourly volume database contained 63,228 hourly volumes of a possible 70,272 from eight APCs in 2016. Figure 7 illustrates the distribution of reasons for removing data in the data cleaning process.

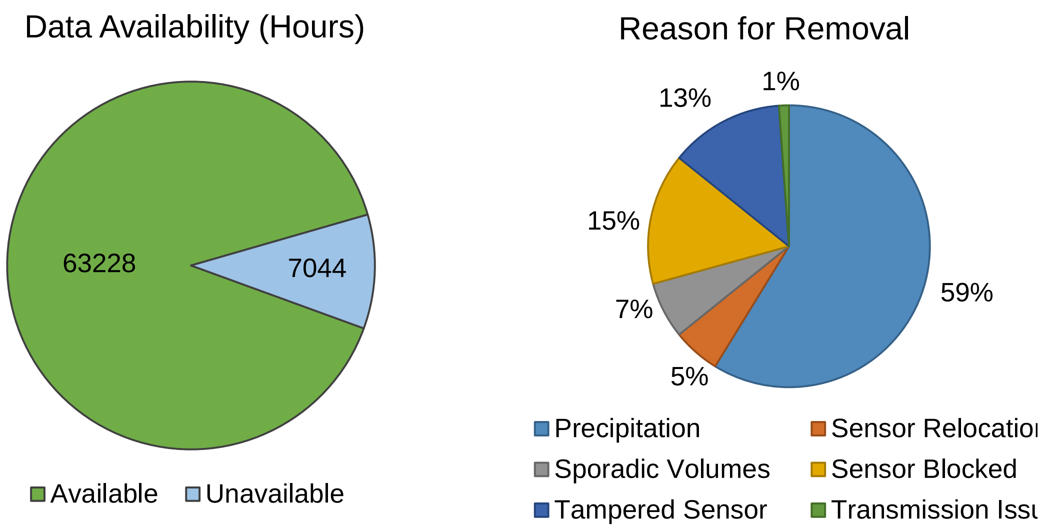


Figure 7: Data Availability and Reason for Removal

3.4.3. Data Availability

This section provides a summary of available data resulting from eight continuous automated pedestrian counts in 2016. The dataset used to analyse pedestrian traffic characteristics and compare adjustment methods was the result of data processing methods applied to the raw dataset. None of the sites produced a full year of pedestrian data. In total, 7,044 of a possible 70,272 hours of traffic data were removed during the quality control process. Reasons for data removal include counter error, misrepresentative counts, and high precipitation events.

Data availability figures were developed for each continuous count site to visualize rejected hours of pedestrian data by day-of-year. First, each day with total precipitation greater than 10 mm was removed from each site. There were 23 days with precipitation greater than 10 mm resulting in a full day of data removed from the analysis at each site.

High precipitation events were responsible for 59% of all hours removed. Figure 8 shows the annual distribution of data removed due to high precipitation events. These hours were removed from each counter's dataset before any analysis was conducted.

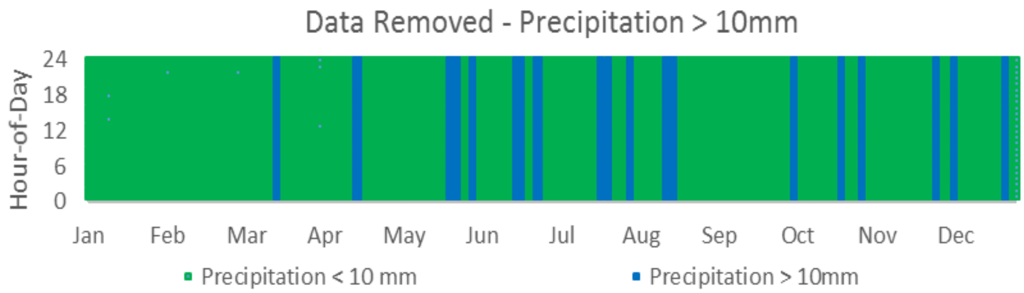


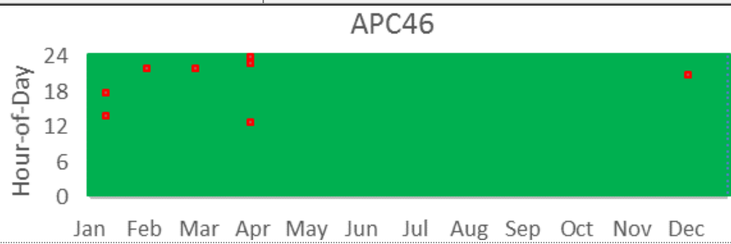
Figure 8: High Precipitation Events - Data Removal

The data availability figures in Table 8 present the data removed at each site due to counter error and misrepresentative counts. Unlike precipitation events, these reasons for data removal are site specific. For each count site, the total possible hours in 2016, the number of hours rejected in data screening, the proportion of that site's data which was rejected, and the proportion of all rejected data were recorded.

Table 8: Data Availability Legend

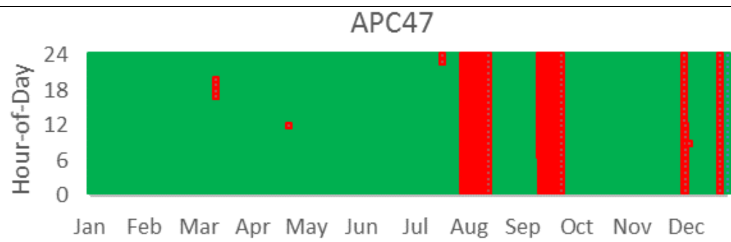
Legend:

Hours Rejected:	The total number of hours rejected from that continuous count site's hourly volume table including precipitation removal (8784 total hours in 2016)
% of APCXX:	The percentage of hourly volumes removed from that APC's hourly volume table.
% of Total Rejected:	The number of rejected hourly volumes at that count site as a proportion of the total rejected values of all sites (7044 total hours rejected between all eight continuous count locations).



- No significant data removal

Total Hours	8,784
Hours Rejected	8
% of APC46:	0.0%
% of total hours rejected	0.0%

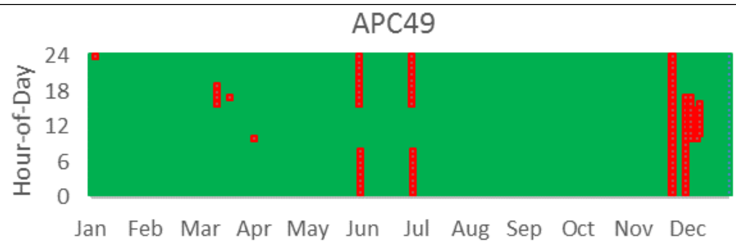


- Sensor temporarily moved in August for other research purposes
- Construction blocked sidewalk from September 14 to September 27
- Sensor blocked by snow on December 6 and 27.

Total Hours	8,784
Hours Rejected	1261
% of APC47:	14.4%
% of total hours rejected	17.9%

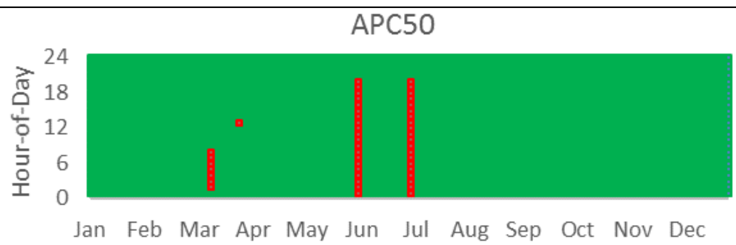
- Sensor malfunction from March 14 to March 18. Produced atypically high and sporadic 15 minute volumes

Total Hours	8,784
Hours Rejected	647
% of APC48:	7.4%
% of total hours rejected	9.2%



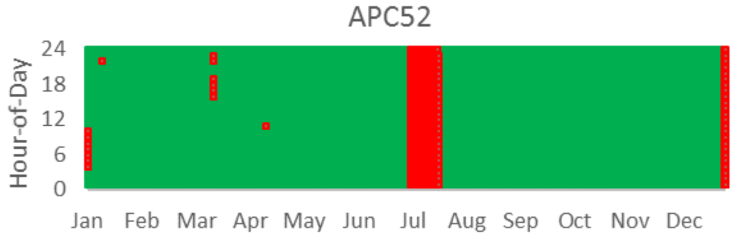
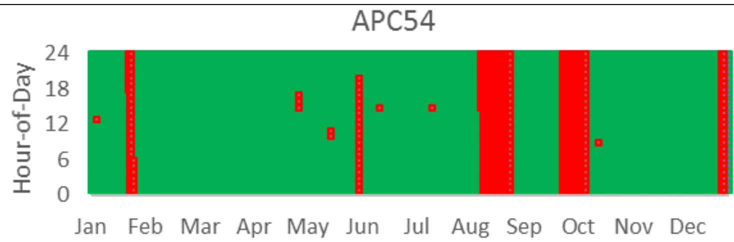
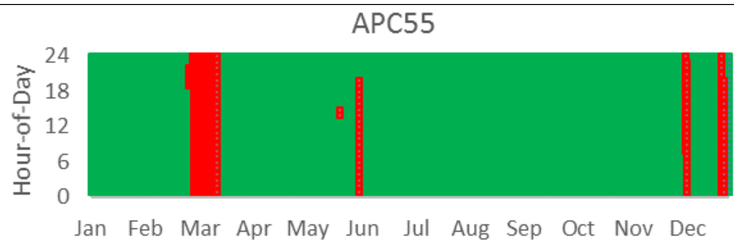
- Sensor transmission issue on June 2 and July 2.
- Sensor blocked from November 28 to November 29
- Sensor blocked December 6,8,9 during midday period

Total Hours	8,784
Hours Rejected	644
% of APC49:	7.3%
% of total hours rejected	9.1%



- Sensor data transmission issue on June 2 and July 2

Total Hours	8,784
Hours Rejected	600
% of APC50:	6.8%
% of total hours rejected	8.5%

	Total Hours	8,784
	Hours Rejected	1000
• Sensor installation compromised. No data collected from July 4 to July 20. • Sensor blocked by snow from December 30 to December 31	% of APC52:	11.4%
	% of total hours rejected	14.2%
	Total Hours	8,784
	Hours Rejected	1347
• Sensor blocked by snow from December 30 to December 31	% of APC54:	15.3%
	% of total hours rejected	19.1%
	Total Hours	8,784
	Hours Rejected	985
• Sensor blocked from February 26 to March 13 • Sensor transmission issue on June 6 • Sensor blocked by snow December 6,7,27,28	% of APC55:	11.2%
	% of total hours rejected	14.0%

3.4.4. Data Correction

Correction factors are used to adjust raw count data to more accurately reflect the ground truth volume of pedestrian traffic (Ryus, et al., 2014, p. 61). Systematic inaccuracies can be caused by occlusion, environmental factors, and imperfect sensor installation.

Correction factors were developed according to a five step procedure outlined in NCHRP Report 767 (2014, p. 61). These steps, as well as actions taken in the research to perform them, are listed below.

1. **Establish accepted reference volume (ARV) count conditions.** NCHRP 797 (2014) recommends a range of count conditions should be used to determine their effect on APC performance. For this research, ARV counts were collected at each of the continuous count sites and represented a range in pedestrian volumes from 50 pedestrians/hour to 400 pedestrians/hour. This was done to capture the low, average, and peak volumes expected across the continuous count sites.

2. **Establish ARV count sample size.** NCHRP Report 797 (2014) recommends 30 count periods at least 15-minutes in duration be analysed to produce correction factors (Ryus, et al., 2014). For this research, 30-minute count periods were used because 15 of the count periods were conducted by the City of Winnipeg using manual video review bins of 30-minutes.

3. **Collect accepted reference volumes.** NCHRP Report 797 (2014) recommends that accepted reference volumes are used to assess the accuracy of APC devices. For this study, ARV counts included eight, 1-hour manual short duration counts (one at each continuous count site), and one, 8-hour count at APC 49. These counts comprise 32, thirty-minute counts.

4. **Plot the ARV and the APC output volume.** A plot of the ARV and APC output volumes can be used to develop a linear relationship factor to correct volumes reported by each APC. Figure 9 illustrates the relationship between ARV and APC output volumes for this study. The slope of the line of best fit from the data points is less than 1.0. This indicates that APC units are prone to systematic undercounting and that a

correction factor should be applied to estimate the actual pedestrian volumes from the raw data.

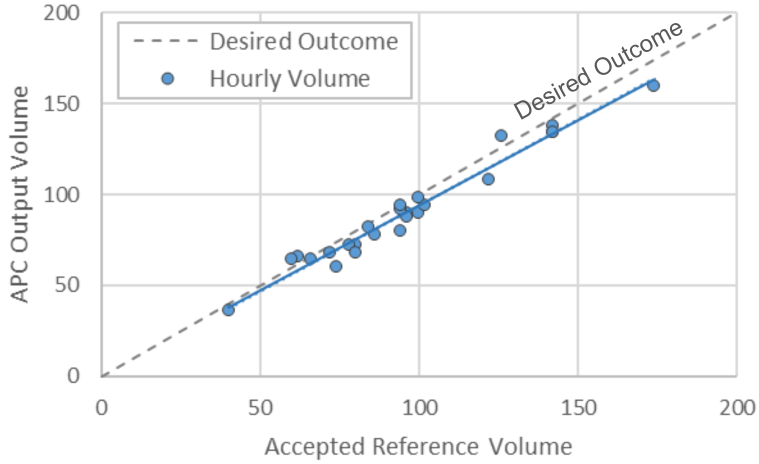


Figure 9: Hourly Volume Plot of Accepted Reference Volume and APC Output

5. **Calculate the correction factor.** The correction factor developed for a linear relationship is the average ratio between the ARVs and corresponding APC output volumes. The equation below describes this relationship and the resulting correction factor derived from this study.

$$Correction\ Factor = \frac{1}{n}\sum_{n=1}^{30}\frac{ARV_n}{Counter\ Output\ Volume_n} = 1.066$$

This value indicates that the eight APCs installed in downtown Winnipeg, on average, undercount pedestrians by 6.6%. Raw count collected by APCs in downtown Winnipeg should be multiplied by 1.066 to minimize the effects of systematic undercounting.

3.5. SUMMARY

The clean and corrected hourly volumes table was produced by following the research methodology. This method was comprised by selecting count technology, selecting sites for automated pedestrian counters (APCs), data collection, and data processing methods.

EcoCounter Passive Infrared PYROBox sensors were used for automated pedestrian traffic data collection. The location of eight continuous count sites for data were selected based on previous research and recommendations made in the literature review (Olfert, 2015). These sites collected pedestrian traffic data continuously throughout 2016. Data processing methods were performed to ensure that the data used for analysis was representative of pedestrian traffic during the study period. This was done through data screening and applying a correction factor based on manual counts as an accepted reference volume. This process resulted in a clean and corrected hourly volume table representing pedestrian traffic volumes at the eight sites throughout 2016. The fields used in the clean and corrected hourly volume database are listed in Table 9.

Table 9: Clean Corrected Hourly Volume Table Fields

Field	Example	Field	Example
Station Number	APC46	Day of Year	158
Date Time	2016-06-06 16:00	Hour of Day	16
Date	06/06/2016	Event	No
Year	2016	Precipitation > 10 mm	No
Month	6	Volume	44
Week of Year	24	Corrected Volume	47
Day of Week	1		

4. CHARACTERIZING PEDESTRIAN ACTIVITY IN DOWNTOWN WINNIPEG

Chapter 4 characterizes pedestrian activity within the study area resulting from a year of data collection at eight continuous count sites. This chapter illustrates average hour-of-day, day-of-week, month-of-year, and seasonal trends for each continuous count site. The adequacy of historically established traffic pattern groups (TPGs) within the study area is also validated. These historical TPGs were developed from short-duration counts conducted in fall 2015 and are compared to the behaviour of the continuous counts conducted throughout the 2016 study period.

4.1. PEDESTRIAN TRAFFIC CHARACTERISTICS

Pedestrian traffic characteristics across the eight continuous counts sites were analyzed based on their recurring variation (hour-of-day, day-of-week, month-of-year, and seasonal). To compare site periodicities, rather than absolute volume, each analysis compared site variability as a percentage of its annual average daily pedestrian traffic (AADPT). This annual metric was used rather than seasonal average daily pedestrian traffic (SADPT) because pedestrian activity was observed to remain relatively consistent throughout the year. This is due to a high degree of consistency in urban commuter activity at each continuous count site.

The recurring, temporal variability of pedestrian traffic was summarized by analyzing hourly, daily, monthly, and seasonal trends. Next, pedestrian traffic pattern groups (TPGs), based on previous short-duration counts, were updated using the continuous count data.

Summarizing the data collected through 2016 confirmed that continuous count sites within the study area do not conform to the “recreational” or “utilitarian” TPGs defined by previous non-motorized traffic research (Miranda-Moreno, Nosal, Schneider, & Proulx, 2013). Rather, downtown Winnipeg is characterized by two TPGs that are distinct in their response to non-recurring events in the downtown area. These are the “Urban Utilitarian” and “Urban Utilitarian – Event” groups.

4.1.1. Annual Pedestrian Traffic Characteristics

Annual average daily pedestrian traffic and SADPT were calculated at each continuous count site for 2016. For this research, May to October months were considered to be seasonal months to calculate SADPT. This seasonal metric is commonly used in non-motorized traffic monitoring to capture the average daily traffic for those who do not walk or cycle during winter months. These types of trips are typically considered to be “discretionary” as opposed to “utilitarian” in nature. Discretionary trips are normally made without a specific commuting purpose but are often recreational and are highly influenced by weather conditions. Seasonal and annual average daily traffic metrics are used to track the change in activity levels from year to year. Figure 10 compares the AADPT and SADPT at each count site for 2016.

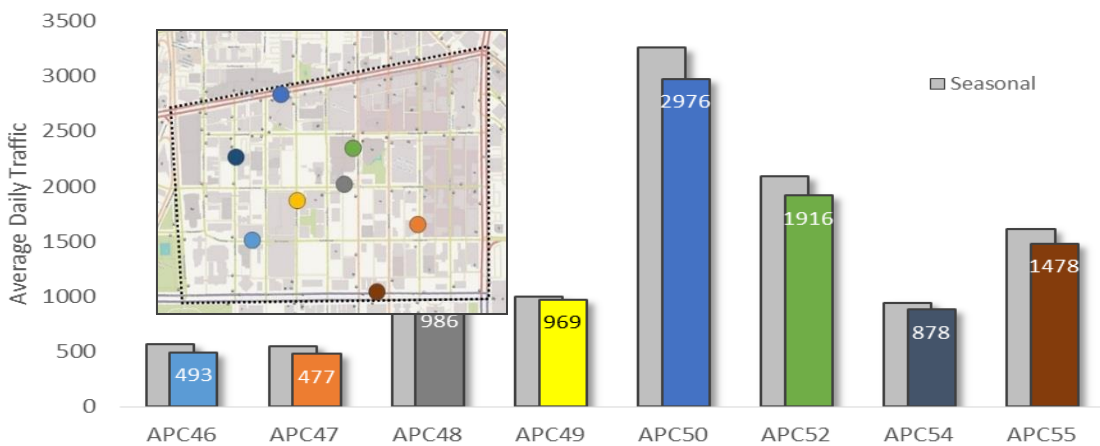


Figure 10: Annual and Seasonal Average Daily Pedestrian Traffic by Continuous Count Site

Figure 10 indicates that the highest traffic levels were observed at APC50 (2,976 pedestrians per day) and the lowest were observed at APC47 (477 pedestrians per day). This figure also illustrates the similarity between SADPT and AADPT. The largest difference between AADPT and SADPT was observed at APC47 with a difference of 15%. The small discrepancy in seasonal and annual traffic across sites justifies the approach to compare recurring traffic variation by their annual measures, rather than seasonal measures. This also suggests that a large proportion of trips made in the study area are utilitarian in nature for commuting purposes as opposed to discretionary or recreational.

APC50, APC52, and APC55 were observed to experience greater pedestrian traffic than the other five sites. These three sites are all on or close Portage Avenue (APC50 and APC52) or Broadway (APC55). In addition to high vehicle traffic volumes on these sites, the sidewalks on both of these streets are highly accommodating to pedestrians, are major public transit routes, and are a popular location for food trucks.

4.1.2. Hourly Pedestrian Traffic Characteristics

The average weekday hour-of-day variation as a percentage of AADPT for each site is shown in Figure 11. Hour-of-day pedestrian activity was observed to be relatively consistent across the eight continuous count sites during 2016. Each site exhibited three peaks in traffic corresponding to morning and afternoon commuter traffic along with a lunch hour peak. Four sites also exhibited a fourth peak occurring between 9:00 p.m. and 12:00 a.m. which range from 4-6% of AADPT. These sites are APC47, APC48, APC49, and APC52. Due to the evening peak at these sites, the morning, lunch, and afternoon peaks in traffic expressed as a percentage of AADPT appear relatively lower than the other four sites.

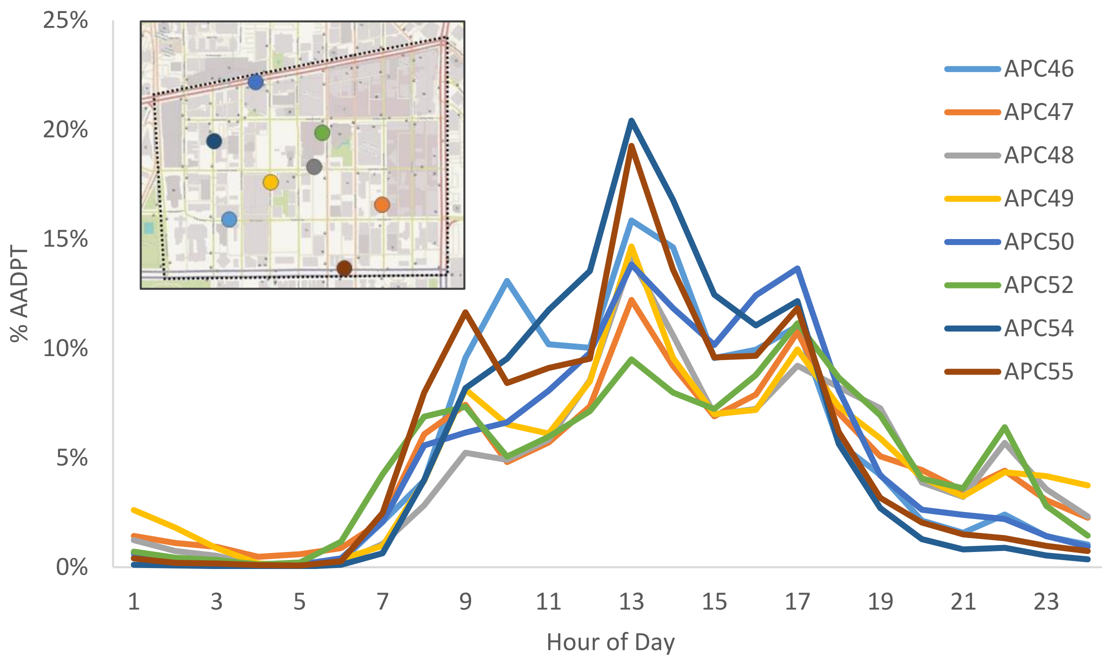


Figure 11: Weekday Hour-of-Day Variation as a Percentage of AADPT

The morning-to-midday index (AMI) was calculated for each site. Table 10 shows the AMI for each site.

Table 10: Morning to Midday Index (AMI)

Site	APC46	APC47	APC48	APC49	APC50	APC52	APC54	APC55
AMI	0.66	0.64	0.39	0.57	0.52	0.78	0.43	0.66

The values listed in Table 10 indicate that each site is characterized by an AMI value less than 1.0. According to research by Miranda-Moreno, et al. (2013), this corresponds to a recreational traffic pattern group as each site's midday traffic is greater than the morning commute traffic. Local knowledge of the study area however indicates that the large noon hour peak is not recreational, but corresponds to a lunch break in a highly work-schedule influenced area.

A summary of hour-of-day traffic for each season was also produced and is shown in Figure 12, Figure 13, Figure 14, and Figure 15 below. March to May were considered Spring months, June to August were considered Summer months, September to November were considered Fall months, and the remaining months were considered as Winter months.

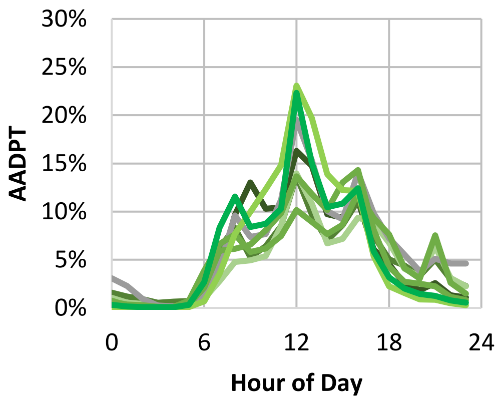


Figure 12: Spring Hour-of-Day Traffic

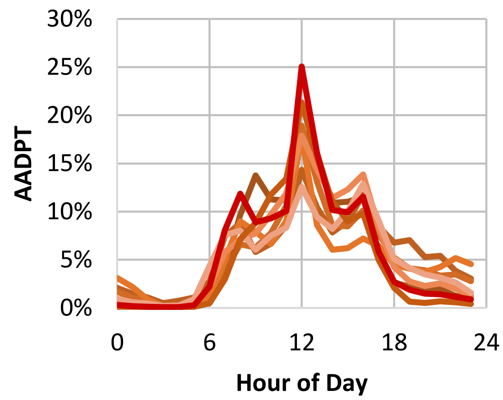


Figure 13: Summer Hour-of-Day Traffic

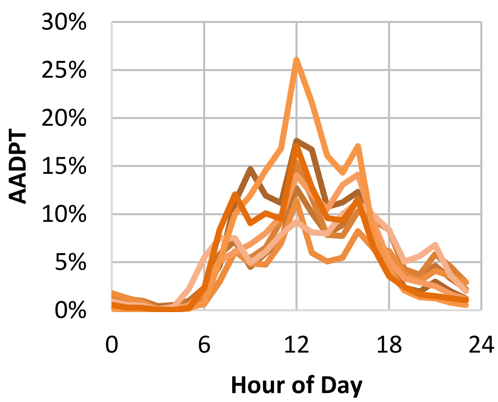


Figure 14: Fall Hour-of-Day Traffic

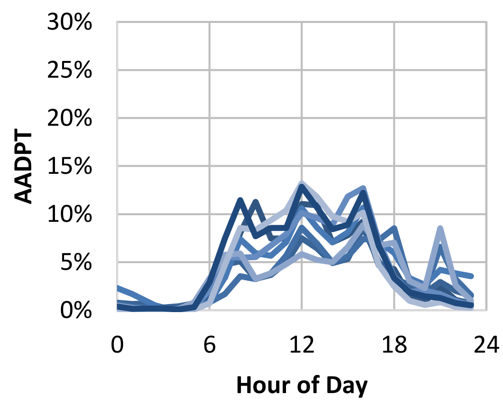


Figure 15: Winter Hour-of-Day Traffic

The hour-of-day by season figures above indicate two things. That traffic remains fairly similar throughout the year by hour of day except for the winter months. Traffic from December to February is not characterized by such a large noon hour peak as the other seasons. Since winter temperatures were observed to be much lower than the other months, the decrease in the noon-hour peak in winter suggests that a greater proportion of noon hour traffic are discretionary trips as opposed to utilitarian trips.

4.1.3. Day-of-Week Pedestrian Traffic Characteristics

The average day-of-week variation as a percentage of AADPT for each site is shown in Figure 16. Day-of-week pedestrian activity was relatively consistent across each continuous count site. Each site was characterized by high weekday traffic relative to weekend traffic. Weekday traffic ranged from 100-140% of AADPT while weekend traffic ranged from 20-75% of AADPT.

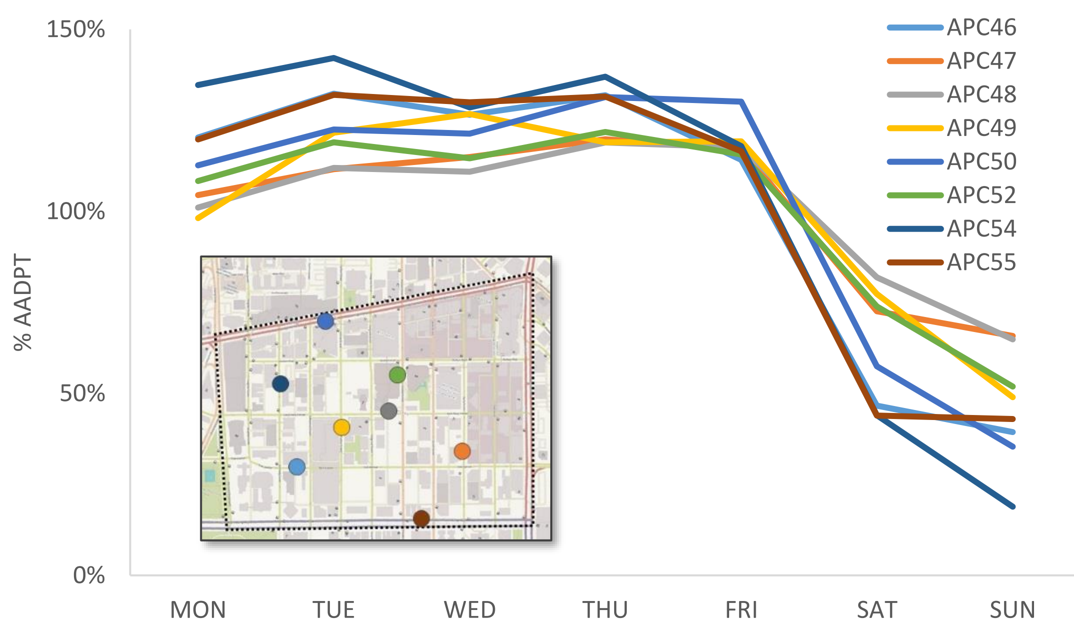


Figure 16: Day-of-Week Variation as a Percentage of AADPT

The weekend-to-weekday index (WWI) was calculated for each site. Table 11 shows the WWI and AMI value for each site. The values listed in Table 11 indicate that each site is characterized by a WWI value less than 1.0. Figure 17 describes each site in terms of their average AMI and WWI values throughout the year.

Table 11: Weekend to Weekday Index

Site	APC46	APC47	APC48	APC49	APC50	APC52	APC54	APC55
AMI	0.66	0.64	0.39	0.57	0.52	0.78	0.43	0.66
WWI	0.32	0.58	0.64	0.52	0.37	0.53	0.23	0.32

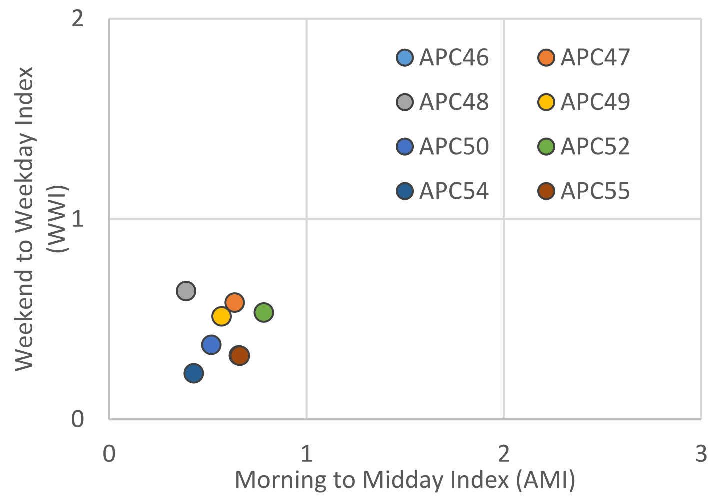


Figure 17: Average Continuous Count Site Characterization

According to Miranda-Moreno, et al. (2013), each of these sites can be categorized as mixed-recreational as their AMI and WWI values are below 1.0. As stated earlier, this site is not as influenced by recreational traffic as the "mixed-recreational" title would imply. Based on local knowledge of the study area, this research describes the recurring traffic patterns within Winnipeg's downtown area as being "Urban Utilitarian".

4.1.4. Month-of-Year Pedestrian Traffic Characteristics

Monthly variation at the eight continuous count sites are not as similar as they were based on their hourly or day-of-week variation. This may be due to downtown construction schedules at specific locations, or certain sites being more prone to the effects of seasons than others. In general, increased pedestrian activity is observed from May to October, while the remaining months experience lower activity levels. Monthly average pedestrian activity levels ranged from 57-140% of AADPT across the eight continuous count sites in

2016. Month-of-year pedestrian traffic variation is shown in Figure 18.

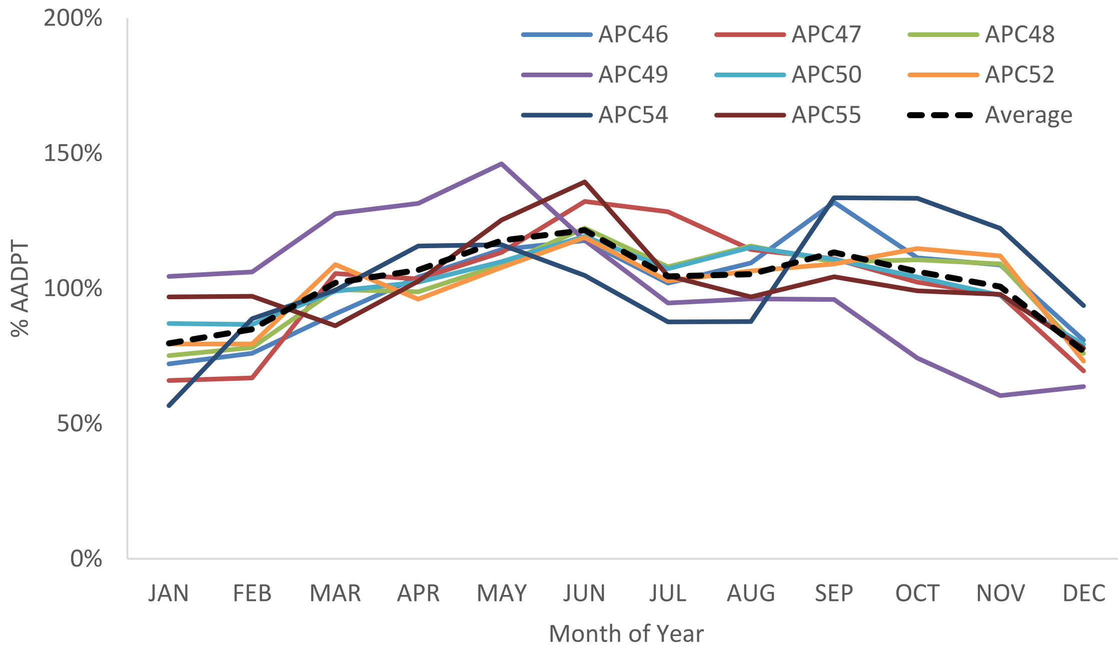


Figure 18: Month-of-Year Variation as a Percentage of AADPT

With respect to other active transportation traffic monitoring research, this consistency of traffic levels throughout the year is not typical for other land use types (e.g.recreational, residential, commercial). Particularly, on average the monthly traffic variation ranges from 80% to 122%. Previous research investigating different land and facility types in Winnipeg observed monthly traffic to range from 30% to 200% of AADPT on recreatonal facilitiesof (Klassen, 2016), and from 50%-160% in commercial zones (Glasgow, 2016). This suggests that downtown areas are characterized by more consistent pedestrian traffic flows and are not as seasonally influenced as other land use types.

This also highlights the prominence of utilitarian trips versus discretionary trips as was obsered in the hour-of-day pedestrian traffic distributions.

To supplement the continuous count data analysis (Figure 17), the AMI and WWI at each site was calculated for each month of the year (Figure 19). This was done to investigate whether the average value of these metrics over simplifies the monthly variation at each count site. Sites were determined to be stable if their monthly estimation of AMI or WWI did not exceed 1.0. These thresholds would indicate a change from mixed-recreational to either recreational (WWI > 1.0) or mixed-utilitarian (AMI > 1.0) (Miranda-Moreno, Nosal, Schneider, & Proulx, 2013).

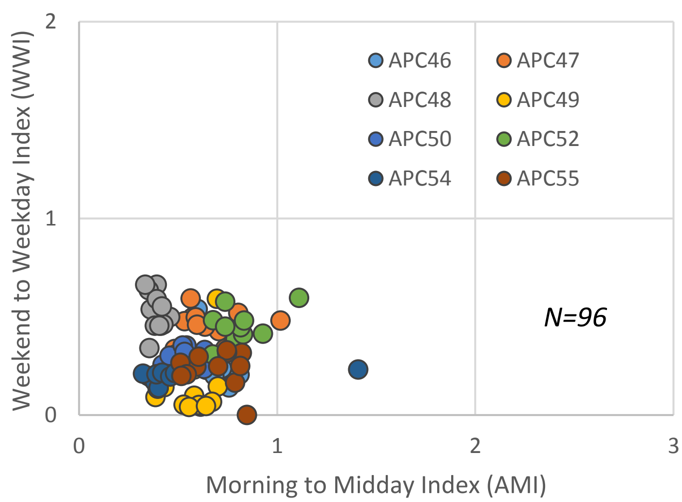


Figure 19: Site Characterization by Month

All but two monthly AMI and WWI values are below one. These correspond with the mixed-recreational traffic pattern type as described by Miranda-Moreno, et al. (2013), which was renamed to the Urban Utilitarian type for this study. The two monthly AMI values greater than 1.0 correspond to APC52 and APC54 calculated for January. Weekdays in January at these two sites were observed to have relatively low noon-hour peaks, which is responsible for a higher AMI value.

4.2. TRAFFIC PATTERN GROUP VALIDATION

Traffic pattern groups are composed of count sites (continuous and coverage) that are observed to behave proportionally similar throughout the year. Since at coverage count sites the annual temporal variation is rarely known, assignment of coverage count sites to traffic pattern groups is typical done using subjective methods such as local knowledge or based on surrounding land uses. The study area used for this research is characterized by high population and employment density. There is also an arena, many smaller event centres, and restaurants which influence pedestrian traffic in the evenings. These land use attributes influence the reason for many pedestrian trips observed in Winnipeg's downtown area.

For vehicular traffic, if the temporal variation of a coverage count site is known throughout the year, statistical methods are typically used to assess the similarity between the coverage count site and the continuous count sites of a traffic pattern group to determine if the assignment is appropriate. For active transportation traffic monitoring, standard statistical methods have not yet been determined for assigning coverage counts to traffic pattern groups. Due to this gap in knowledge, count sites are normally assigned by assessing the hour-of-day and day-of-week variability visually and by using the AMI and WWI indices. This research followed this practice by summarizing the annual and monthly AMI and WWI values at each site and then comparing the hour-of-day and day-of-week variability visually. Beyond this standard practice, the consistency of sites within each TPG was assessed statistically using the analysis of variance (ANOVA) test.

Pedestrian traffic pattern groups were initially developed for downtown Winnipeg using short-duration counts in 2015 (Olfert, 2015). These traffic pattern groups (TPGs) were based on the degree to which short-duration count sites were influenced by events hosted at Winnipeg's downtown arena. This research updated these groups with continuous data from 2016. Figure 20 illustrates the annual average hour-of-day pedestrian traffic on weekdays where events were hosted at the downtown arena for 2016. There were 143 events hosted at the downtown arena throughout the research period.

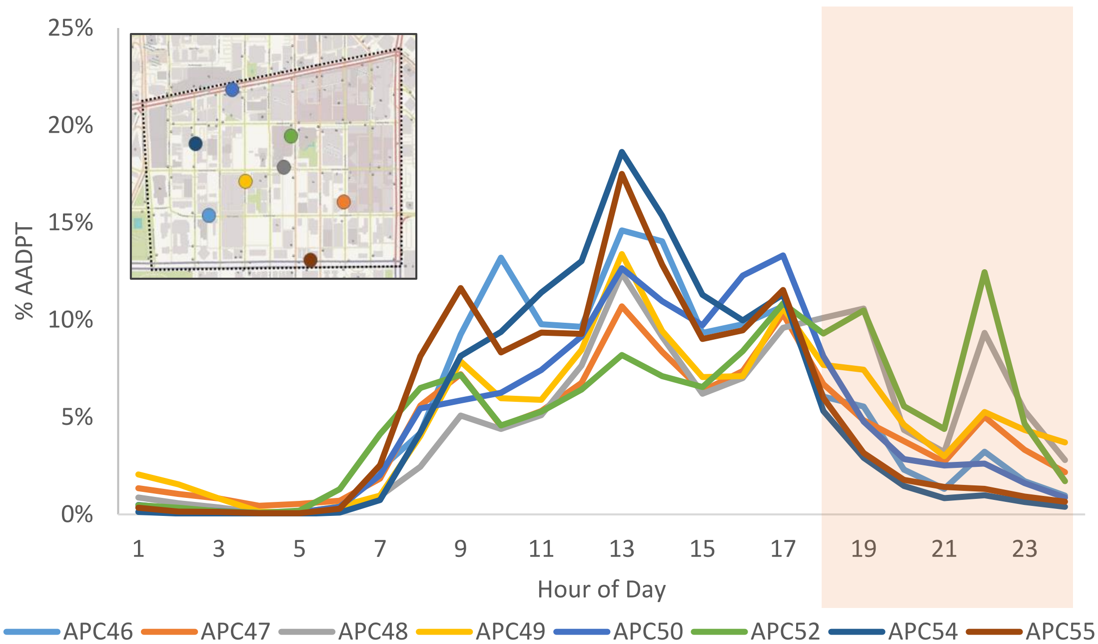


Figure 20: Weekday Annual Average Hour of Day Pedestrian Traffic – *Event Days*

Figure 20 confirms that there is a range in response to events hosted at the downtown arena between 6:00 p.m. and 12:00 a.m.. The initial traffic pattern groups developed by Olfert (2015) are shown in Table 12.

Table 12: Initial Continuous Count Site TPG Assignment

TPG 1 – Urban Utilitarian

Location	*Counter ID*
Broadway	APC 55
Kennedy St.	APC 54
Garry St.	APC 47
York Ave.	APC 46

TPG 2 – Urban Utilitarian-Event

Location	*Counter ID*
Carlton St.	APC 49
Donald St.	APC 52
Portage Ave.	APC 50
St. Mary Ave.	APC 48

Figure 21 and Figure 22 show the weekday annual average hour of day pedestrian traffic for event days in 2016 grouped by the initial traffic pattern groups developed by Olfert

(2015). These initial groups were constructed to categorize count sites which specifically behaved similarly in the hours from 06:00 p.m. to 12:00 a.m. on event days.

Figure 21:
TPG 1 - Urban Utilitarian Initial Event Days

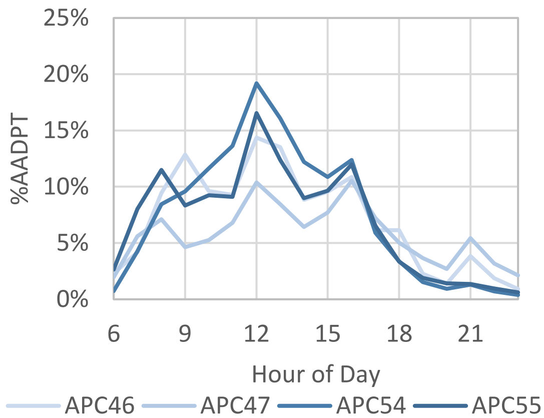
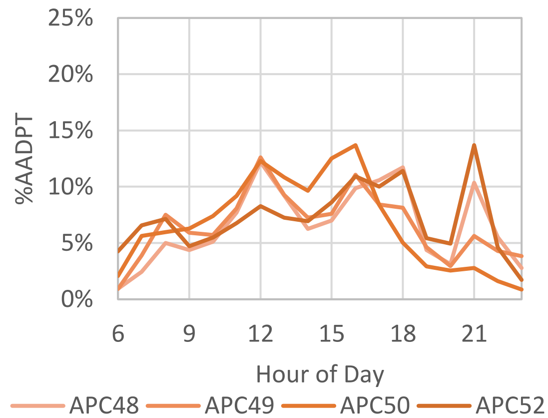


Figure 22:
TPG 2 - Urban Utilitarian Event Initial Event Days



Considering only event days in Figure 21 and Figure 22, a range in evening traffic is observed in both TPGs when referencing a complete year of data in 2016. This inconsistency within the initial traffic pattern groups was reason to reassess which count sites were assigned to each TPG. For example, APC50 was originally assigned to TPG2 while exhibiting a minimal peak in evening traffic. Also, considering event days only, APC47 is assigned to TPG1 and was observed to have an evening peak above 5% of AADPT.

Since the TPGs will be used to adjust short-duration counts throughout 2016, not just event days, the analysis to verify TPG assignment was conducted considering all weekday traffic data from 2016. Since statistical methods for assigning coverage count sites to TPGs for pedestrian traffic have not been determined in previous research, sites were compared visually on an average hour-of-day and average day-of-week and grouped into similarly behaving groups. Once these groups had been determined, the consistency of hour-of-day and day-of-week variability was assessed using the analysis of variance (ANOVA) test for each time period.

Figure 23 and Figure 24 present the hour-of-day, day-of-week, and month-of-year variation in pedestrian traffic for all weekdays in 2016 categorized by the initial TPGs.

Figure 23:
TPG 1 - Urban Utilitarian Initial

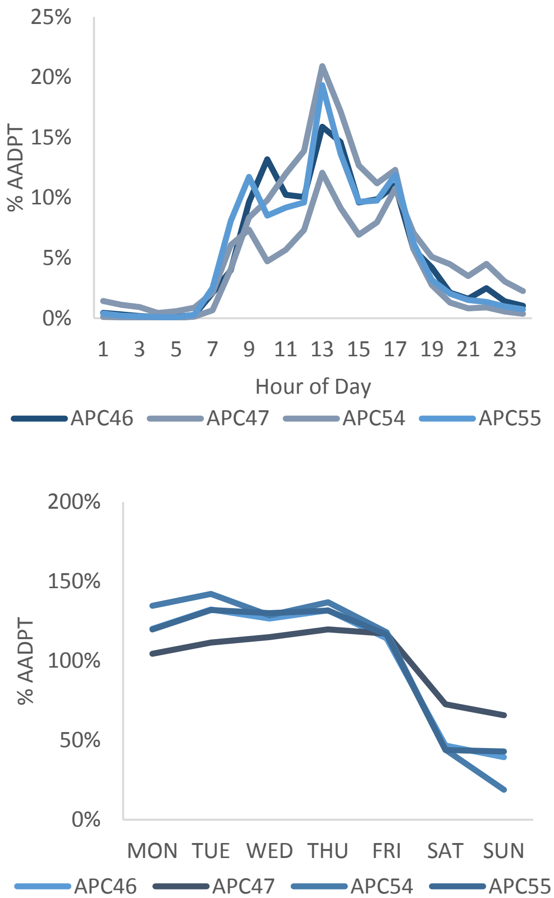
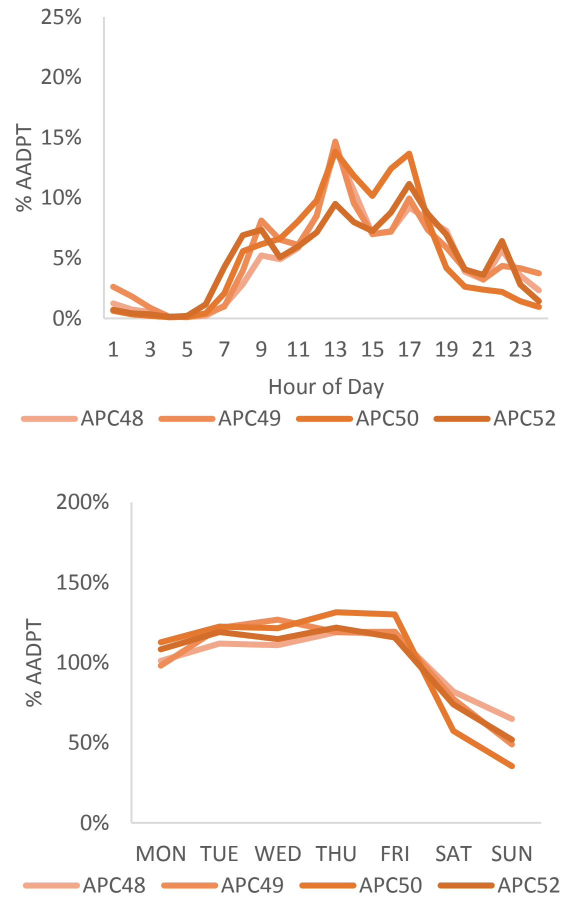
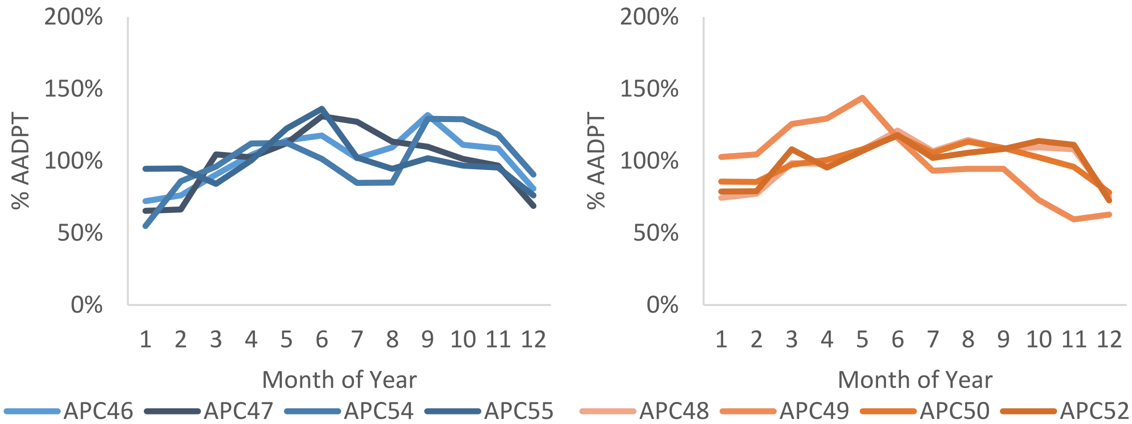


Figure 24:
TPG 2 - Urban Utilitarian Event Initial





These hour-of-day, day-of-week, and month-of-year plots were produced to validate if the initial traffic pattern group assignment made by Olfert (2015) based on short-duration counts. Visual observation of the hour-of-day and day-of-week periodicities led to the following observations in the initial TPGs:

- APC47 appears to exhibit activity like TPG2 rather than TPG1 based on the large evening peak in hour-of-day traffic.
- APC50 behaves more similarly to TPG1 than TPG2 based on low evening volumes. This site however, only exhibits a midday and afternoon peak of approximately equal proportion which is inconsistent with the other count sites in TPG1.
- APC52 exhibits similar peaks to the other sites in TPG2, however the magnitude of peaks differ. APC52 has the largest evening peak, meaning reassigning it to TPG1 would be inappropriate.

Based on these observations, the following TPG assignment configurations were deemed to behave similarly and were analysed statistically.

Table 13: Final Continuous Count Site TPG Assignment

TPG 1 – Urban Utilitarian

Location	*Counter ID*
Broadway	APC 55
Kennedy St.	APC 54
Portage Ave.	***APC50***
York Ave.	APC 46

TPG 2 – Urban Utilitarian Event

Location	*Counter ID*
Carlton St.	APC 49
Portage Ave.	***APC 47***
St. Mary Ave.	APC 48
Donald Ave.	APC52

Figure 27 and Figure 28 present the hour-of-day, day-of-week, and month-of-year variation in pedestrian traffic for all weekdays in 2016 categorized by the final TPG assignment.

Figure 25:
TPG 1 - Urban Utilitarian Final

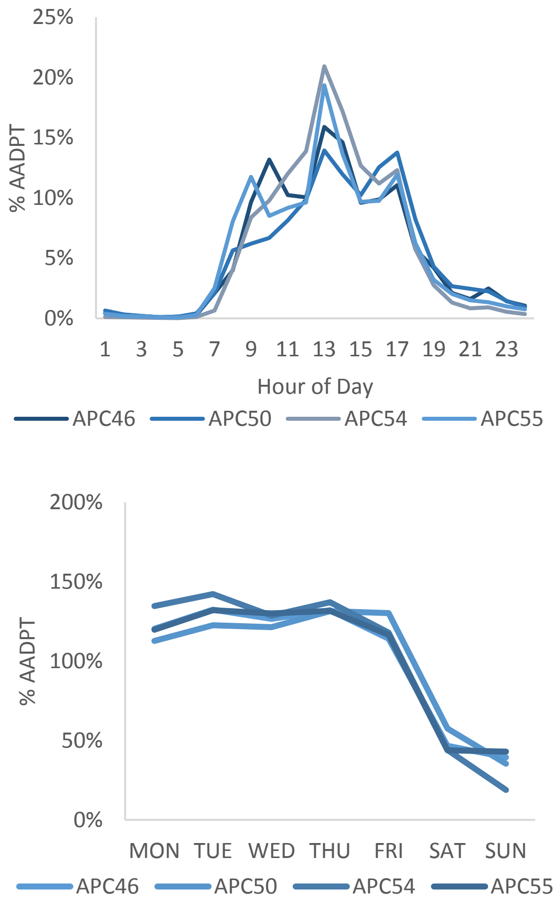
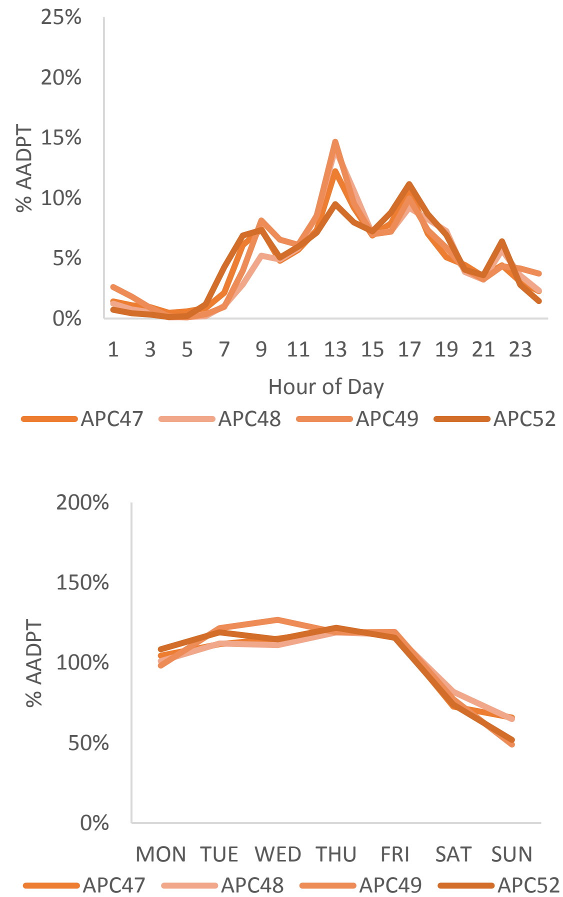
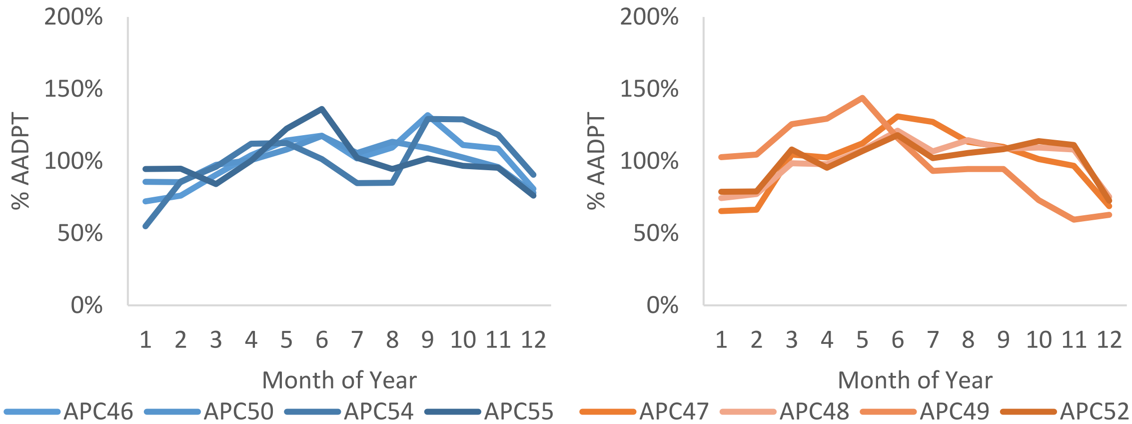


Figure 26:
TPG 2 - Urban Utilitarian-Event Final





To assess the internal consistency of these new groups, an ANOVA and F-Test were conducted for each time interval (hourly, weekly, and monthly variation). The single factor ANOVA is a statistical method used to evaluate the variation within a group of means. The F-Test is used to test whether a group of sample means are different, or if they are the same and the variation between them can be ascribed to sampling variability. For the ANOVA and F-Test, the null hypothesis (H_o) and alternative hypothesis (H_a) for population means (μ_i) and *k* population treatments are:

$$H_o: \mu_1 = \mu_2 = \cdots \mu_k$$

$$H_a: at\ least\ two\ of\ the\ \mu's\ are\ different$$

For each ANOVA and F-Test conducted, a P-value less than 0.1 was used to test whether mean traffic proportions were different. This corresponds to a 90% confidence that the difference in mean traffic proportions between groups are due to sampling variability and not differences in the population the samples are taken from. To evaluate variance between count sites, the p-value was calculated for each group based on the calculated F-value and F-distribution. Determining the F-value requires multiple calculations based on values from each sample set. These calculations are described in Table 14.

Table 14: F-Test Parameters

Statistic	*Calculation*
Treatment sum of squares	$SSTr = n_1(\bar{x}_1 - \bar{x})^2 + n_2(\bar{x}_2 - \bar{x})^2 + \cdots n_k(\bar{x}_k - \bar{x})^2$
Error Sum of Squares	$SSE = (n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \cdots (n_k - 1)s_k^2$
Mean Square for Treatments	$MSTr = \frac{SSTr}{k-1}$
Mean Square for Error	$MSE = \frac{SSE}{N-k}$
F-Value	$F = \frac{MSTr}{MSE}$
Treatment Degrees of Freedom	$df_1 = k - 1$
Error Degrees of Freedom	$df_2 = N - k$
P-Value	F-Distribution evaluated at p(F,df_1,df_2)
Where:	
k	Number of populations or treatments being compared
μ	Population or treatment mean
n	Sample size
$\bar{x}$	Sample mean
s	Sample variance
N	Total number of observations in the dataset

To evaluate the variance of each pedestrian traffic time interval as a proportion of AADPT, the p-value was evaluated on the F-distribution using the F-value, degrees of $freedom_1$, and degrees of $freedom_2$. If the p-value was less than the 0.1, the null hypothesis (H_o) was rejected and at least one sample mean is different from the other sample means of the group. If the p-value is less than 0.1 for a given time interval, it means there is 90% confidence that count sites being compared behave differently. By performing this test on each time interval for a group of traffic distributions, the similarity of count sites may be assessed.

For both TPGs, the ANOVA and F-Test were conducted on each hour-of-day, and day-of-week time interval to assess the variance within groups. The month-of-year ANOVA was not performed since there did not appear to be differentiating characteristics between the two TPGs in terms of monthly variation. The strength of a pattern group is correlated with the number of time intervals where each count site exhibits similar proportions of AAPDT.

4.2.1. Urban Utilitarian Traffic Pattern Group

The urban utilitarian TPG includes sites that are relatively unaffected by evening events occurring at the downtown arena. The pedestrian activity at these sites are primarily dictated by recurring patterns resulting from commuter work schedules and noon-time activity.

On an average hourly basis, this group experiences an increase in traffic from 07:00 a.m. to 09:00 a.m. followed by a large peak at 12:00 p.m.. Pedestrian traffic then decreases after noon, followed by an afternoon commuter peak at 04:00 p.m. Traffic then decreases gradually throughout the evening. Figure 27 and Table 15 describe TPG1 on an hourly basis and present the results of the ANOVA test.

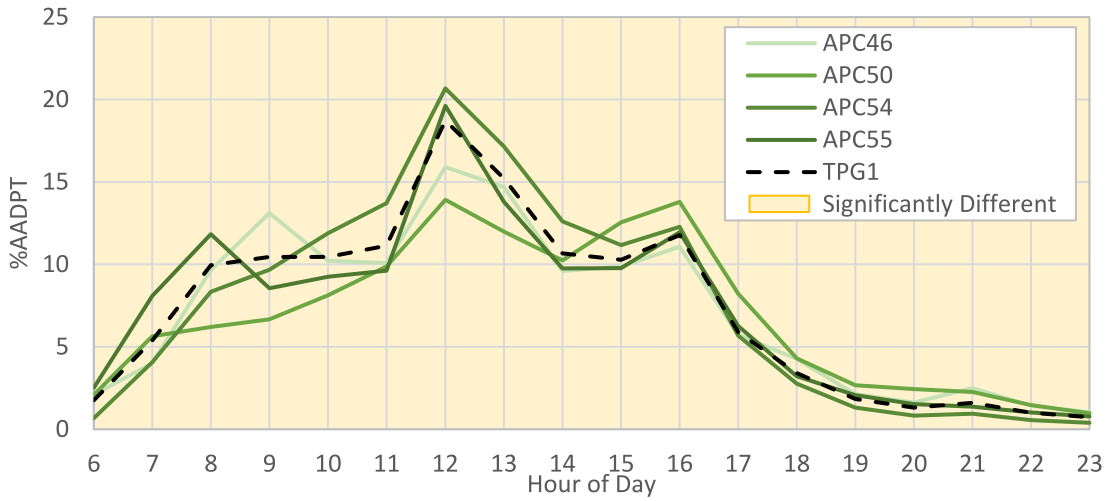


Figure 27: TPG1 Hourly Pedestrian Traffic

Table 15: TPG1 Mean Hourly Proportions of Daily Pedestrian Traffic

	Hour of Day [%AADPT]																	
APC	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
46	2.1	4.0	9.7	13.1	10.2	10.1	15.9	14.7	9.6	9.9	11.1	5.7	4.3	2.1	1.6	2.5	1.4	1.0
50	2.1	5.6	6.2	6.7	8.1	9.9	13.9	12.0	10.2	12.5	13.8	8.2	4.3	2.7	2.4	2.3	1.5	1.0
54	0.7	4.1	8.3	9.7	11.9	13.7	20.7	17.1	12.6	11.2	12.3	5.7	2.8	1.3	0.8	0.9	0.6	0.4
55	2.5	8.1	11.8	8.6	9.2	9.6	19.6	13.8	9.8	9.8	12.0	6.3	3.2	2.1	1.5	1.4	1.0	0.8
TPG Mean	**1.8**	**5.4**	**9.9**	**10.4**	**10.5**	**11.1**	**18.7**	**15.2**	**10.7**	**10.3**	**11.8**	**5.9**	**3.4**	**1.8**	**1.3**	**1.6**	**1.0**	**0.7**
ANOVA Test Results*																		
p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**0.0 value indicates the calculated p-value is <0.05.*

On average, the four continuous count sites in TPG1 exhibit different proportional volumes during every hour of the day assessed at a p-value equal to 0.1.

Day-of-week variance was also analyzed for TPG1. On an average day-of-week basis, this group experiences steady traffic volumes on weekdays at approximately 130% of AADPT. The weekend exhibits much lower pedestrian traffic volumes at approximately 40% of AADPT. A higher degree of variance between days is observed on Sundays, ranging from 19% to 43% of AAPDT. Figure 28 and Table 16 describe TPG1 on a day-of-weekly basis and present the results of the ANOVA test.

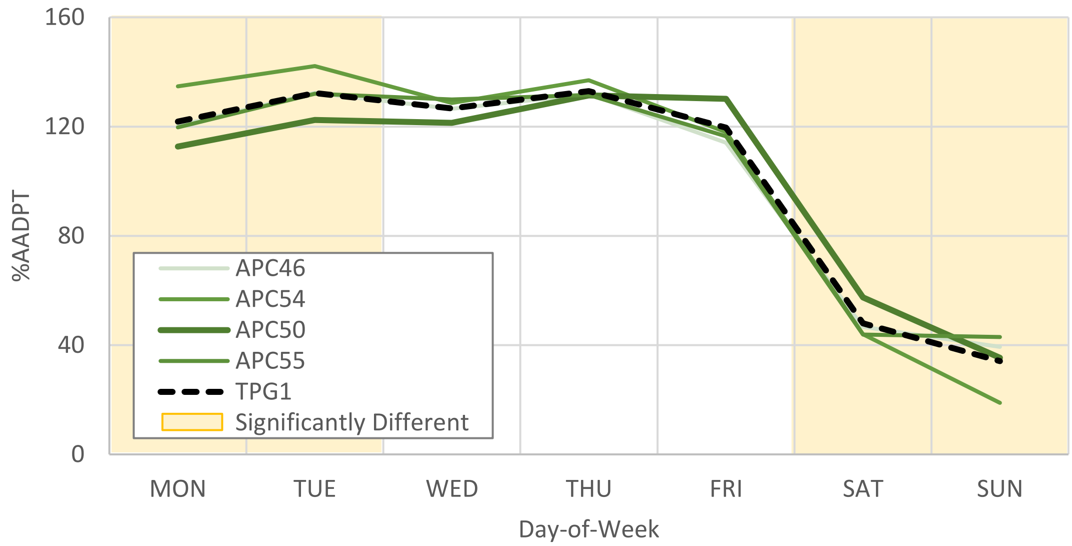


Figure 28: TPG1 Day-of-Week Pedestrian Traffic

Table 16: TPG1 Mean Day-of-Week Proportions of Daily Pedestrian Traffic

	Day-of-Week [%AADPT]						
APC	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*	*Sun*
46	120	132	127	132	114	47	39
50	113	122	121	131	130	57	35
54	135	142	129	137	118	44	19
55	120	132	130	132	116	44	43
TPG Mean	**122**	**132**	**127**	**133**	**120**	**48**	**34**
	ANOVA Test Results						
p	0.0	0.0	0.4	0.6	0.1	0.0	0.0

**0.0 value indicates the calculated p-value is <0.05.*

On average, the four continuous count sites in TPG1 exhibit different proportional volumes on Sundays throughout the year at a significance level of 0.1.

The ANOVA test of temporal trends for sites in TPG1 indicate that the group is more internally consistent by day-of-week than by hour of day comparisons. One of the seven days of week does not produce similar traffic proportions within the group while each of the eighteen hours included in the test resulted in significant differences within the group at a 0.1 significance level. Based on these results, it is expected that the hourly adjustment method will produce less accurate estimates of AADPT than adjustment methods which consider multiple full-day counts for TPG1.

4.2.2. Urban Utilitarian – Event Traffic Pattern Group

The Urban Utilitarian-Event TPG includes sites that are affected by evening events occurring at the downtown arena. The pedestrian activity at these sites are primarily dictated by recurring patterns resulting from commuter work schedules and noon-time activity and experience an additional evening peak on days where events area hosted at the downtown arena.

On an average hourly basis, this group experiences an increase in traffic from 07:00 a.m. to 09:00 a.m. followed by a large peak at 12:00 p.m.. Pedestrian traffic then decreases after 12:00 p.m., followed by an afternoon commuter peak at 04:00 p.m. Traffic then decreases gradually until 09:00 p.m. where an evening event peak is observed. The presence of this fourth peak dilutes size of the other three peaks of the day in terms of proportion of AADPT. Figure 27 and Table 15 describe TPG1 on an hourly basis and present the results of the ANOVA test.

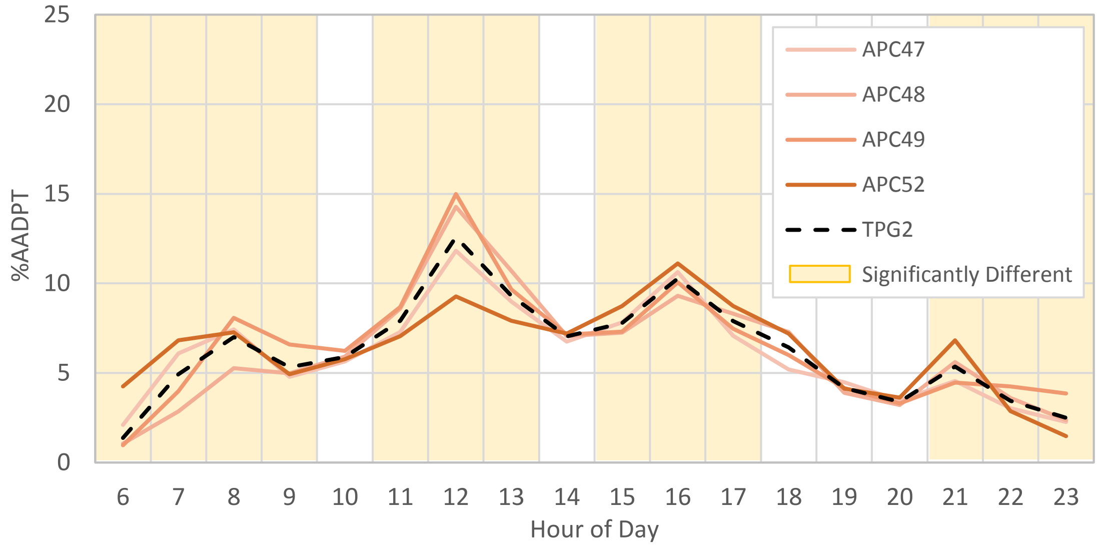


Figure 29: TPG2 Hourly Pedestrian Traffic

Table 17: TPG2 Mean Hourly Proportions of Daily Pedestrian Traffic [%] and ANOVA Results

	Hour of Day																	
APC	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
47	2.1	6.1	7.4	4.8	5.6	7.3	11.8	9.0	6.8	7.8	10.6	7.1	5.2	4.5	3.5	4.6	3.0	2.3
48	1.1	2.8	5.3	5.0	5.9	8.6	14.3	10.7	7.1	7.3	9.3	8.3	7.3	3.9	3.2	5.6	3.6	2.4
49	1.0	4.0	8.1	6.6	6.2	8.7	15.0	9.7	7.1	7.3	10.1	7.5	6.0	4.2	3.3	4.5	4.3	3.9
52	4.2	6.8	7.3	4.9	5.8	7.1	9.3	7.9	7.2	8.7	11.1	8.7	7.2	4.1	3.6	6.8	2.9	1.5
TPG Mean	**1.4**	**4.9**	**7.0**	**5.3**	**5.9**	**7.9**	**12.6**	**9.3**	**7.0**	**7.8**	**10.3**	**7.9**	**6.4**	**4.2**	**3.4**	**5.4**	**3.4**	**2.5**
	ANOVA Test Results																	
p	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.6	0.7	0.0	0.0	0.0

**0.0 value indicates the calculated p-value is <0.05.*

The four continuous count sites in TPG2 exhibit different proportional volumes during fourteen of the eighteen hours of day on average throughout the year at a confidence value of 0.1.

Day-of-week variance was also analyzed for TPG2. On an average day-of-week basis, this group experiences steady traffic volumes on weekdays at approximately 130% of AADPT. The weekend exhibits much lower pedestrian traffic volumes at approximately

60% of AADPT. A higher degree of variance between days is observed on Sundays, ranging from 52% to 65% of AAPDT. Figure 30 and Table 18 describe TPG2 on a day-of-weekly basis and present the results of the ANOVA test.

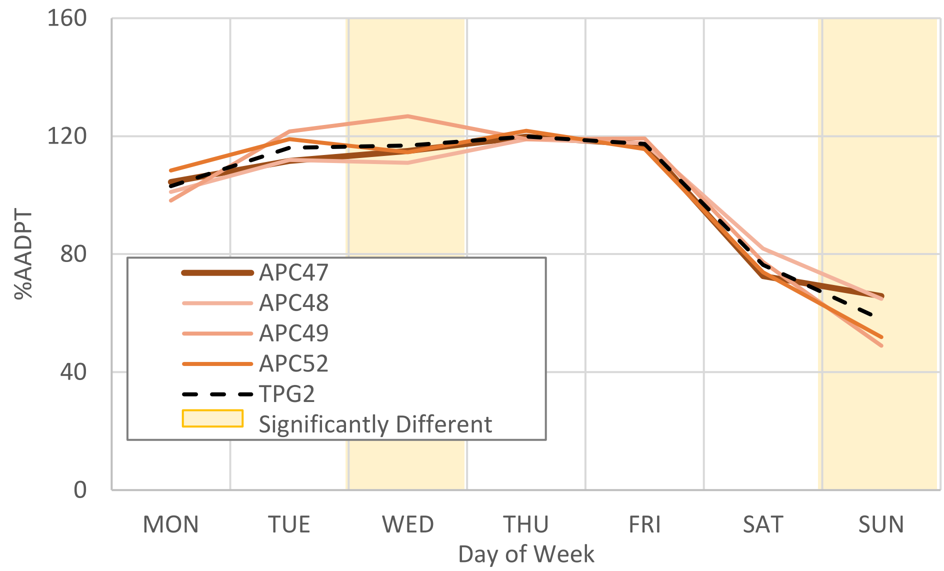


Figure 30: TPG2 Day-of-Week Pedestrian Traffic

Table 18: TPG1 Mean Day-of-Week Proportions of Daily Pedestrian Traffic

	Day-of-Week [%AADPT]						
APC	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*	*Sun*
47	104	112	115	120	117	73	66
48	101	112	111	119	118	82	65
49	98	122	127	119	119	77	49
52	108	119	115	122	116	74	52
TPG Mean	**103**	**116**	**117**	**120**	**117**	**76**	**58**
	ANOVA Test Results						
p	0.3	0.3	0.0	0.9	0.9	0.2	0.0

On average, the four continuous count sites in TPG2 exhibit different proportional volumes on Sundays throughout the year at a significance level of 0.1.

The ANOVA test of temporal trends for sites in TPG2 also indicate that the group is more internally consistent by day-of-week than by hour of day. One of the seven days of week does not produce similar traffic proportions within the group while fourteen of the eighteen hours included in the test resulted in significant differences within the group at a 0.1 significance level. Based on these results, it is expected that the hourly adjustment method will produce less accurate estimates of AADPT that adjustment methods which consider multiple full-day counts for TPG2.

4.3. SUMMARY

This chapter reports pedestrian traffic across eight continuous count sites throughout 2016 and verifies previously established traffic pattern groups within the study area. Pedestrian traffic characteristics were summarized based on each site's seasonal, hour-of-day, day-of-week, and hour-of-day variation.

An analysis of annual traffic statistics showed that there is only a minor difference between seasonal (May to October) and annual average daily pedestrian traffic (AADPT). This is different than previous research conducted by Klassen (2016), indicating that downtown pedestrian traffic behaves differently that multi-use paths in terms of seasonal variation. For this reason, comparisons of pedestrian traffic between sites were normalized by AADPT.

Analyzing day-of-week and hour-of-day trends enabled recurring traffic variation to be categorized using the AMI and WWI. It was found that the activity at each site can be categorized as mixed-recreational. Local knowledge however indicates the recurring traffic within the study area is not recreational, but actually utilitarian which experiences a large noon-time peak. Therefore, each continuous count site was determined to have an "urban-utilitarian" classification with respect to recurring variation.

Analysing the hour-of-day and day-of-week variation revealed that over the course of a full year, the initial TPG assignment did not adequately represent how sites respond to special events. To amend this discrepancy, APC47 was assigned to TPG 2 and APC50 was assigned to TPG 1.

An analysis of variance using a series of F-tests was performed to evaluate the consistency of each TPG based on their hour of day and day of week variation. These analyses determined that both TPGs are more consistent by day of week than by hour of day. Performing this statistical analysis also revealed that despite the apparent visual consistency within each TPG by hour-of-day or day-of-week,that differences did exist statistically.

There are two important implications for pedestrian traffic monitoring resulting from the analysis summarized in this chapter. The first is that hour-of-day pedestrian traffic patterns in downtown Winnipeg are different from motorized traffic. Pedestrian counts, which are normally conducted in the morning or afternoon peak periods are susceptible to missing the true peak pedestrian traffic which may occur in the noon hour or late evening. This may result in under designing pedestrian infrastructure such as sidewalks or crossing control. The second is that partial day counts cannot be as confidently assigned to TPGs as counts spanning multiple days. This suggests that coverage counts spanning multiple days is expected to produce more precise estimates of AADPT than partial day counts. This is explained further in Chapter 5.

5. PEDESTRIAN DATA ADJUSTMENT METHODS

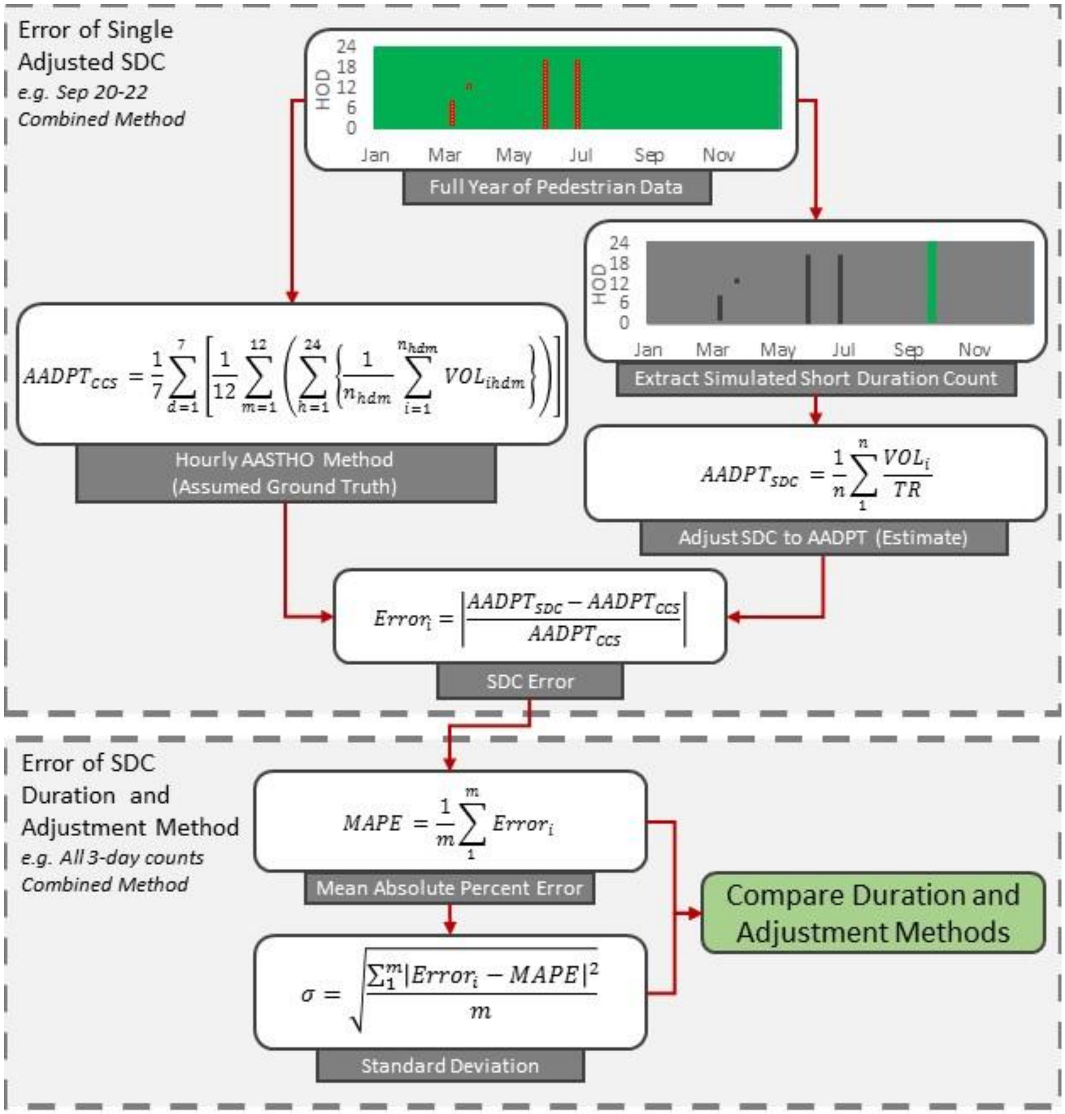
This chapter presents results of the analysis to evaluate adjustment methods of short-duration pedestrian counts conducted in downtown Winnipeg to produce estimates of annual average daily pedestrian traffic (AADPT). The four adjustment methods analyzed include the Hourly, Separated, Combined, and Day-of-Year factor methods. The expected error of each adjustment method is analyzed under varying short-duration count conditions. These include the count duration and time of year when the count was conducted.

A consistent procedure was followed to analyze each short-duration adjustment method. Using the available data from each continuous count site, each possible short-duration count of differing time periods was extracted to simulate a sample of short-duration counts. These durations consisted of partial and full day periods and were chosen to be consistent with typical pedestrian traffic monitoring practices. Using the traffic pattern groups (TPGs) developed in Chapter 4, estimates of AADPT were calculated for every simulated count using each applicable adjustment method. Each estimate of AADPT resulting from a short-duration count was compared to the AADPT calculated from the continuous count site using the Hourly AASHTO method.

A distribution of expected error was produced for each short-duration count period and disaggregated by the month of year. This enabled the comparison of the mean absolute percent error (MAPE) for each count duration by time of year.

Figure 31 illustrates the analysis process for comparing adjustment methods.

Figure 31: Short-Duration Count by Adjustment Method Analysis Process



Where:

$HOD = Hour\ of\ day$

$CCS\ = Continuous\ count\ site$

$SDC\ = Short\ duration\ count$

$VOL_i = Daily\ volume\ resulting\ from\ a\ SDC$

$Error_i = Error\ of\ an\ adjusted\ short\ duration\ count\ in\ reference\ to\ AADPT_{CCS}$

$MAPE\ = Mean\ absolute\ percent\ error\ of\ a\ SDC\ duration\ for\ an\ adjustment\ method$

$\sigma\ = Standard\ deviation\ of\ a\ SDC\ duration\ for\ an\ adjustment\ method$

$n = number\ of\ daily\ volumes\ in\ a\ SDC$

$m = number\ of\ error\ estimates\ in\ a\ SDC\ duration\ for\ an\ adjustment\ method$
$i\ = the\ i^{th}\ simulated\ short\ duration\ count$
$h = the\ h^{th}\ hour\ of\ day\ (h = 0\ to\ 23)$
$d = the\ d^{th}\ day\ of\ the\ short\ duration\ count$

5.1. AADPT ESTIMATION AT CONTINUOUS COUNT SITES

Ground truth annual average daily pedestrian traffic (AADPT) values are required for each continuous count site to evaluate the performance of each adjustment method. The true value of AADPT was not possible to produce at any site as none of the sites captured a complete year of pedestrian data. This was due to counter errors, misrepresentative counts, and precipitation events. The Hourly AASHTO Method was used to estimate the AADPT at each site to be used as a ground truth. This method was chosen because it allows for data from partially complete days to be used in the analysis, unlike the Traditional AASHTO Method. Enough data was available at each continuous count site to use this method without requiring data imputation. The Hourly AASHTO Method equation is shown in [Eq. 11].

[Eq. 11]

$$AADPT_{CCS} = \frac{1}{7}\sum_{d=1}^{7}\left[\frac{1}{12}\sum_{m=1}^{12}\left(\sum_{h=0}^{23}\left\{\frac{1}{n_{hdm}}\sum_{i=1}^{n_{hdm}} VOL_{ihdm}\right\}\right)\right]$$

Where:

VOL_{ihdm}	the hourly traffic volume for the *ith* occurrence of the *hth* hour-of-day within the *dth* day-of-week of the *mth* month-of-year
i	Index of the *ith* hour-of-day within the *dth* day-of-week of the *mth* month-of-year (i=1,2,…n_{hdm})
h	The *hth* hour of day (h=0,1,…23)
d	The *dth* day-of-week (d=1,2,…7)
m	The *mth* month-of-year (m=1,2,…12)
n_{hdm}	A count of hours with available data for the *hth* hour-of-day within the *dth* day-of-week for the *mth* month-of-year (n_{hdm} ranges from 1 to 5)

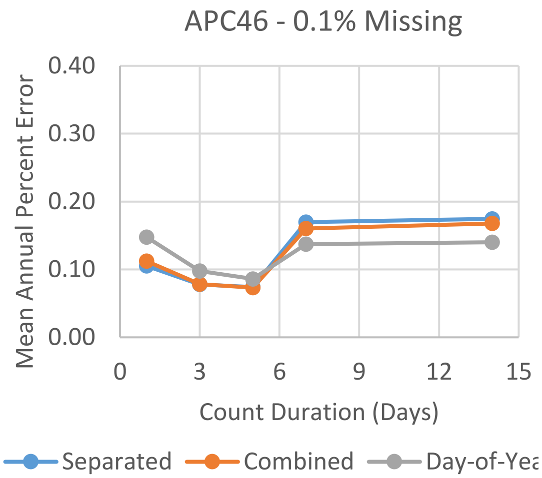
Table 19 provides a summary of AADPT values estimated at each continuous count site using the Hourly AASHTO method.

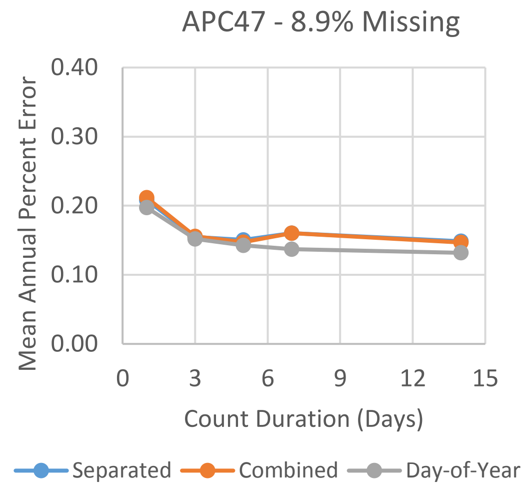
Table 19: Hourly AASHTO Method Estimates of AADPT

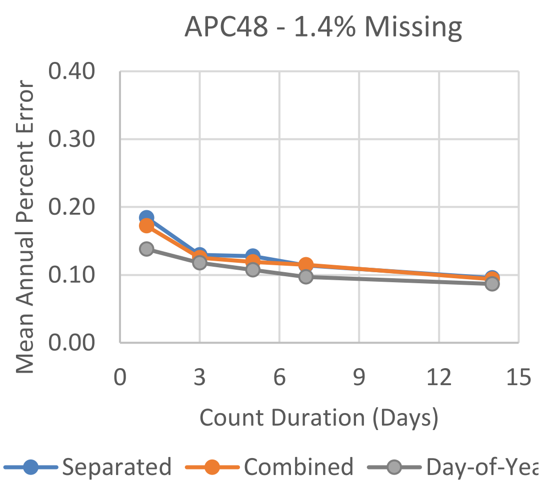
APC	46	47	48	49	50	52	54	55
AADPT Estimate	493	473	976	955	2931	1902	850	1444

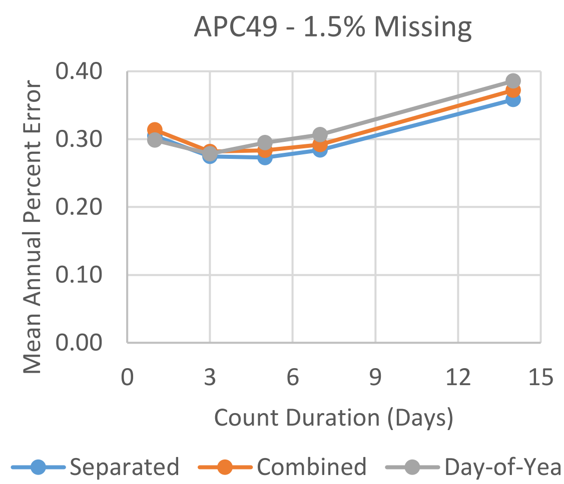
5.2. MISSING DATA EFFECTS

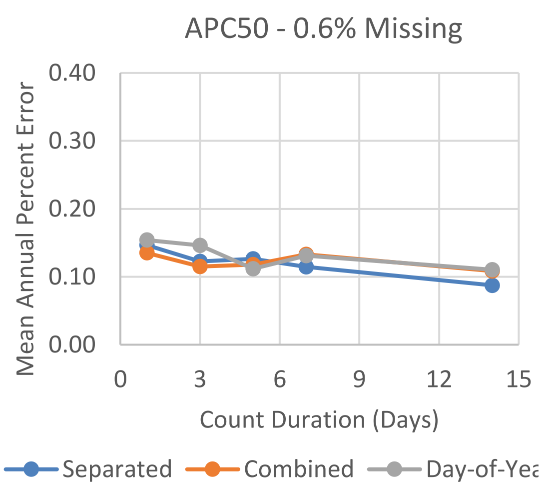
As discussed in chapter 5.1, pedestrian data collection at each continuous count site resulted in an incomplete dataset for traffic volumes in 2016. Missing data was a result of counter malfunction, sidewalk closures due to construction, precipitation events, and misrepresentative counts. To produce estimates of annual average daily pedestrian traffic (AADPT), the Hourly AASHTO method was used. The values of AADPT used in the analysis to estimate the mean average percent error (MAPE) for each adjustment method therefore were not relative to the true AADPT at each site, but to the estimate produced by the Hourly AASHTO method. Given that the accuracy of the AADPT estimates are dependent on the amount and configuration of data missing from each counter data set, an analysis was performed to investigate how varying levels of missing pedestrian data can affect estimates of MAPE between the different adjustment methods. By comparing the performance of each adjustment method for each site individually, the range in response from missing data for this research can be investigated. The amount of data missing from each continuous count site ranged from 6.4% at APC46 to 15.3% at APC54. The total amount of hourly volumes possible in 2016 at each site was 8,784. The MAPE values for each count duration were calculated individually for each count site and are summarized in Figure 32.

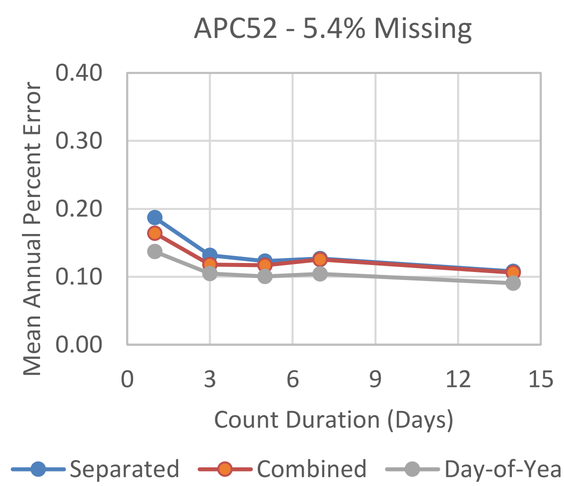

APC46 - 0.1% Missing
Mean Annual Percent Error
0.40
0.30
0.20
0.10
0.00
0
3
6
9
12
15
Count Duration (Days)
Separated
Combined
Day-of-Yea


APC47 - 8.9% Missing
Mean Annual Percent Error
0.40
0.30
0.20
0.10
0.00
0
3
6
9
12
15
Count Duration (Days)
Separated
Combined
Day-of-Year


APC48 - 1.4% Missing
Mean Annual Percent Error
0.40
0.30
0.20
0.10
0.00
0
3
6
9
12
15
Count Duration (Days)
Separated
Combined
Day-of-Yea


APC49 - 1.5% Missing
Mean Annual Percent Error
0.40
0.30
0.20
0.10
0.00
0
3
6
9
12
15
Count Duration (Days)
Separated
Combined
Day-of-Yea


APC50 - 0.6% Missing
Mean Annual Percent Error
0.40
0.30
0.20
0.10
0.00
0
3
6
9
12
15
Count Duration (Days)
Separated
Combined
Day-of-Yea


APC52 - 5.4% Missing
Mean Annual Percent Error
0.40
0.30
0.20
0.10
0.00
0
3
6
9
12
15
Count Duration (Days)
Separated
Combined
Day-of-Yea

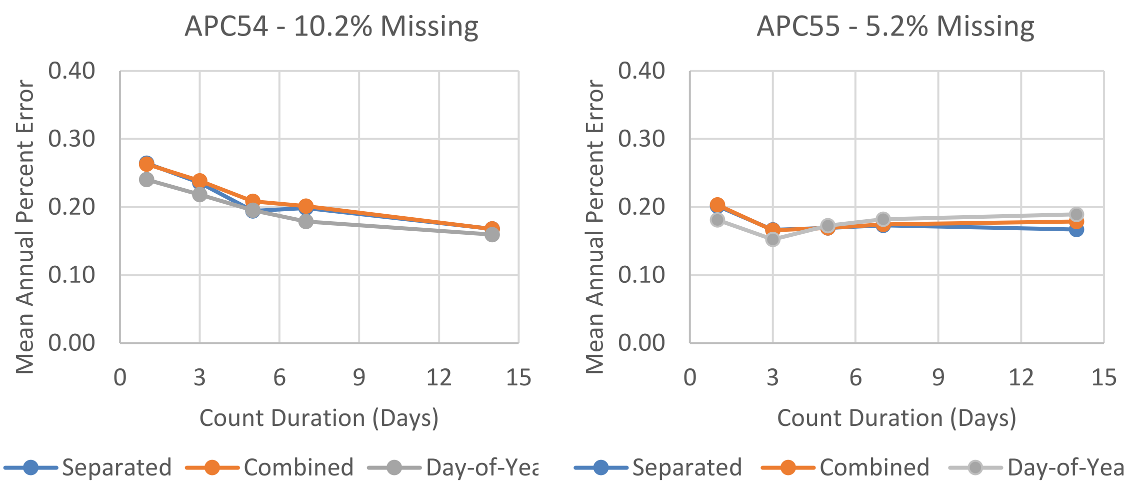


Figure 32: MAPE by Count Site and Duration

The shape and range curves illustrated in Figure 32 provide two insights relevant to this research. The first is that the amount of missing data does not necessarily correlate to greater MAPE values. For example, the APC49 count site produced the highest MAPE values for each full-day count duration while only losing 7.3% of the hourly pedestrian volumes in 2016. Conversely, APC52 which lost 11.4% of hourly pedestrian volumes in 2016 produced lower MAPE than APC48 which lost only 7.4% of hourly pedestrian volumes.

The second insight Figure 32 provides is that MAPE values produced for each count site do not vary largely between adjustment methods. For each count site described in Figure 32, the MAPE values are clustered closely together for each count duration. This suggests that even though the amount of missing data does have an effect on MAPE values produced, the difference between how adjustment methods react to missing data is observed to be similar. For the purposes of this research, this insight allows for the MAPE of adjustment methods to be compared despite estimates of AADPT being based on partially complete datasets.

5.3. SHORT-TERM COUNT ADJUSTMENT METHODS

The four adjustment methods analysed in this research are the Separated Method, Combined Method, Day-of-Year Method, and Hourly Method. Five partial day, and five full-day short-duration count periods were analysed that are consistent with typical traffic monitoring practices. Partial day durations consisted of 2-hours, 4-hours, 6-hours, 8-hours, and 12-hours while full day counts consisted of 1-day, 3-day, 5-day, 7-day, and 14-day count periods.

Table 20 and Tables 21 summarize the time periods where partial counts are typically conducted while Table 21 summarizes the days of week that full-day counts typically start on. For this study, weekdays were defined as Tuesdays, Wednesdays, and Thursdays to be consistent with current pedestrian traffic monitoring practices (Poapst, 2015).

Table 20: Typical Partial-Day Counts

Partial-Day Count Duration	*Start Hours-of-Day*	*Counts Per Weekday*
2 h	06:00 – 16:00	11
4 h	06:00 – 14:00	9
6 h	06:00 – 12:00	7
8 h	06:00 – 10:00	5
12 h	06:00	1

Table 21: Typical Full-Day Counts

Full-Day Count Duration	*Start Days-of-Week*	*Counts Per Week*
1-Day	TWR	3
3-Day	T	1
5-Day	M	1
7-Day	Any	7
14-Day	Any	7

5.3.1. Short Duration Count Methods

This section summarizes the adjustment methods analyzed for this research. These include the Separated, Combined, Day-of-Year, and Hourly Factor Methods.

5.3.1.1. Hourly Method

The hourly method is the only method which allows for partial day counts to be adjusted to annual averages. Many jurisdictions collect pedestrian data as part of an existing turning movement count program for motorized traffic resulting in partial day counts. The hourly method can be used to leverage pedestrian counts which are conducted this way (Nordback, Marshall, Janson, & Stolz, 2013, p. 8). This method does not account for hourly variation throughout the year, but assumes each hourly time period is consistent throughout the year. The hourly method traffic ratio equation is shown in [Eq. 12].

[Eq. 12] $$TR_h = \frac{AAHDPT_h}{\sum_{h=0}^{23} AAHDPT_h}$$

Where: $AAHDPT_h$ The annual average hourly weekday pedestrian traffic

h The hour-of-day (h=0-23)

5.3.1.2. Separated Factor Method

The Separated Factor Method is a two-step process that separately applies traffic ratios to represent monthly and daily variation. This method requires twelve month-of-year ratios and seven day-of-week ratios. This method does not recognize that day-of-week variation may change throughout the year, but assumes it is constant. Also, the Separated Method does not account for non-recurring variation. This method is the simplest to understand and employ as it requires the least number of unique traffic ratios (TAC, 2017, p. 250). The monthly and daily traffic ratio equations are shown below in [Eq. 13] and [Eq.14] respectively.

[Eq. 13] $$TR_m = \frac{MADPT_m}{AADPT}$$

Where: $MADPT_m$ The monthly average daily pedestrian traffic for month *m*

$AADPT$ The annual average daily pedestrian traffic

m the month-of-year (1-12)

[Eq. 14]

$$TR_d = \frac{AADWPT_d}{AADPT}$$

Where:	$AADWPT_d$	The annual average day-of-week pedestrian traffic for day of week *d*
	$AADPT$	The annual average daily pedestrian traffic
	d	the day-of-week (1-7)

5.3.1.3. Combined Method

The Combined Method requires 84 monthly average day-of-week pedestrian traffic (MADWPT) values to produce traffic ratios at a continuous count site. This method recognizes that sites may experience a change in day-of-week patterns by month and only requires the application of a single traffic ratio. Similar to the Separated Method, it does not recognize the effects of non-recurring variation on pedestrian traffic (TAC, 2017, p. 250). The combined method traffic ratio equation is shown below in [Eq. 15].

[Eq. 15]

$$TR_{md} = \frac{MADWPT_{md}}{AADPT}$$

Where:	$MADWPT_{md}$	The monthly average day-of-week pedestrian traffic
	$AADPT$	The annual average daily pedestrian traffic
	m	the month-of-year (1-12)
	d	the day-of-week (1-7)

5.3.1.4. Day-of-Year Method

Day-of-year traffic ratios are calculated for each day of the year. This method implicitly accounts for non-recurring variation at a short-duration count site under the assumption that the continuous count sites within the same TPG are similarly affected by these events. For example, if a precipitation event results in low pedestrian traffic volumes throughout a TPG, the non-recurring variation experienced by continuous count sites will be imposed on the coverage counts as it is adjusted by that day-of-year factor. This method recognizes that pedestrian count sites may experience day-to-day variation throughout the year due to recurring and non-recurring events (Hankey, Lindsey, & Marshall, 2014, p. 5). The day-of-year traffic ratio equation is shown below in [Eq. 16].

[Eq. 16]
$$TR_{DOY,i} = \frac{DailyVol_i}{AADPT}$$

Where:

$DailyVol_i$	The total pedestrian volume observed on the *ith* day-of-year
$AADPT$	The annual average daily pedestrian traffic
i	The day-of-year (i=1-366)

5.3.2. Simulated Short-Duration Counts

For the eight continuous count sites, each available partial and full day count period was extracted to simulate a unique short-duration count. Due to events including construction, counter malfunction, or misrepresentative counts, the dataset available for analysis was incomplete. Table 22 below provides a summary of the possible number of short-duration counts by differing time periods and the number of simulated short-duration counts extracted from the available dataset in 2016.

Table 22: Summary of Simulated Short-Duration Counts

	Possible Counts		***Available Counts Simulated***	
Duration	*Per Site*	*Total (8 Sites)*	*Total*	*Sample Proportion*
2-Hour	1716	13 728	12 327	0.90
4-Hour	1404	11 232	10 095	0.90
6-Hour	1092	8736	7858	0.90
8-Hour	780	6240	5615	0.90
12-Hour	156	1248	1123	0.90
1-Day	156	1248	1154	0.92
3-Days	52	416	373	0.90
5-Days	52	416	358	0.86
7-Days	360	2880	2399	0.83
14-Days	353	2824	2104	0.75

The resulting sample of full-day simulated short-duration counts were adjusted by the Separated, Combined, and Day-of-Year factor methods while the partial-day counts were adjusted by the Hourly Factor Method. This resulted in 56,182 estimates of AADPT used in the analysis.

5.3.3. Traffic Ratios

Traffic ratios are used to estimate AADPT from short-duration counts and are based on the temporal variation of the corresponding TPG. The general application of traffic ratios is described in [Eq. 17].

[Eq. 17]

$$AADPT_{SDC} = \frac{1}{n}\sum_{1}^{n}\frac{VOL_i}{TR}$$

Where:

$AADPT_{SDC}$ Estimate of annual average daily pedestrian traffic from the short duration count

VOL_i The total pedestrian volume observed on the *ith* day of the short duration count

TR	Product of the appropriate traffic ratio(s)
i	The day of the short-duration count (I = 1, ... , n)
n	The number of full days in short-duration count

Adjusting short-duration counts is a three-step process. The first step is to calculate the appropriate traffic ratios for each adjustment method for each continuous count site. The second was defining proper traffic ratios for each simulated short-duration count. The proper traffic ratio for a short duration count is defined as the average applicable traffic ratio from the three other continuous count sites in the same traffic pattern group. Finally, each daily volume of the short-duration count is divided by the TPG's applicable traffic ratio to estimate AADPT. The average of these estimates is used as the estimate for the count period.

For example, consider expanding a simulated single day short duration count extracted from APC46 on Wednesday June 23, 2016 using the Combined Method. Since APC46 is in TPG-1, it is adjusted by the average applicable traffic ratio ($TR_{6,4}$, [Eq. 15]) from APC50, APC54, and APC55. To adjust the short duration count, the daily volume is divided by $TR_{6,4}$. This process is illustrated below.

1. Extract short duration count.

Continuous Count Site	Simulated SDC	Month	Day of Week	Volume
APC46	Jun 23, 2016	6	4	**730**

2. Determine the applicable average traffic ratio for TPG-2. This calculation is tabulated below.

Continuous Count Site	$MADWPT_{6,4}$	÷	AADPT	=	$TR_{6,4}$
APC47	741	÷	478	=	1.55
APC54	1257	÷	879	=	1.43
APC55	2426	÷	1479	=	1.64
Average					**1.54**

3. Adjust short duration count to produce an estimate of AADPT.

$$AADPT_{SDC} = \frac{1}{n}\sum_{1}^{n}\frac{VOL_i}{TR_{6,4}} = \frac{730}{1.54} = 474$$

Based on this calculation, the simulated single day short duration count from June 23, 2016 produces an estimate of AADPT equal to 474. This three-step process was performed to produce an $AADPT_{SDC}$ value for each simulated short duration count that was summarized in Table 22.

5.4. COUNT DURATION ERROR ANALYSIS

The purpose of the analysis was to compare methods for adjusting coverage counts based on the expected level of error relative to a ground truth value of annual average daily pedestrian traffic (AADPT). Since the true value of AADPT was not available at any continuous count site, estimates were made using the Hourly AASHTO Method. Each adjusted simulated short-duration count was compared to the AADPT estimate of the corresponding continuous count site.

For the purposes of this research, the true AADPT value at each site is not required to compare adjustment methods. Given that each adjustment method makes use of the same dataset, the amount of error resulting from incomplete pedestrian data is proportional to the number of times the AADPT estimate from a continuous count site is referenced through the application of traffic ratios. The combined, day-of-year, and hourly adjustment methods each apply a traffic ratio once to produce and estimate of AADPT from a short-duration count. This means that the error resulting from an incomplete dataset is consistent across these three adjustment methods. The separated method applies traffic ratios twice (day of week, month of year), resulting in additional error for the estimate of AADPT. This was observed in the error analysis, and is an inherent limitation of the separated adjustment method.

For each adjustment method, the mean absolute percent error (MAPE) was compared across differing count durations using [Eq. 18].

[Eq. 18]

$$MAPE = \frac{1}{nm}\sum_{i=1}^{n}\sum_{j=1}^{m}\left|\frac{(AADPT_{CCS_i} - AADPT_{SDC_j})}{AADPT_{CCS_i}}\right|$$

Where:	$AADPT_{CCS_i}$	Estimation of annual average daily pedestrian traffic from the *ith* continuous count site
	$AADPT_{SDC_i}$	Estimation of annual average daily pedestrian traffic from the *jth* short duration count
	i	Continuous count site number (1,2,…8)
	j	The day of the short-duration count (j = 1, ... , m)
	n	The number of continuous count sites (n = 8)
	m	The number of short duration counts sampled for analysing the adjustment method (see Table 22)

The following sections describe the error expected for using each adjustment method to estimate AADPT from short duration counts.

5.4.1. Hourly Factor Method

The hourly factor method applies a single annual average hour-of-day traffic ratio to estimate AADPT from short duration counts. This method represents the current City of Winnipeg data collection status quo which is made up of partial day manual counts and video turning movement counts. The error reported in the section is representative of what the City of Winnipeg can expect if data resulting from current pedestrian monitoring practices are adjusted to estimate annual traffic levels.

Hour-of-day traffic ratios were applied to each simulated partial day short-duration count (Table 22) and compared to the corresponding $AADPT_{CCS}$ value (Table 19) to produce an error estimate. The mean absolute percent error (MAPE), standard deviation, and 95th percentile error was evaluated for each count duration separately and are plotted in Figure 33.

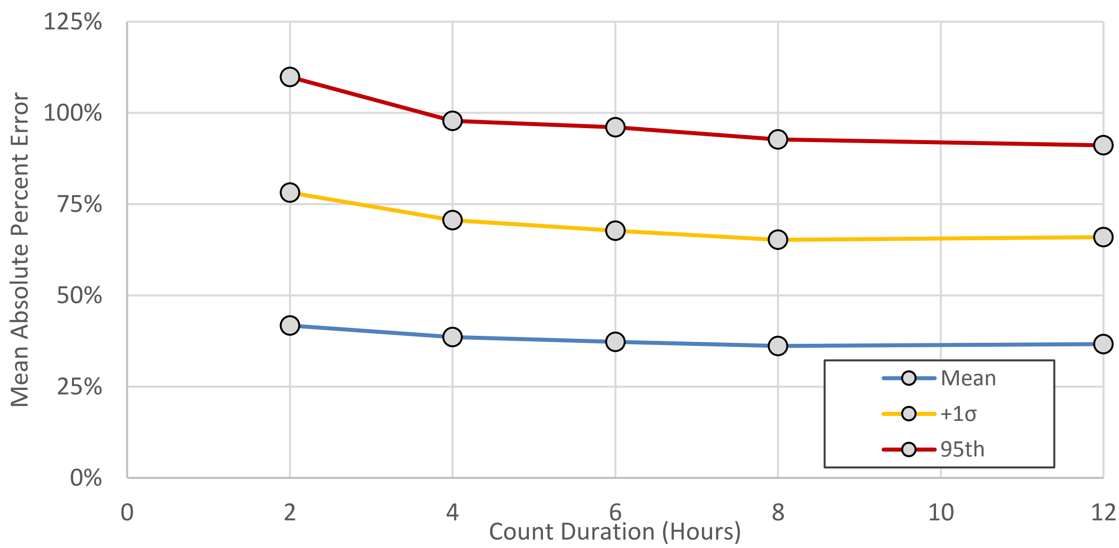


Figure 33: Hourly Method Error Analysis

The MAPE decreases in an approximately linear fashion from 42% for two-hour counts to 37% for twelve-hour counts. There is a decrease in the standard deviation between a two-hour and four-hour count (78% to 71%) with minimal decrease beyond six hours. A decrease in the 95th percentile is observed between two-hour and four-hour duration count (110% to 80%). The MAPE, standard deviation, and 95th percentile values remain approximately constant beyond a six-hour count duration. Compared to the Separated, Combined, and Day-of-Year methods, it is observed that the Hourly Method produces larger errors and more variability in estimating AADPT. This method applies a single traffic ratio that is based on an estimate of AADPT. Table 23, Table 24, and

Table 25 summarize the mean absolute percent error, standard deviation, and 95th percentile error for each count duration and adjustment method respectively.

Table 23: Mean Absolute Percent Error Comparison by Count Duration and Adjustment Method

Count Duration (Days)	*Separated Method*	*Combined Method*	*Day-of-Year Method*	**Count Duration (Hours)**	*Hourly Method*
1	0.20	0.20	0.19	**2**	0.42
3	0.16	0.16	0.16	**4**	0.39
5	0.15	0.15	0.15	**6**	0.37
7	0.17	0.17	0.16	**8**	0.36
14	0.16	0.17	0.16	**12**	0.37

Table 24: Standard Deviation Comparison by Count Duration and Adjustment Method

Count Duration (Days)	*Separated Method*	*Combined Method*	*Day-of-Year Method*	**Count Duration (Hours)**	*Hourly Method*
1	0.38	0.37	0.38	**2**	0.78
3	0.30	0.31	0.30	**4**	0.71
5	0.29	0.30	0.28	**6**	0.68
7	0.34	0.35	0.32	**8**	0.65
14	0.34	0.36	0.36	**12**	0.66

Table 25: 95th Percentile Comparison by Count Duration and Adjustment Method

Count Duration (Days)	*Separated Method*	*Combined Method*	*Day-of-Year Method*	**Count Duration (Hours)**	*Hourly Method*
1	0.55	0.57	0.50	**2**	1.10
3	0.48	0.48	0.43	**4**	0.98
5	0.48	0.48	0.44	**6**	0.96
7	0.44	0.44	0.43	**8**	0.93
14	0.44	0.47	0.44	**12**	0.91

5.4.2. Separated Factor Method

The Separated Factor Method applies month-of-year and day-of-week traffic ratios to estimate AADPT from a short duration count. These traffic ratios were applied to each simulated full day short-duration count (Table 22) and compared to the corresponding $AADPT_{CCS}$ (Table 19) value to produce an error estimate. The mean absolute percent error (MAPE), first standard deviation, 95th percentile error was evaluated for each count duration separately and are plotted in Figure 34.

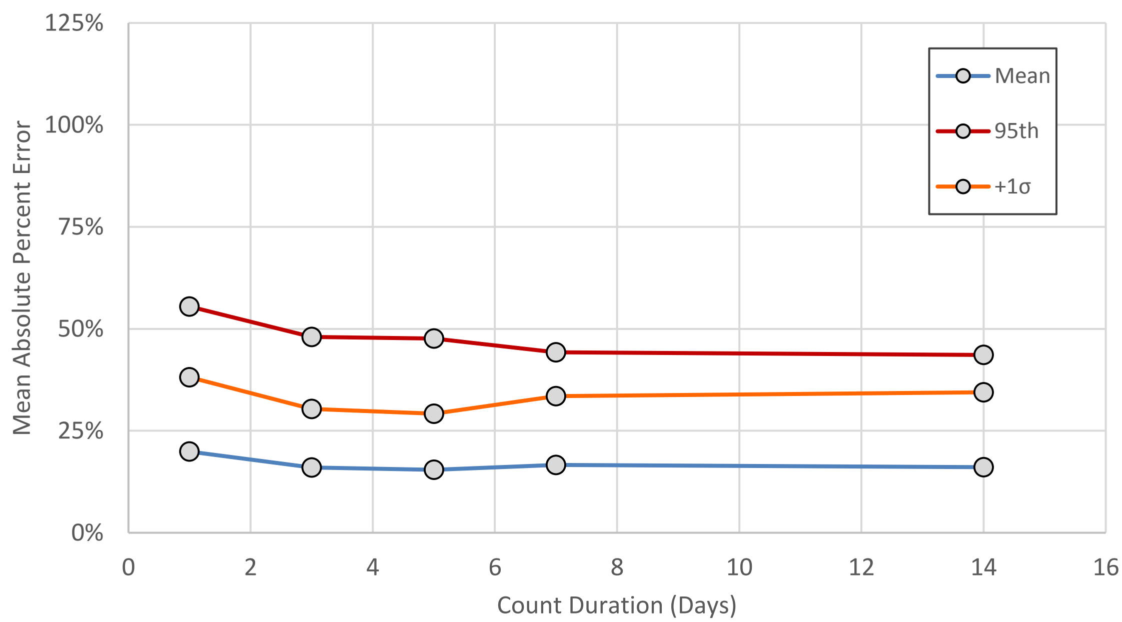


Figure 34: Separated Method Error Analysis

The MAPE decreases in an approximately linear fashion from 20% for single day counts to 0.16 for a two-week count. There is a decrease in the standard deviation between a single day and three-day count (38% to 30%) and actually increases once weekends are included (5 day, 7 day counts). A decrease in the 95th percentile is observed between and single and three day duration count (55% to 48%) indicating that single day counts have the tendency to produce extreme estimates of AADPT.

5.4.3. Combined Factor Method

The combined method applies a single monthly average day of week traffic ratio to estimate AADPT from short duration counts. These traffic ratios were applied to each simulated full day short-duration count (Table 22) and compared to the corresponding $AADPT_{CCS}$ value (Table 19) to produce an error estimate. The mean absolute percent error (MAPE), standard deviation, and 95th percentile error was evaluated for each count duration separately and are plotted in Figure 35.

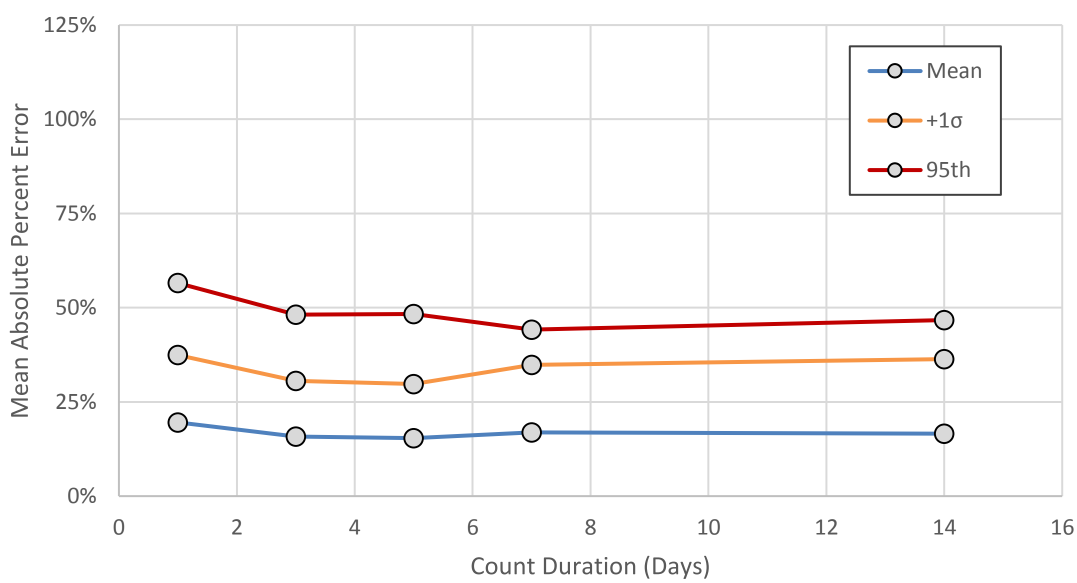


Figure 35: Combined Method Error Analysis

The MAPE decreases in an approximately linear fashion from 20% for single day counts to 17% for a two-week count. There is a decrease in the standard deviation between a single day and three-day count (37% to 31%) and similar to the Separated Method, standard deviation increases for counts greater than 5 days in length. A decrease in the 95th percentile is observed between and single and three-day duration count (57% to 48%) indicating that single day counts also can produce extreme estimates of AADPT for the combined method. This method applies a single traffic ratio that is based on an estimate of AADPT.

5.4.4. Day-of-Year Factor Method

The day-of-year method applies a single daily traffic ratio to estimate AADPT from short duration counts. These traffic ratios were applied to each simulated full day short-duration count (Table 22) and compared to the corresponding $AADPT_{CCS}$ value (Table 19) to produce an error estimate. The mean absolute percent error (MAPE), standard deviation, and 95th percentile error was evaluated for each count duration separately and are plotted in Figure 36.

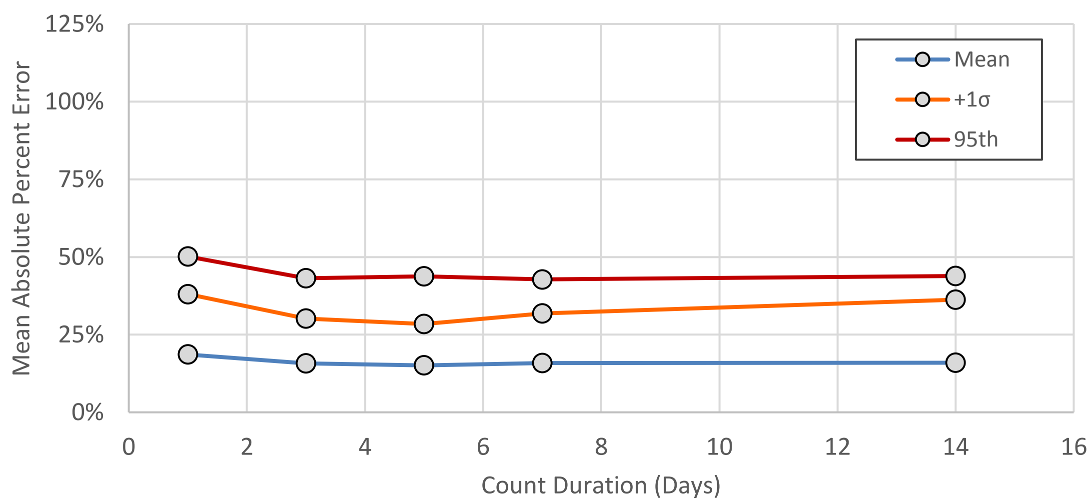


Figure 36: Day-of-Year Method Error Analysis

The MAPE decreases in an approximately linear fashion from 19% for single day counts to 16% for a two-week count. There is a decrease in the standard deviation between a single day and three-day count (38% to 30%). Beyond a three-day count, the MAPE remains approximately constant while increases are seen in the standard deviation for counts greater than 5 days.

5.4.5. Monthly Adjustment Error Analysis

The mean absolute percent error (MAPE) of short-duration counts to produce annual average daily pedestrian traffic (AADPT) was disaggregated by month for each adjustment method. This was done to evaluate the monthly variation of MAPE values for each adjustment method and identify optimal months for pedestrian data collection and adjustment in a coverage count program.

The monthly distribution of MAPE values for each adjustment method is plotted in Figure 33, Figure 34, Figure 35, and Figure 36.

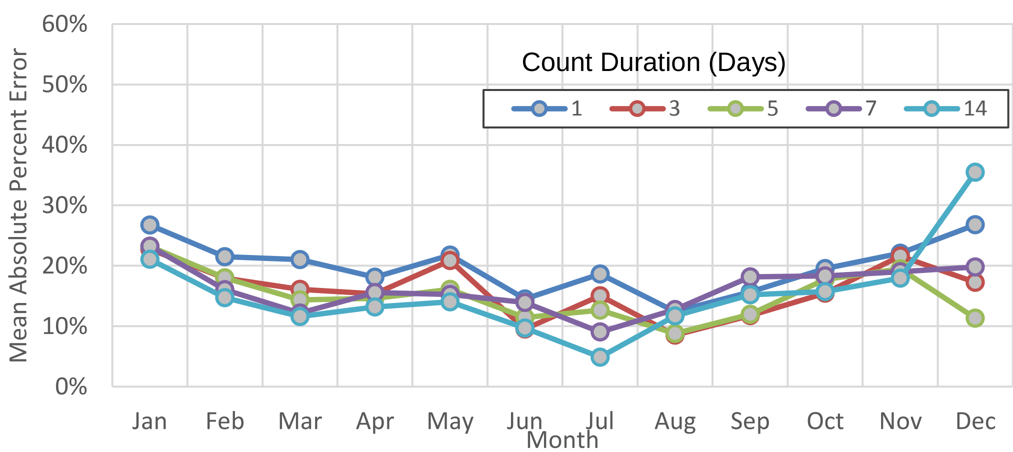


Figure 37: Separated Method MAPE by Month

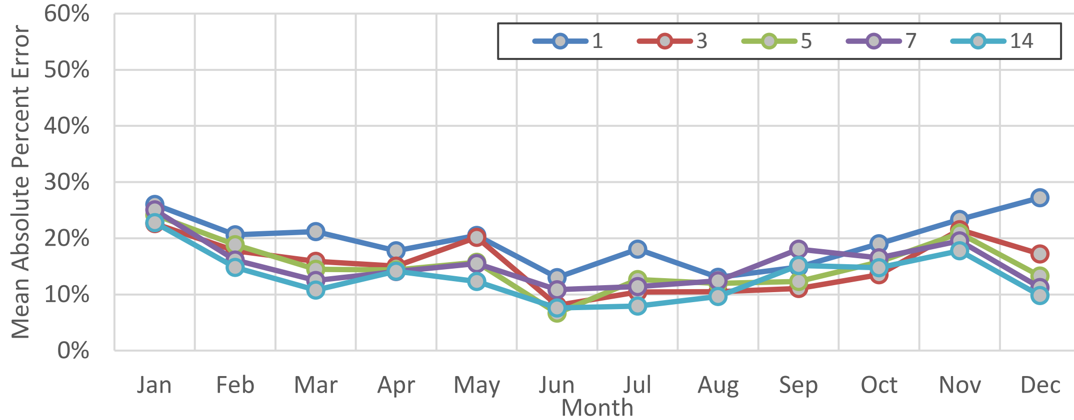


Figure 38: Combined Method MAPE by Month

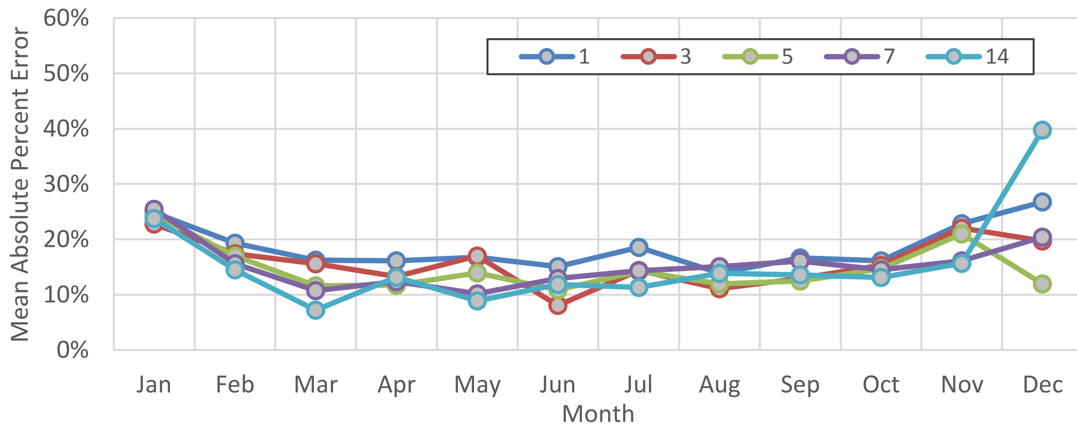


Figure 39: Day-of-Year MAPE by Month

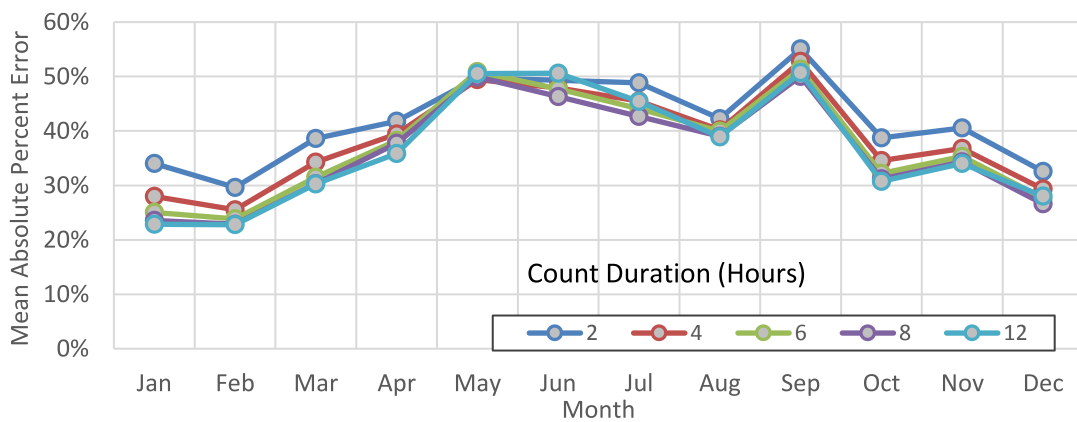


Figure 40: Hourly Method MAPE by Month

The shape of each full day count adjustment method are similar and characterized by lower MAPE values from April to October and higher MAPE values in the remainder of the year. The hourly method however performs in the opposite fashion with relatively large MAPE values in the summer and lower MAPE values in the winter. Relatively lower pedestrian volumes in the winter months and frequent events are part of the reason for the variation in MAPE values for each adjustment method. Since events occur more frequently from October to March with varying attendance, full-day adjustment methods were observed to produce higher MAPE values during these months compared to the remaining months of the year where fewer events occur.

In general, full-day count adjustment methods perform better than the partial-day adjustment method for each month of the year. The separated, combined, and day-of-year adjustment methods produce the lowest MAPE values in the months from April to October.

Table 26 presents a tabulated view of MAPE values disaggregated by month of year and count duration to compare full-day count adjustment methods. Highlighted cells indicate the lowest month-count duration pair between the three full-day adjustment methods. For example the separated method produced the lowest MAPE value for five day counts conducted in January so it has been highlighted in green.

Table 26: Adjustment Method MAPE Comparison by Month of Year and Count Duration

	SEPARATED METHOD					COMBINED METHOD					DAY-OF-YEAR METHOD				
	1	3	5	7	14	1	3	5	7	14	1	3	5	7	14
Jan	0.27	0.23	0.23	0.23	0.21	0.25	0.22	0.23	0.21	0.19	0.25	0.23	0.24	0.20	0.18
Feb	0.22	0.18	0.18	0.16	0.15	0.21	0.19	0.20	0.13	0.11	0.21	0.20	0.19	0.12	0.11
Mar	0.21	0.16	0.14	0.12	0.12	0.21	0.15	0.12	0.12	0.10	0.21	0.15	0.11	0.12	0.10
Apr	0.18	0.15	0.15	0.16	0.13	0.17	0.15	0.15	0.14	0.14	0.16	0.13	0.13	0.14	0.15
May	0.22	0.21	0.16	0.15	0.14	0.20	0.20	0.16	0.16	0.14	0.17	0.17	0.14	0.13	0.11
Jun	0.15	0.10	0.11	0.14	0.10	0.13	0.08	0.07	0.12	0.11	0.16	0.08	0.09	0.16	0.17
Jul	0.19	0.15	0.13	0.09	0.05	0.19	0.11	0.12	0.17	0.16	0.17	0.13	0.14	0.15	0.11
Aug	0.12	0.09	0.09	0.13	0.12	0.13	0.12	0.13	0.12	0.11	0.14	0.12	0.14	0.15	0.15
Sep	0.16	0.12	0.12	0.18	0.15	0.16	0.13	0.13	0.17	0.14	0.18	0.15	0.13	0.15	0.12
Oct	0.20	0.15	0.18	0.18	0.16	0.20	0.15	0.17	0.16	0.14	0.17	0.16	0.16	0.15	0.14
Nov	0.22	0.22	0.19	0.19	0.18	0.24	0.23	0.22	0.20	0.18	0.23	0.22	0.21	0.16	0.16
Dec	0.27	0.17	0.11	0.20	0.35	0.30	0.21	0.17	0.12	0.11	0.27	0.18	0.17	0.18	0.31

Table 26 shows that a wide variation exists for each full-day adjustment method depending on the month of year and duration of a short-duration count conducted. According to the annualized results of chapter 5.4, none of the multi-day short duration count adjustment methods clearly perform better than the others.

Table 26 indicates that depending on the month of year and count duration, any of the three full-day adjustment methods may produce the lowest expected MAPE value. For example, if 3-day counts are being conducted in April, the Day-of-Year method is expected to produce a more accurate estimate of AADPT than the Separated or Combined methods. If 7-day counts are being conducted in June, the Separated Method is expected to produce the most accurate estimate of AADPT. The most accurate adjustment method by each count duration-month of year pair is summarized in Table 27.

Table 27: Lowest Expected MAPE Month - Count Duration Pair

	Month											
Count Length	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	C	D	D	D	D	C	D	S	S	D	S	S
3	C	S	C	D	D	D	C	S	S	C	S	S
5	C	S	D	D	D	C	C	S	S	D	S	S
7	D	D	D	D	D	C	S	C	D	D	D	C
14	D	D	C	S	D	S	S	C	D	C	D	C

Pink = Separated Method
Blue = Combined Method
Green = Day-of-Year Method

The findings of chapter 5.4 and the information summarized in Table 26 and Table 27 have implications for how coverage counts are adjusted to annual statistics. If a coverage count program is implemented using specific count-durations during specific months of year, Table 27 indicates which adjustment method is expected to produce the most accurate estimate of AADPT and expected error.

5.4.6. Count Duration Error Analysis Summary

The performance of each adjustment method was evaluated by comparing the MAPE, standard deviation and 95th percentile error for each count duration. These metrics describe the average expected error from each type of short duration count as well as an indication of the variation and extreme values resulting from many adjusted counts.

There are a number of implications resulting from this analysis. The first is that partial day counts produce less accurate estimates of AADPT with more variability than multi-day counts. This is evidenced by the significantly greater MAPE, standard deviation, and 95th percentile error values in comparing the Hourly Method to any multi-day duration regardless of factor method. The second implication is that given the 2016 dataset, where each continuous count site used over 85% of all possible hours of traffic, the Separated, Combined, and Day-of-Year method each perform similarly. Evaluating each count duration and month of year pairing, it is shown that the Day-of-Year Method most frequently produced the lowest MAPE values, however the relative decrease in MAPE values compared to the Separated and Combined Methods are small. Finally, this analysis shows that for each multi-day factor method, short-duration counts conducted between the months of April and October produce lower MAPE values than the remaining months of the year.

5.5. SUMMARY

This chapter presents a summary of annual average daily pedestrian traffic (AADPT) estimation methods and results using the hourly AASHTO method and the procedures followed for simulating and adjusting shorting duration counts. Once estimated, AADPT values were produced using continuous and simulated short-duration count data, the mean absolute percent error (MAPE) for each simulated short duration count was used to evaluate the effects of count duration and the time of year counts are conducted. This analysis found that on average, the day-of-year adjustment method produces the lowest MAPE values but that there are count duration-month of year pairs where the separated and combined adjustment methods produced lower MAPE values. Also, counts performed in summer months produced lower MAPE values for each adjustment method than counts performed throughout the rest of the year.

This analysis also examined how each adjustment method performs for varying levels of data availability resulting from a year of pedestrian traffic. Between the eight continuous count sites, data loss through the quality control process ranged from 6.4% to 15.3%. Correlation between data availability and MAPE values was not observed for any full-day count period. Also, it was observed that the Separated, Combined, and Day-of-Year Factor methods behave similarly for each count duration regardless of data availability.

This observation confirms that the MAPE of the full-day count adjustment methods may be compared using sites of varying data availability, as is the case with this research.

6. CONCLUSIONS & FUTURE RESEARCH

This chapter discusses the research findings and identifies future research opportunities.

6.1. SUMMARY OF FINDINGS

This research evaluated the performance of four methods for adjusting mid-block short-duration pedestrian counts to estimate annual average daily pedestrian traffic (AADPT). The research defines performance in terms of expected error in estimating AADPT. Eight automated pedestrian counters (APCs) were installed on sidewalks throughout downtown Winnipeg and continuously collected pedestrian traffic volumes throughout 2016. These data were used to validate previously defined pedestrian traffic pattern groups (TPGs) within the study area using continuous data as current monitoring efforts make use of groups defined by short-duration counts. Traffic data were also used to evaluate the expected error of four different adjustment methods under varying implementation parameters.

This research develops adjustment factors for each of the adjustment methods for the year 2016 to produce annual pedestrian traffic statistics. The adjustment methods investigated are: the Separated Factor Method, the Combined Factor Method, the Day-of-Year Factor Method, and the Hourly Factor Method.

Chapter 2 summarized a literature review on current practices and research for developing pedestrian traffic monitoring programs. The literature review identified several key findings relevant to this thesis. Current practices related to system-wide pedestrian traffic monitoring, pedestrian traffic variability, data collection, and processing methods were each considered for developing the methodology and analysis for this research.

The literature review provided insight into current pedestrian traffic monitoring practices.

Miranda-Moreno, et al., (2013) outline an approach for classifying pedestrian count sites based on recurring traffic patterns. Using this approach, count sites may be assigned to recreational, mixed-recreational, mixed-utilitarian or utilitarian traffic pattern groups (TPGs). The review also provided a summary of common short-duration count practices. Full-day counts are typically conducted between 1 and 14 days with minimal adjustment error improvement observed beyond seven days of data collection (Jackson, Stolz, & Cunningham, 2014).

Pedestrian traffic behaves differently from motorized traffic. The literature review states that the seasonal traffic should be considered separately if there is large variation between summer and winter traffic. While pedestrian traffic is strongly dictated by recurring, scheduled based factors, it is also highly susceptible to the effects of non-recurring events. Pedestrian activity is prone to atypical events such as precipitation and special events. Current literature recommends removing these events in an effort to report typical pedestrian traffic.

The literature review identified data processing methods which formed the methodology and analysis for this research. The hourly AASHTO method was identified to estimate annual average pedestrian traffic (AADPT) from incomplete continuous data sets. Also, the separated, combined, day-of-year, and hourly method were identified to adjust short duration counts. Finally, the mean absolute percent error (MAPE) was identified as an effective way to compare the performance of adjustment methods to produce an estimate of AADPT.

In chapter 3, a clean and corrected hourly volumes table was produced by following the research methodology. This method consisted of selecting count technology and sites for automated pedestrian counters (APCs), data collection, and data processing.

EcoCounter Passive Infrared PYROBox sensors were used for automated pedestrian traffic data collection. The location of eight continuous count sites for data were selected based on previous research and recommendations made in the literature review (Olfert, 2015). These sites collected pedestrian traffic data continuously throughout 2016. Data processing methods were performed to ensure that the data used for analysis was representative of pedestrian traffic during the study period. This was done through data screening and applying a correction factor based on manual counts as an accepted reference volume. This process resulted in a clean and corrected hourly volume table representing pedestrian traffic volumes at the eight sites throughout 2016. The fields used in the clean and corrected hourly volume database are listed in Table 9.

Chapter 4 reported pedestrian traffic across eight continuous count sites throughout 2016 and updates previously established TPGs within the study area. Pedestrian traffic characteristics were summarized based on each site’s seasonal, hour-of-day, day-of-week, and hour-of-day variation.

An analysis of annual traffic statistics showed that there is only a minor difference between average seasonal traffic(May to October) and average annual traffic. This is different than previous research conducted Klassen (2016) and Glasgow (2016), indicating that downtown pedestrian traffic behaves differently than multi-use paths in terms of seasonal variation. For this reason, comparisons of pedestrian traffic between sites were normalized by AADPT rather than seasonal average daily pedestrian traffic (SADPT).

Analyzing day-of-week and hour-of-day trends enabled recurring traffic variation to be categorized using the AMI and WWI. The research found that the activity as each site can be categorized as mixed-recreational. Local knowledge however indicates the recurring traffic within the study area is not recreational, but actually utilitarian which experiences an additional large noon hour peak. Therefore, each continuous count site was classified as “urban-utilitarian” with respect to recurring variation.

A visual cluster analysis was performed to verify that continuous count sites behaved consistently with the initial TPGs which were based on short-duration counts (Olfert, 2015). Analyzing the hour-of-day and day-of-week variation revealed that over the course of a full year, the initial TPG assignment did not adequately represent how sites respond to special events. To amend this discrepancy, APC47 was assigned to TPG 2 and APC50 was assigned to TPG 1.

An analysis of variance using a series of F-tests was performed to evaluate the consistency of each TPG based on their hour-of-day and day-of-week variation. These analyses determined that both TPGs are more consistent by day-of-week than by hour-of-day. This suggests that using multi-day short duration counts to estimate AADPT should produce lower error than partial-day short duration counts.

Chapter 5 presents a summary of AADPT estimation results using the hourly AASHTO method and the procedures followed for simulating and adjusting short duration counts. Once estimated, AADPT values were produced using continuous and simulated short-duration count data. The MAPE for each simulated short duration count was used to evaluate the effects of count duration and the time of year counts are conducted. This analysis found that on average, the day-of-year adjustment method produces the lowest MAPE values for each count duration and that counts performed in June produced the lowest MAPE values for each adjustment method. There are however count duration-month of year pairs where the separated and combined adjustment methods produced lower MAPE values.

This analysis also examined how each adjustment method performs for varying levels of data availability resulting from a year of pedestrian traffic. Between the eight continuous count sites, data loss through the quality control process ranged from 0.1% to 10.2%. A correlation between data availability and MAPE values was not observed for any full-day count period. Also, it was observed that each adjustment method behaves similarly for each count duration regardless of data availability. This observation confirms that the MAPE of the full-day count adjustment methods may be compared using sites of varying data availability, as is the case with this research.

6.2. IMPLICATIONS FOR PEDESTRIAN COUNTING

The following is a list of applications for traffic data practitioners resulting from this research.

- Traditional active transportation data collection is based on practices developed for measuring vehicular traffic and where partial day counts are typically limited to the morning and afternoon peaks. For downtown Winnipeg, this research identified two additional recurring peak traffic periods for pedestrian traffic; the noon peak and evening peak, which are often larger in magnitude than the morning and afternoon peaks. If conducting partial day counts, traffic data practitioners should consider noon and evening peak periods include the true peak traffic volumes.
- For adjusting short-duration counts to estimate annual pedestrian traffic statistics, full day and multi-day counts perform significantly better than partial day counts. Also, count durations longer than three days provide minimal improvement to estimating annual average daily pedestrian traffic (AADPT).
- Future coverage counts conducted in Winnipeg's downtown area should be adjusted by the two traffic pattern groups developed in this research resulting from

a full year's worth of data; these being the Urban Utilitarian and Urban Utilitarian-Event groups.

- For simulated counts taken from 2016 count data, the day-of-year factor method most frequently produced the lowest mean average percent error when estimating AADPT. When adjusting short-duration counts of at least 24 hours, the day-of-year factor method should be used.
- In downtown Winnipeg, pedestrian traffic remains relatively stable throughout the year compared to other land use types such as recreational paths or commercial zones. Planning for pedestrian activity in the downtown area should reflect this sustained traffic throughout the winter months.

In general, applying the recommendations listed above will have a direct impact on engineering and planning decisions involving pedestrian traffic in downtown Winnipeg. Improved precision for pedestrian traffic may be used to inform processes such as snow clearing prioritization, pedestrian crossing control, the design of street side spaces, and allow the city to better understand the return on investment for prioritizing the accessibility and connectivity of the pedestrian network.

6.3. RECOMMENDATIONS FOR FUTURE RESEARCH

- The ability of traffic monitoring programs to produce annual statistics by adjusting coverage count data is dependent on the quality of continuous count data. In this research, each continuous count site produced a dataset with varying amounts of missing data. While this research was able to compare adjustment methods using incomplete data sets using estimates of AADPT, the precision of AADPT estimates from continuous count sites is unknown for pedestrian traffic in the study area.

Future research is needed to assess the level of accuracy expected from continuous count sites of varying completeness.

- This research was conducted to compare adjustment methods for pedestrian traffic in urban environments using continuous count sites and simulated short-duration counts. Future research is needed to assess the performance of each adjustment method using coverage counts that are not simulated from continuous count sites using the final traffic pattern groups developed in this research.
- Future research is also needed to assign pedestrian coverage counts to traffic pattern groups in the absence of known temporal variation. Using more subjective methods such as considering surrounding land use types should be investigated to perform this initial assignment.

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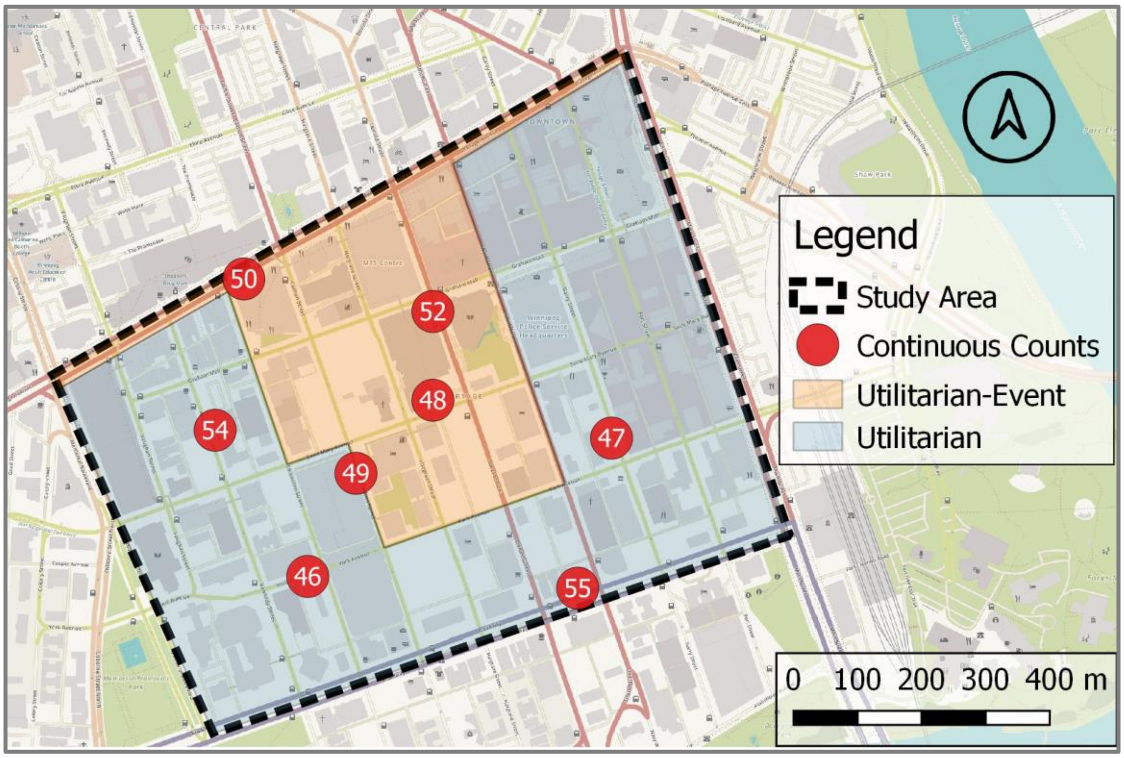
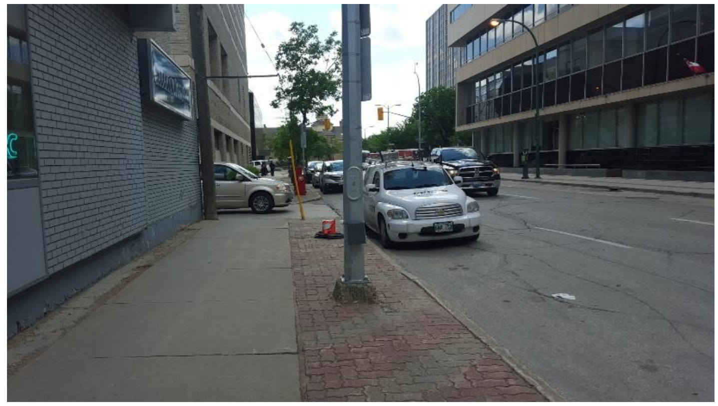
APPENDIX A: CONTINUOUS COUNT SITE SUMMARIES



Continuous Count Site Locations

APC 46

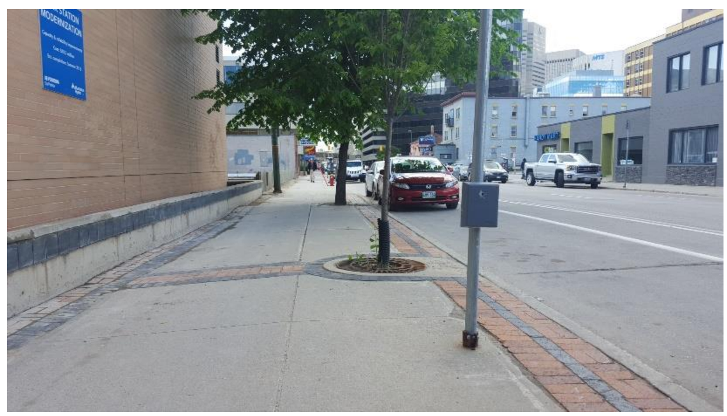
Location	York Ave. Edmonton St.
TPG	1
Facility Type	Sidewalk
AADT	10 600
AADPT	491



Site Description: APC 46 is located one block east of the convention centre. This site is on the south sidewalk of York Ave east of Edmonton St.

APC 47

Location	York Ave. Garry St.
TPG	2
Facility Type	Sidewalk
AADT	N/A
AADPT	472



Site Description: APC47 is located on the on the east sidewalk of Garry Street north of York Avenue. This site is located near to four on street parking lots which may have an impact on pedestrian traffic.

APC 48

Location	St. Mary Ave. Donald St.
TPG	2
Facility Type	Sidewalk
AADT	16 800
AADPT	972

Site Description:	APC48 is located on the north sidewalk of St. Mary Avenue east of Donald Street. This block is between the Winnipeg Millennium Library and Convention Centre.

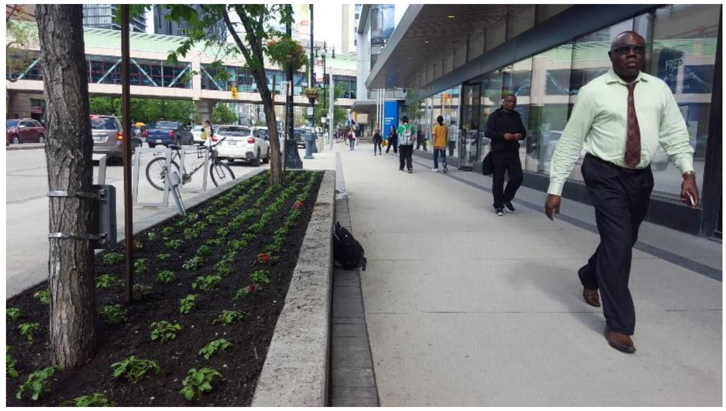
APC 49

Location	St. Mary Ave. Carlton St.
TPG	2
Facility Type	Sidewalk
AADT	16 800
AADPT	949

Site Description:	APC49 is located on the east sidewalk of Carlton Street south of St. Mary Avenue. The convention centre is on the opposite side of Carlton Street from APC49.

APC 50

Location	Portage Ave. Edmonton St.
TPG	1
Facility Type	Sidewalk
AADT	34 800
AADPT	2917



Site Description: APC50 is located on the south sidewalk of Portage Avenue east of Edmonton Street. This site is two blocks west of the downtown arena, and immediate in front of Manitoba Hydro's head office.

APC 52

Location	Graham Ave. Donald St.
TPG	2
Facility Type	Sidewalk
AADT	10 700
AADPT	1894

Site Description: APC52 is located on the west sidewalk of Donald Street south of Graham Avenue. This site is one block south of the downtown arena and across the street from the Winnipeg Millennium Library.

APC 54

Location	Graham Ave Edmonton St.
TPG	1
Facility Type	Sidewalk
AADT	N/A
AADPT	847

Site Description: APC54 is located on the east side of Edmonton Street south of Graham Avenue. This site is one block north of the Winnipeg Convention Centre.

APC 55

Location	Broadway at Donald St.
TPG	1
Facility Type	Sidewalk
AADT	22 400
AADPT	1436

Site Description: APC 55 is located on the south side of Broadway east of Donald Street.

APPENDIX B: MANUAL COUNT SUMMARIES FOR AUTOMATED PEDESTRIAN COUNTER CORECTION FACTORS

Continuous Counter ID	Date	Time	30-Minute Periods	Performed by
46	Oct 6, 2016	12:00 – 13:00	2	C. Olfert
	July 7, 2016	10:00 – 16:00	16	City of Winnipeg
47	Oct. 17 2016	16:00 – 17:00	2	C. Olfert
48	Oct 6, 2016	16:00 – 17:00	2	C. Olfert
49	Oct 13, 2016	16:00 – 17:00	2	C. Olfert
50	Oct 7, 2016	16:00 – 17:00	2	C. Olfert
52	Oct. 13, 2016	8:00 – 9:00	2	C. Olfert
	July 7, 2016	8:00 – 18:00	20	City of Winnipeg
54	Oct 12, 2016	8:00 – 9:00	2	C. Olfert
55	Oct 7, 2016	8:00 – 9:00	2	C. Olfert
Total			52	