Analysis of Pedestrian Traffic along a Commercial District Corridor

By

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ABSTRACT

Pedestrian traffic monitoring is in its infancy, and the volatility of pedestrian traffic creates a need for guidance on site selection in traffic monitoring programs. A robust knowledge base surrounding pedestrian traffic patterns and the degree to which a single counting station is representative of a larger area are essential in developing an accurate program for estimating pedestrian traffic volumes.

This research analysed long term hourly data from automated pedestrian counting devices on four consecutive blocks along an entertainment area corridor to determine the shifts in temporal pedestrian traffic characteristics and volumes along a corridor. Features of the built environment were identified that can aid in estimating pedestrian traffic patterns along a corridor.

Results indicate daily pedestrian traffic volumes can vary significantly between consecutive city blocks, limiting the applicability of a single count location to represent a larger area. Additionally, shifts in temporal traffic patterns occur over short distances. Finally, features of the built environment correlate with shifts in traffic patterns.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 PURPOSE

The purpose of this research is to analyze pedestrian traffic patterns and volumes along a corridor and identify factors in the built environment that lead to these patterns. Studying a corridor will permit the analysis of the shifts in hourly, daily, and monthly pedestrian volume distributions on a block-to-block basis. This knowledge will focus on site selection for pedestrian traffic monitoring in a neighbourhood, rather than a larger network, by understanding and explaining the variability in pedestrian traffic characteristics along a corridor.

1.2 BACKGROUND AND NEED

Walking is an important aspect of the transportation system, and information about non-motorized traffic is necessary to support planning and management of the network (Lindsey, Nordback, & Figliozzi, 2014). While the knowledge base surrounding motorized vehicle traffic monitoring is very comprehensive, non-motorized traffic monitoring is still an emerging area (Federal Highway Administration, 2013) (Schweizer, 2005) (Sauter, Hogertz, Tight, Thomas, & Zaidel, 2010). As such, the data collection for non-motorized traffic is on a much smaller scale compared to motorized traffic monitoring and available data is often the outcome of manual counts performed by volunteers or advocacy groups (Ryan & Lindsey, 2013).

Collecting pedestrian volume data and expanding the knowledge base regarding expanding short-term counts have a variety of uses including:

- Counting at select locations to quantify pedestrian exposure for pedestrian-vehicle crash risk,
- Monitoring temporal patterns of pedestrian activity,
- Documenting pedestrian characteristics,
- Prioritizing locations for engineering, education, and enforcement,
- Predicting and measuring the impact of new developments on surrounding pedestrian facilities, and
- Assessing the need for treatments or improvements to pedestrian facilities.

Expanding short term counts is one method that is used to estimate pedestrian volumes. Short term counts can be completed through manual counts or by automated pedestrian counters (APCs), and are adjusted using a variety of factors. Short term counts can be expanded based on temporal trends (Federal Highway Administration, 2013), weather (Nosal, 2014), and existing permanent count stations (Hottenstein, Turner, & Shunk, 1997). Each of these methods of estimating pedestrian traffic relies on short term counts to estimate a useful measure of pedestrian traffic.

One similarity among all pedestrian traffic monitoring methods is the paramount importance of APC placement and factor group assignment. Cities often have limited resources for counting pedestrians, so the cost of manual counts and APCs is a primary barrier to collecting pedestrian data. There is currently little guidance on site selection and how well sites are representative of larger areas (Federal Highway Administration, 2013).

Once a location is selected for short term counts, it must be assigned a factor group to expand the count volumes. Each factor group has distinct traffic patterns and therefore its own set of expansion factors. Factor groups are typically assigned to locations on an ad hoc basis, using local knowledge, and a limited number of factor groups (National Cooperative Highway Research Program, 2014). A major issue with this practice is the broad classification of factor groups. The National Bicycle and Pedestrian Documentation (NBPD) Project has developed factors for two factor groups: (1) multi-use pathways, and (2) high-density pedestrian and entertainment areas (PED) (Alta Planning and Design, 2015). However, it has been shown that multi-use pathways can display a wide spectrum of traffic patterns (Budowski, 2015). To improve the accuracy of expansion factor methods, it is necessary to understand how to better identify factor groups and assign factor groups to a counting site.

Analysing pedestrian traffic patterns along a corridor will provide information on pedestrian behaviour and the shift in pedestrian traffic characteristics as while transitioning from one factor group to another, as well as the contributing changes in the built environment. Monitoring pedestrian traffic at count locations within close proximity of one another is expected to demonstrate the level of volatility in pedestrian volumes between nearby locations and can influence the site selection process used in non-motorized traffic monitoring programs. Focusing research on sidewalk traffic in an urban commercial district will address a weakness in pedestrian monitoring where counting has often been conducted on multi-use paths.

Additionally, conducting research in Winnipeg provides an opportunity to study seasonal trends in a colder Canadian city. Winnipeg has a humid continental climate that is characterized by large seasonal temperature differences, leading to winters that are much colder than most North American cities. By collecting data throughout an entire year, it is possible to evaluate the seasonal shifts in traffic patterns and identify the effect of Winnipeg's extreme climate on hourly, day-of-week, and monthly traffic patterns.

This research addresses gaps in pedestrian counting knowledge by conducting continuous counts using passive infrared counters on consecutive blocks along a corridor to investigate the impact of site selection on traffic patterns over a 12-month period.

1.3 APPROACH

This research explores pedestrian traffic patterns and volumes along a commercial district corridor by comparing temporal pedestrian traffic patterns at four consecutive mid-block counting locations. The sidewalk pedestrian traffic data used in this research was gathered using automated pedestrian counters to collect continuous hourly volumes and cleaned manually to remove atypical days. The traffic patterns and volumes were compared on an hourly, day-of-week, and monthly basis, and also between sites to demonstrate the shifts in traffic patterns along a corridor. Easily accessible data on the built environment was evaluated against pedestrian traffic characteristics in order to quantify the impact of features of the built environment on pedestrian traffic patterns and volumes.

1.4 OBJECTIVES AND SCOPE

The objective of this research is to analyze the variations in pedestrian travel patterns within a commercial entertainment district, and more specifically, along a corridor. This thesis has the following objectives:

i. Explore and evaluate the pedestrian travel patterns along a commercial corridor to determine variations of hourly, day-of-week, and monthly pedestrian volume distributions at different locations

ii. Investigate and quantify features in the built environment that could contribute to pedestrian traffic patterns,

iii. Compare trends in the built environment to shifts in pedestrian traffic characteristics to identify features that give rise to particular traffic pattern characteristics, and

iv. Present findings of characteristics to consider during the site selection stage of a pedestrian traffic monitoring project.

The scope of this research was constrained by the following factors:

- Pedestrians are defined as all people walking, in wheelchairs, or other form of non-motorized transportation that were detected by the APC while travelling on the sidewalk.
- The study area was located along Corydon Avenue, between Cockburn St. and Stafford St.
- Automated pedestrian counters were located on the North side of the street and were set up in mid-block locations appropriate for the use of Eco-Counter pyroelectric counters.

1.5 THESIS ORGANIZATION

Chapter 2 – Literature Review: This chapter provides a literature review detailing the relevant research in non-motorized traffic monitoring and methods used to estimate pedestrian volumes, with a focus on indirect methods that expand short term counts. In addition, current and previous research in pedestrian volumes and traffic patterns will be described, highlighting the variations in pedestrian volume distribution, by hour, day-of-week, and month, and the many factors that impact pedestrian volumes.

Chapter 3 – Methodology: This chapter presents the methodology used for this research, including site selection, instrument setup, and data collection and processing.

Chapter 4 – Analysis: This chapter describes the results of the following analyses: (1) the hourly, day-of-week, and monthly pedestrian traffic patterns found at each block of the study area; (2) the development of pedestrian traffic performance metrics to easily compare traffic characteristics between sites, and; (3) the correlation of features of the built environment with the established pedestrian traffic performance metrics.

Chapter 5 – Conclusion and opportunities for future research: This last chapter presents the key findings of the research and discusses areas of the research that would benefit from further research.

1.6 TERMINOLOGY

The following terms are used throughout this thesis.

Automated pedestrian counter (APC) - This is a device that automatically detects and logs the number of pedestrians that walk by.

City block – This can refer to a rectangular area, between surrounding streets. A city block also denotes the distance along a street between consecutive intersections.

High density pedestrian entertainment district (PED) – This type of area is denoted by the National Bicycle and Pedestrian Documentation Project (Alta Planning and Design, 2015) as having higher pedestrian density and some entertainment uses such as restaurants.

Monthly average daily pedestrian traffic (MADPT) – This is a measure of the average volume of daily pedestrian traffic in a month. A total of 12 MADPT values exist for one year of data.

Monthly average day of week pedestrian traffic (MADWPT) – This is a measure of the average volume of daily pedestrian traffic on a particular day of week and month. A total of 84 MADWPT values exist for one year of data.

Pedestrian traffic pattern – This characteristic of a count location is the particular temporal distribution of pedestrian traffic, analysed by hour of day, day of week, or month.

2 LITERATURE REVIEW

This chapter presents the results from a review of existing research about pedestrian traffic monitoring. This chapter addresses available automated pedestrian counting technologies, methods of expanding short term counts, factors that influence pedestrian traffic, and pedestrian traffic patterns.

2.1 COUNTING METHODS

Several different counting technologies have been developed to monitor pedestrian traffic. Due to the numerous types of APCs, count duration is no longer limited by staff hours during manual counts. Although APCs permit continuous counts where manual counts cannot, manual counting and APC technologies both provide many unique advantages. The lack of time and money are the two most common deterrents when it comes to collecting more non-motorized traffic data (National Cooperative Highway Research Program, 2014).

2.1.1 Manual Counting

Manual counting is one of the simplest and most accurate methods of counting pedestrians. The only equipment required is a handheld counter or pencil and paper. With a handheld counter, a person can count up to 4,000 pedestrians an hour (Schweizer, 2005). Other benefits of manual counting are the ability to record pedestrian characteristics such as gender or age, and the ability to count bicycles and motor vehicles at the same time. The person counting can also often provide explanations for irregularities in count data or special events.

A main disadvantage of manual counting is the time required by staff. Although equipment costs are minimal, the hourly cost of having staff performing counts can add up quickly. The person who is counting must also be very reliable in that they will be punctual and alert throughout the entire count duration. Longer duration counts may become less accurate as time goes on, as the observer becomes fatigued (Schneider, Arnold, & Ragland, 2009A).

2.1.2 Passive Infrared

Passive infrared counters identify pedestrians from the body heat emitted as they walk past. If the temperature exceeds a certain threshold, the counter is triggered. The use of double pyroelectric sensors allows the device to determine direction of travel. Passive infrared technologies are commonly used for counting pedestrians because they are portable, easy to set up, and have an unobtrusive appearance (Federal Highway Administration, 2013).

A passive infrared counter may not be able to distinguish between one or more pedestrians travelling in close proximity, and therefore generally underestimate pedestrian volumes (Bu, Greene-Roesel, Diogenes, & Ragland, 2007). The Traffic Monitoring Guide indicates that passive infrared counters cannot distinguish between cyclists and pedestrians, and error may be affected by weather (Federal Highway Administration, 2013). When the ambient air temperature approaches body temperature, the sensor has more difficulty in detecting pedestrians. In addition, direct sunlight may lead to false counts for the counter.

2.1.3 Active Infrared

Active infrared counters, or infrared beam counters, use a transmitter and receiver to count pedestrians. The transmitter emits an infrared beam that is picked up by the receiver. When a solid object, such as a pedestrian, passes between the transmitter and receiver, the beam is interrupted and a pedestrian is identified by the data logger. Main benefits of the active infrared counter are its low power consumption, its ability to detect direction, and its high portability.

Bu et al. (2007) identified two disadvantages of using an active infrared counter. The first of which is the counter's inability to differentiate between pedestrians and other objects. Vehicles, raindrops, or insects can elicit a response from the counter. The second disadvantage is that the transmitter and receiver need to be aligned very carefully. Any disturbance to the two components may position them in a way that the receiver does not receive the infrared beam from the transmitter. For these reasons, active infrared counters are popular for indoor use. Active infrared counters are unable to count multiple pedestrians if they cross the beam simultaneously (Wang, Lindsey, Hankey, & Hoff, 2013).

2.1.4 Laser Sensors

Laser scanner sensors work by emitting infrared pulses and detecting the reflected pulses. The distance of the object from the laser scanner is proportional to the time it takes for the reflected pulse to be detected. The laser "image" is then analyzed and objects are classified according to their characteristics. Horizontal laser scanners can detect and count pedestrians within a 15 m range, while vertical laser scanners can cover a path with a width of 26 m and provide directional counts (Bu, Greene-Roesel, Diogenes, & Ragland, 2007). Additionally, vertical laser scanners have the added benefit of being able to classify pedestrians based on their height, and can distinguish between pedestrians travelling side-by-side (Lovas & Barsi, 2015).

Laser scanners have the disadvantage that their performance may be reduced in poor weather conditions. Fog and snow may limit the detection range of scanners. Due to the complexity of processing the laser image, a dedicated CPU (central processing unit) could be required for each laser scanner. Laser scanners have difficulty making the distinction between pedestrians travelling in pairs or larger groups, and have high costs for the equipment and batteries (Schweizer, 2005). Lastly, laser scanners require a dedicated power source and overhead infrastructure to be mounted on.

2.1.5 Piezoelectric Pad

Piezoelectricity is the charge that builds up in certain solid materials when mechanical pressure is applied. In piezoelectric pad counters, a mat is created using a material that when stepped on, produces an electrical signal. To reduce the occurrences of pedestrians stepping around the pads, placement is recommended where pedestrians are channeled into a crossing. In addition, many piezoelectric pad counters can be utilized together for a larger coverage area (Bu, Greene-Roesel, Diogenes, & Ragland, 2007). Multiple steps by the same pedestrian can be accommodated through a timing system to prevent overestimating pedestrian volumes.

The main disadvantage of piezoelectric pads is the installation, which can be both expensive and disruptive when installed beneath pavement.

2.2 METHODS FOR EXPANDING SHORT TERM COUNTS

Various methodologies have been developed to expand short term non-motorized traffic counts. The expansion of short term vehicle counts to AADT has become an established practice in motorized traffic monitoring across North America (Federal Highway Administration, 2013). Due to the costs and time required for long term continuous pedestrian counts, estimates expanded from short term counts could be a feasible alternative for the determination of long term or average daily pedestrian volumes. Expansion methods have been developed for short term pedestrian counts that are based on vehicular traffic, or focus on a variety of different factors that influence pedestrian travel patterns and volumes.

- Milligan, Poapst, & Montufar (2013) compared the accuracy of using a composite of pedestrian counts from other cities to the use of local vehicle counts to generate annual estimates of pedestrian traffic. A main goal of the study was to evaluate the application of temporal factors from the National Bicycle and Pedestrian Documentation Project to expand short term counts for use in safety performance measurement and analysis. The research developed hourly, day-of-week, and month-of-year temporal patterns for pedestrian crossing volumes from continuous video data covering 12 months at an intersection crosswalk in downtown Winnipeg, Canada.

  From the continuous video data, 200 2-hour short term counts were sampled. Each of the short term counts were expanded using each of the NBPD method and the Vehicle Factors method. These estimates were compared to the reference value, which was calculated by averaging the amount of pedestrian activity over all 84 days of video data and multiplying it by 365. Overall, the Vehicle Factors method resulted in the best precision and accuracy when compared to the NBPD method. However, the range of errors was still high and errors of around 50%, in either direction, were not out of the ordinary.

- Nordback, Bahrami, & Marshall (2014) compared non-motorized and motorized traffic patterns at four test locations in Colorado. In this study, the normalized hourly, daily, and monthly traffic for both non-motorized and motorized were plotted and compared with one another. Generally, the motorized and non-motorized traffic did not share the same traffic patterns, despite coming from the same geographic area or corridor. Hourly patterns did not show a strong correlation with the exception of the one non-motorized count with the strongest commuter pattern. Daily traffic patterns were not well correlated either, even producing an inverse correlation where high weekday counts were paired with high weekend counts. Lastly, monthly patterns showed the strongest correlation of the three types of comparisons. However, non-motorized volumes fluctuated significantly more on a seasonal basis than motorized traffic. Overall, the research suggested that motorized traffic patterns are not a good indicator of non-motorized activity. In the event motorized traffic patterns are used to expand non-motorized counts, proximity or sharing the same corridor are not adequate reasons to select a specific factor group.

- Schneider, Arnold, & Ragland (2009A) presented a methodology for estimating weekly pedestrian intersection crossing volumes from 2 hour short term counts. In the study, a sample of 50 intersections in Alameda County, California, were subject to 2 hour counts in the months of April, May, and June. Five infrared sensors were shared between 13 sites to generate travel patterns due to time-of-day, weather, and surrounding land use. The adjustment factors created from the sensor data were used to expand the manual counts to weekly volumes. Manual counts were completed on Tuesday, Wednesday, or Thursdays because they have the most consistent travel patterns, week over week, and on Saturdays. In addition, counts were only taken from 9 to 11 a.m., 12 to 2 p.m., and 3 to 5 p.m. The five automated counters were used to identify differences in travel patterns by time, day of week, weather condition, and location type.

Each intersection was counted at two different time intervals and extrapolated to weekly volumes using the factors generated from the automatic counter data. These two weekly volumes were then averaged out, resulting in a final weekly pedestrian volume estimate. The study produced preliminary adjustment factors for Alameda County, but more research is needed to evaluate the accuracy of the factors in different settings and conditions.

- Schneider, Arnold, & Ragland (2009B) presented a preliminary model of pedestrian intersection crossing volumes. The pedestrian crossing model was developed using pedestrian volume data collected from 50 intersections in Alameda County, California. The intersections were strategically selected to account for all possible combinations of median income level, population density, and proximity to commercial property. Pedestrians were counted if they crossed within a crosswalk or within 50 ft. of either side of a crosswalk. Two manual counts were completed at each site: one on a weekday, and one on a Saturday. Weekday counts were conducted on Tuesday, Wednesday, or Thursday because they have the most consistent travel patterns, week over week. In addition, counts were only taken from 9 to 11 a.m., 12 to 2 p.m., and 3 to 5 p.m. Eco-counter dual infrared pyroelectric pedestrian counters were set up at 13 of the 50 sites and were used to extrapolate the 2-hour counts to daily and weekly volumes.

  Three models were developed based on the weekly counts and a variety of land use variables, transportation system variables, neighbourhood socioeconomic variables, and intersection site variables. The recommended model was selected due to its good overall model fit, statistically significant and independent variables, and its ability to be estimated using readily-available data. The model includes the following variables: total population within 0.5 mi of the intersection, total employment within 0.25 mi of the intersection, number of commercial retail properties within 0.25 mi of the intersection, and the number of regional transit stations within 0.10 mi of the intersection. During validation, the pilot model estimated historical counts to within 50% at 30 of 46 comparison intersections.

2.3 FACTORS AFFECTING PEDESTRIAN VOLUMES

Many studies have investigated the factors that influence pedestrian traffic patterns and volumes. Understanding the reasons why people walk, where people walk, and when people walk, will improve accuracy of methods to estimate pedestrian volumes.

- Greenwald and Boarnet (2001) analyzed non-work walking travel in Portland, Oregon. The study made use of two models to estimate the number of non-work trips made by an individual, using input collected from socio-demographic data, trip distances and speeds, and the nature of related activities. The results of the models showed that the impact of density on non-work walking trips depends on the local built environment rather than on a regional scale. This differs significantly with non-work automobile trips, which rely more on regional land use traits. Another finding of the study suggests trip distance is the most important determinant of walking behaviour. People are more likely to walk for trips of shorter distances.

- Miranda-Moreno and Chapman Lahti (2013) investigated the impact of weather on pedestrian volumes on sidewalks in Montreal, Canada. In the study, five Eco-Counter Pyro electric, short-range sensors were installed at five locations over a period of twelve months. Three of the counters were located on sidewalks with low pedestrian volumes and moderate land use mixes, whereas the other two were installed on high-volume streets in downtown Montreal. The classical land use mix index was used to confirm the difference between the two land uses in the study. The seasons were split between temperate and winter months, with the difference being winter months had an average monthly temperature below zero degrees Celsius. Weekdays and weekends were analyzed separately because of their different traffic patterns. In addition, periods from 10 p.m. to 6 a.m. were left out of the study due to low count volumes.

Count volumes in the winter were lower than in the temperate months; however, the hourly distributions remained consistent. The average hourly pedestrian volumes over all five locations had three peaks on weekdays; at 8 a.m., 12 p.m., and 5 p.m. The authors noticed the three-peak daily pattern was evident in the counters located in downtown Montreal. Both downtown locations had a significant reduction in pedestrian activity on weekends. It was found that the built environment affects the volume of pedestrian activity as well as the hourly patterns.

- Aultman-Hall, Lane, & Lambert (2009) evaluated the impact of weather and season on pedestrian traffic volumes in Montpelier, Vermont. The study used a single Eco-Counter pyro double middle range device to count pedestrians travelling on a downtown sidewalk for a one year period. The automated pedestrian counts were used in conjunction with weather data from the National Climatic Data Center. The temperature, relative humidity, precipitation, and wind speed were recorded. Due to low volumes at night, only the period of 10 a.m. to 6 p.m. was estimated in the regression models.

The research suggests that season and weather affect the level of pedestrian traffic in downtown Montpelier. Precipitation reduces the average hourly volume by 13% while volumes are reduced by 16% during winter months. Weather variables contribute to a maximum of 30% of variation in hourly volumes. Additionally, the hourly distribution does not feature a.m. or p.m. peaks, but rather a single peak at 1 p.m. The single-peak hourly distribution in downtown Montpelier contrasts with results from downtown Montreal by Miranda-Moreno (2013), suggesting that pedestrian volumes are very site specific.

- Hankey et al. analyzed a set of bicycle and pedestrian counts taken at 259 locations in Minneapolis (Hankey, et al., 2012). All counts were taken on weekdays during the month of September from 2007 to 2010. Of these counts, 43 were 12-hour counts (6:30 a.m. to 6:30 p.m.), while the rest were mostly 2-hour counts. Separate scaling factors were developed for bicycles and pedestrians to estimate 12-hour volumes using hourly counts. The 12-hour volumes were used to develop ordinary least squares and negative binomial regression models for estimating bicycle and pedestrian volumes over the same 12-hour period.

  The research showed that average 12-hour counts can be predicted with similar reliability using one or two hour, peak hour counts. The models developed to estimate 12-hour volumes indicate that the correlates used to estimate bicycle and pedestrian traffic vary by mode and model. Significant correlates included weather, built environment, and socio-demographic variables. The resulting models can be used to estimate non-motorized traffic on streets where counts are unavailable or to estimate changes to non-motorized traffic levels due to variations in the built environment.

- Lerman and Omer (2016) compared pedestrian movement in traditional and contemporary urban areas in Tel Aviv. Four pairs of adjacent contemporary and traditional neighbourhoods were analysed to determine the build environment factors that influence pedestrian traffic volumes. Manual five and ten minute counts were taken at several locations within each area between the hours of 3 p.m. and 8 p.m. on sunny weekdays.

  This research analysed spatial, functional, physical, and demographic variables of the built environment, demonstrating that commercial land uses are related to greater pedestrian volumes, and spatial structure, such as road connectivity, have significant impacts on pedestrian traffic.

2.4 TRAFFIC PATTERNS FOR PEDESTRIANS

Expanding short term counts using factors requires the assignment of a traffic pattern group to the count location in order to select the appropriate factors. Traditionally, identified traffic patterns for non-motorized traffic have included a mix of commuter, recreational, and utilitarian trips (Federal Highway Administration, 2013). However, the majority of research on non-motorized traffic has focused on facilities that are easiest to monitor, like multi-use paths, and relatively little is known about pedestrian traffic on sidewalks (Lindsey, Nordback, & Figliozzi, 2014).

- Turner, Qu, & Lasley (2012) identified three traffic pattern groups for non-motorized traffic in Colorado. In the study, the authors analyzed data from eight existing Colorado Department of Transportation (CDOT) permanent count locations and recommended three factor groups: Commuter and work/school-based trips, recreation/utilitarian, and a third category, mixed trip purposes. Commuter and work/school-based trips were characterized as having highest peaks in the morning and evening, higher weekday than weekend traffic, and relatively consistent traffic through all seasons. The recreation/utilitarian factor group has a peak at mid-day or no peak at all, has higher weekend traffic compared to weekday, and higher traffic during warmer months. Lastly, the mixed trip factor group is a middle ground between the two other groups.

- Lindsey, Nordback, & Figliozzi (2014) summarized non-motorized traffic monitoring in Colorado, Minnesota, and Oregon. The departments of transportation and research in these states identified a combined nine traffic patterns, including some overlap. These patterns include commuter, mixed commuter, mixed recreation, and recreation/non-commuter patterns. In Colorado, mountain traffic patterns were also observed. All three states focus on multiuse paths, which could influence the observed traffic patterns.

Existing research has relied on assumptions of consistent hourly traffic patterns at different locations. Instead of collecting a full 24 hours of pedestrian traffic data, many jurisdictions collect pedestrian data over a specific portion of the day and assume the percentage of daily traffic occurring outside of the count duration remains consistent between comparison sites or when applying expansion factors.

- Hankey et al. (2012) developed models of bicycle and pedestrian traffic in Minneapolis using 12hr counts from 6:30 a.m. to 6:30 p.m. during weekdays in September. Scaling factors were developed to normalize hourly counts to 12 hr counts. This study did not analyse the relationship between the true daily traffic volumes and the 12 hour traffic volumes in the study.

- Zegeer, Opiela, & Cynecki (1985) collected data over several study sites in Seattle to determine a peak 12 hr period of pedestrian traffic. It was found that the peak 12 hour volumes occurred between 7 a.m. and 7 p.m., and accounted for an average of 86% of daily traffic. This benchmark was applied to central business district (CBD), outlying business district (OBD), and residential area counts to expand hourly volumes as a percent of 12-hour volumes to percentages of 24-hour volumes. Limited research on this topic has been undertaken in the past 30 years. It can be expected that pedestrian traffic characteristics have changed since this was published.

- The National Bicycle and Pedestrian Documentation (NBPD) Project recommends jurisdictions to apply a factor of 1.05 to expand non-motorized counts collected from 6 a.m. to 11 p.m. to daily volumes estimates (Alta Planning and Design, 2009). The adjustment factor of 1.05 is intended to account for the night time traffic that is not recorded. It is applied to weekdays, weekends, multi-use paths, and high-density pedestrian and entertainment districts alike. The factor of 1.05 is recommended for use at all sites unless there is evidence that there is no traffic between those hours. No special recommendations are made for locations with high late night traffic volumes.

3 METHODOLOGY

This chapter presents the methodology developed and applied in this research, from selecting the equipment used in the study to processing the collected data. This chapter discusses; (1) the selection of the technology and manufacturer of the APC to be used in the study, (2) the choice of the study corridor, and specific counting locations along it, (3) the data collection system, including the data sources for weather, built environment characteristics, and APC counts, (4) the method applied to verify the performance of the counters, and (5) the processes used to clean the dataset of APC malfunctions and erroneous volumes.

3.1 SELECTION OF COUNTER FOR ANALYSIS

There are a wide variety of technologies available for automated pedestrian counting, as described in Chapter 2.

Passive infrared APCs were selected for this research for their many benefits over other technologies and their suitability for the selected counting locations. Passive infrared counters were chosen because of their portability and ease of setup, their cost, and the extensive literature available regarding accuracy and calibration. Additionally, passive infrared counters can be easily mounted onto sign posts, street lights, or trees, without requiring a receiver to be setup directly across the sidewalk.

Eco-Counter PYRO sensors were selected based on ease of installation, longer battery life, high data storage, automatic wireless data transmission, and their application in previous research in Winnipeg and North America.

3.2 SELECTION OF CORRIDOR AND SITES FOR DATA COLLECTION

A four block segment of Corydon Avenue was selected as the study area for this research. The segment runs East-West from Cockburn Street to Stafford Street, as shown in Figure 1, and an APC was installed on each of the four blocks within the study area. Three of the four APC’s collected data for 12 months and the remaining APC was installed later than the others and counted for 6 months. Corydon Ave. was chosen for this study because of its high evening pedestrian traffic, relative to daytime traffic flows. Summer and fall pedestrian traffic along Corydon had been monitored by an APC prior to the start of this study as part of research by Poapst (2015). This preliminary count suggested the presence of an entertainment area traffic pattern, characterized by high evening peaks in pedestrian traffic volumes. Many commercial properties with late business hours, such as restaurants and lounges, are located along the corridor and contribute to high pedestrian volumes outside of typical commuting peak hours, forming a distinct hourly traffic pattern. Corydon Avenue is a four lane major arterial in Winnipeg with two lanes in each direction. The average weekday daily traffic along this segment of Corydon Avenue is 27100 vehicles (City of Winnipeg Public Works Department, 2013).

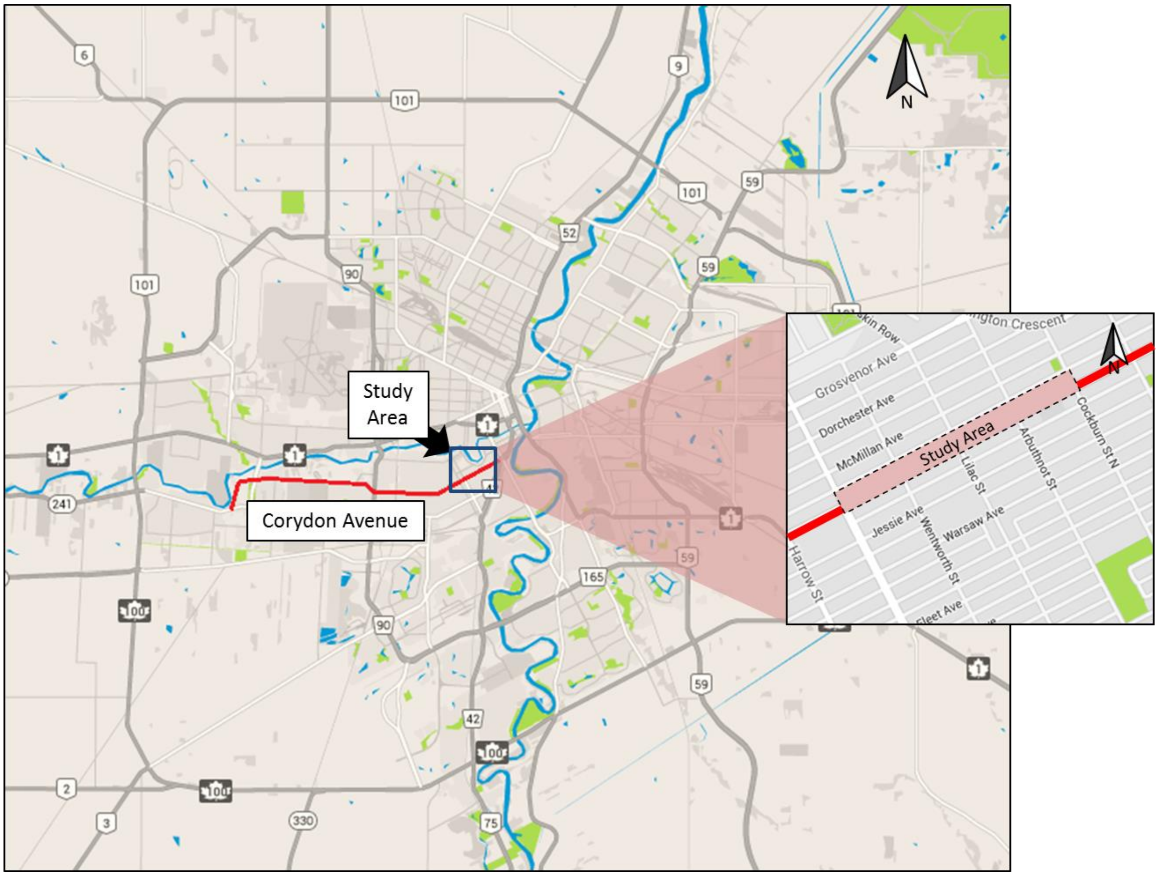


Figure 1: Study Area in Winnipeg, Canada

APCs are most effective when pedestrians are channeled along a path. An ideal scenario would have the counter facing a windowless wall directly along the sidewalk. With passive infrared sensors, it is crucial that pedestrians are not stopping or loitering in front of the counter. Therefore, sites were deemed unsuitable for monitoring when benches or other features that encourage sojourning were within sight of the APC's sensors. Being in a popular entertainment area of the city, restaurant patios, sidewalk benches, and business entrances are common obstacles within the corridor that are important to consider when installing the selected APC. The counters were mounted on sign posts, street lights, or trees along the outside edge of the sidewalk, so a lack of any of the aforementioned items prevented the installation of an APC at that location.

The segment of Corydon Ave between Cockburn St and Stafford St was selected due to each of the four blocks within the segment having sites optimal for installing the APC. The block east of Cockburn St has many restaurants and patios, but the patios and property fronts made it difficult to mount an APC without sensor interference. It was important that study locations were on consecutive blocks in order to focus on the changes in pedestrian traffic that can occur within short distances. The four blocks along Corydon Ave, west of Cockburn St, provide a segment of four consecutive and easily monitored blocks with at least one block having an entertainment area traffic pattern. The four count locations are labeled Corydon 1 to Corydon 4, as shown in Figure 2.

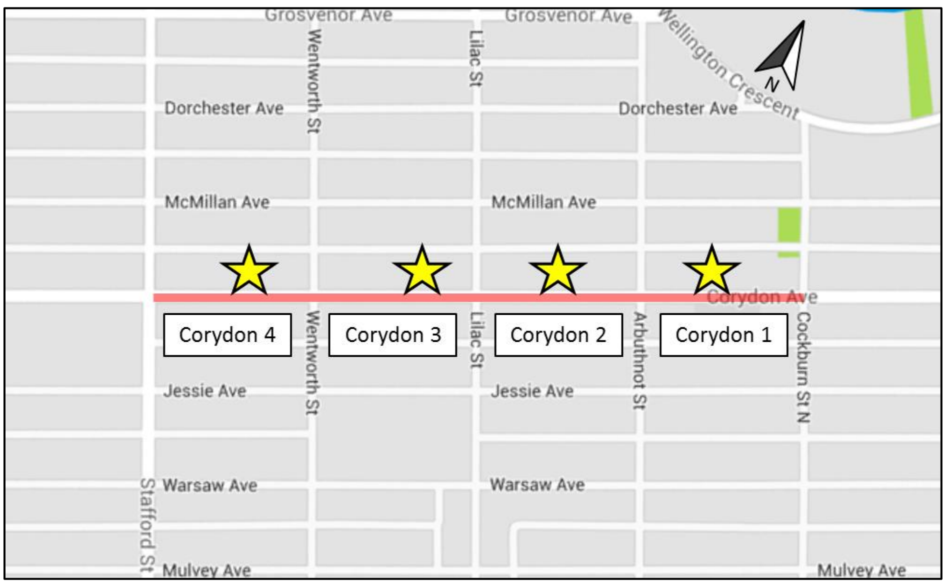


Figure 2: APC Locations in Study Area

Only pedestrian traffic on the north sidewalk along Corydon Ave was monitored. Past research in Winnipeg indicates hourly pedestrian traffic patterns are influenced differently by adjacent sidewalks (Poapst, 2015). The built environment characteristics along sidewalks on opposing sides of the road can contribute to different traffic patterns and volumes on the adjacent sidewalks. As pedestrians on either side of the road may behave differently, the traffic on the south Corydon sidewalk was omitted from the scope of this research.

3.3 DATA COLLECTION SYSTEM

The data collection system included four primary components: (1) the setup and installation of the data collection system; (2) pedestrian traffic data collected by the APCs; (3) online weather data from Environment Canada, and; (4) manually collected information on the counting sites and surrounding environment. Together, these components provide the data used in the processing and analysis of this research

3.3.1 Field Equipment Setup

The Eco-Counter sensors were mounted on sign posts, trees, or street lights located near the outside edge of the sidewalk. The counters were positioned so their sensors were directed across the sidewalk, and angled slightly if necessary. Locations were selected so the counter was opposite a solid building wall to reduce the likelihood of other objects interfering or being picked up by the sensor. It was important that the post where the counters were mounted was near the edge of the sidewalk closest to the road, to restrict pedestrians from walking around the counter and avoiding detection. APCs were positioned to avoid business entrances, and benches, and were installed away from bus stops as to avoid loitering pedestrians waiting for their bus. As recommended by the manufacturer, the counters were positioned at a height of 70 cm above the ground (Eco-counter, 2012). Steel hose clamps were used to secure the counter to the pole or tree. The installation of each counter is shown in Figure 3.

Figure 3: APC Installations

3.3.2 Field Data Collection

The APCs were installed along the study corridor for a minimum of seven months. Three of the four counters collected data for 12 consecutive months. The furthest west counter was only located along the study corridor for seven months, from January to July. Prior to being installed at the Corydon 4 location, this counter was being used by the City of Winnipeg and was unavailable for use in this research until January 2015. The APCs collected pedestrian volumes and automatically uploaded data to Eco-Counter's own servers every night. Data could be accessed and analyzed using Eco-Counter's online software platform Eco-Visio to view and analyze data in intervals ranging from 15 minute volumes to monthly, quarterly, or even annual volumes. Eco-visio allows users to export data to a spreadsheet file for further processing and analysis.

3.3.3 Weather Data Collection

Historical climate data was gathered from Environment Canada's website. The data used was collected from the weather station located at the Winnipeg James Armstrong Richardson International Airport. The collected data consisted of hourly weather conditions, temperature, and daily precipitation. Hourly precipitation was omitted in preference of daily precipitation due to data availability. Local weather stations accessible through Environment Canada did not have complete hourly precipitation totals; only hourly weather conditions.

This data collection follows the Traffic Monitoring Guide's recommendation of collecting precipitation, high temperatures, and low temperatures (Federal Highway Administration, 2013).

3.3.4 Site Characteristics Collection

Characteristics of the built environment surrounding each count location were recorded in order to identify factors contributing to the differences in traffic patterns between sites. Data collected was used to quantify entertainment businesses, by number of properties and property frontage, and multi-modal characteristics such as on-street parking and local bus routes and stops. Table 1 lists the built environment characteristics analysed in this research. Analysis considered these characteristics on a single-block basis, as well as three-block segments, in order to determine the reach of the characteristic's impacts.

Table 1: Built Environment Characteristics to be Analysed

Parameter	Units
Restaurants	#
Licensed restaurants	#
Total restaurant frontage	% of block length
Total licensed restaurant frontage	% of block length
On-street parking	% of block length
Bus stops and routes	#

For example, Figure 4 shows how built environment characteristics on the blocks adjacent to each counter were quantified. The Corydon 1 APC is located between Cockburn St. and Arbuthnot St. The Corydon 1 segment refers to the built environment characteristics between Hugo St. and Arbuthnot St. The built environment characteristics used in this research only include properties fronting on the sidewalk on which the APC is installed.

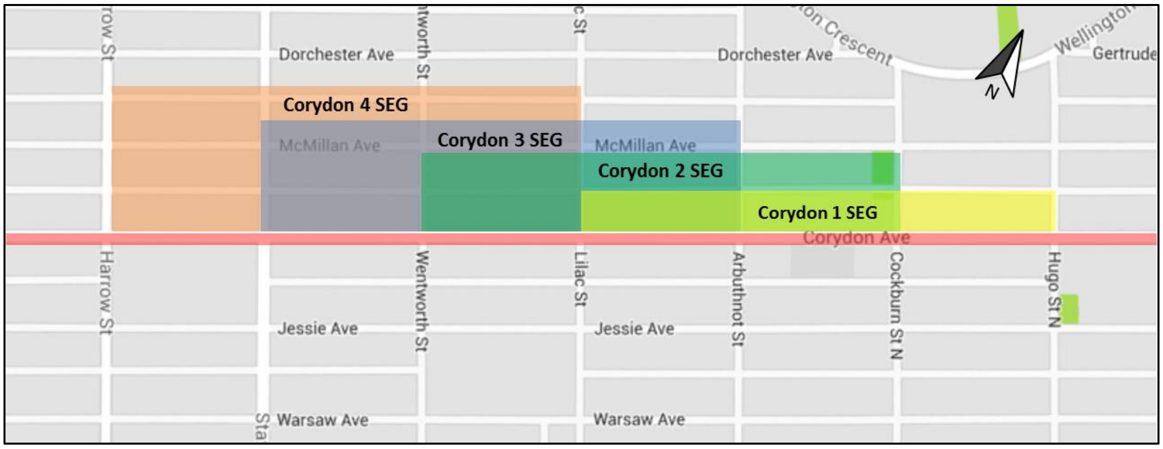


Figure 4: Corydon Segments for Analysing the Effects of the Built Environment

In this research, entertainment properties refer to businesses that are open late and become a common destination for evening pedestrian traffic. Entertainment properties include restaurants, bars, and lounges, but exclude services like 24/7 convenience stores, businesses offering services like dry-cleaning, and small retail stores that remain open for the evening. The intention of noting the number of entertainment properties is to tabulate the number of properties that attract evening traffic contributing to traffic peaks outside of typical daytime business hours. Entertainment properties were classified as restaurants and licensed restaurants. While restaurants included all establishments that served food and drink, licensed restaurants only included establishments that were licensed to serve alcohol. Both restaurants and licensed restaurants were analysed to determine if one was a stronger indicator of pedestrian traffic pattern characteristics than the other.

Property frontage measurements, typically used for property tax calculations, were found on the City of Winnipeg's assessment and taxation webpage. Property frontage refers to the length of the boundary between a plot of land and the road that it faces. It is not uncommon for multiple small businesses to operate on the same property. In these situations, Google Maps was used to estimate the frontage of each business. Property frontage measurements are easily available and could improve estimates of a businesses impact on pedestrian patterns by treating properties of varying sizes differently.

On-street parking signage along each block was identified through site visits and distances were measured in Google Maps. Along Corydon Ave, when parking was permitted during the day (9 a.m. to 5:30 p.m.), there was a 2 hour limit. The total length of permitted parking used for this research included the 2 hour limits, and locations where parking was only restricted for a specific 2 hour period during the day, such as loading zones from 7 to 9 a.m.. When a fire hydrant was located adjacent to on-street parking, six metres was deducted from the calculated on-street parking length to account for parking laws (Province of Manitoba, 2015). On-street parking on both sides of the street was used because many drivers may park on one side of the street and then cross the street while walking to their destination. The length of permissible on-street parking was converted to a percentage of the block length for ease of comparing between locations. This means that if each direction of traffic had on-street parking along 75% of the block, the total on-street parking was 150% for the block. In this study, the city blocks were each approximately 152 m in length, from curb to curb.

The bus stops along the study corridor were another site characteristic documented in order to help analyze the shifts in pedestrian traffic patterns and volumes. The bus routes passing through with stops in the study area, as well as the location and frequency of the stops along the corridor were consistent. Only one bus route had stops in the study area, and it had a stop along each block. Busy bus stops may cause one block to see significantly higher traffic than an adjacent block if the APC is located close to the stop.

3.4 AUTOMATED PEDESTRIAN COUNTER VERIFICATION

Manual counts were conducted at each of the count locations to ensure proper APC installation and to determine if all the APCs performed to similar standards. The manual counts collected ground truth data and were used to evaluate the relative error of the APC data over varying volumes and time of day. Most of the manual counts were conducted at two locations; Corydon 1 and Corydon 3. This allowed the data collection efforts to focus on two sites instead of four, and collect larger samples at these sites. The Corydon 1 and Corydon 3 locations were chosen for their differences in pedestrian volumes and their spacing in the study area, amongst the four blocks. A total of 46 hours of manual counts were conducted at the Corydon 1 APC and 48 hours were conducted at the Corydon 3 APC.

During manual counts, an observer was stationed near the APC so that they would have clear sight lines of pedestrians approaching the counter from both directions. At all locations, on-street parking was available adjacent to the counter and offered a sheltered vantage point for manual counts in the winter. The manual counts collected data in hourly blocks and recorded the number of people that walked past the APCs in each hour.

The relative error was calculated for each hour of manual counts by comparing the number of detections recorded by the APC during that hour to the true volume of passing pedestrians according to the ground truth. The relative error was calculated as follows:

$$relative\ error = \frac{(APC\ detections - ground\ truth)}{ground\ truth}$$

The relative error was used to analyze the effect of time of day and volume on APC accuracy at each count location. A positive relative error denotes overcounting by the APC, while a negative relative error indicates undercounting. Each hour of ground truth data was used to determine the corresponding relative error. Each pair of values, the relative error and hour of day, was plotted to identify trends in APC error throughout the day. Overall, the average relative error was -18% at the Corydon 1 APC and -16% at the Corydon 3 APC. When averaging the absolute relative errors, the Corydon 1 and Corydon 3 APCs saw average absolute relative errors of 19% and 17%, respectively. This data indicates the passive infrared APCs frequently undercount, but there are instances of overcounting, agreeing with the findings of past research (Nytepchuk, 2015).

As described in Chapter 2.1.2, passive infrared counters are subject to undercounting due to pedestrian occlusion. When pedestrians walk beside one another, a passive infrared counter is likely to only detect one pedestrian rather than each pedestrian in the group. The relative error of the APCs at the Corydon 1 and Corydon 3 locations are shown over several hours of the day in Figure 5. The average relative error has a very weak correlation with the time of the day at both locations, and the relative error fluctuated significantly between different counts taken at the same time of day. The average level of undercounting does not follow a discernable pattern over the course of a day. Therefore, average APC accuracy was similar between sites and different hours of the day.

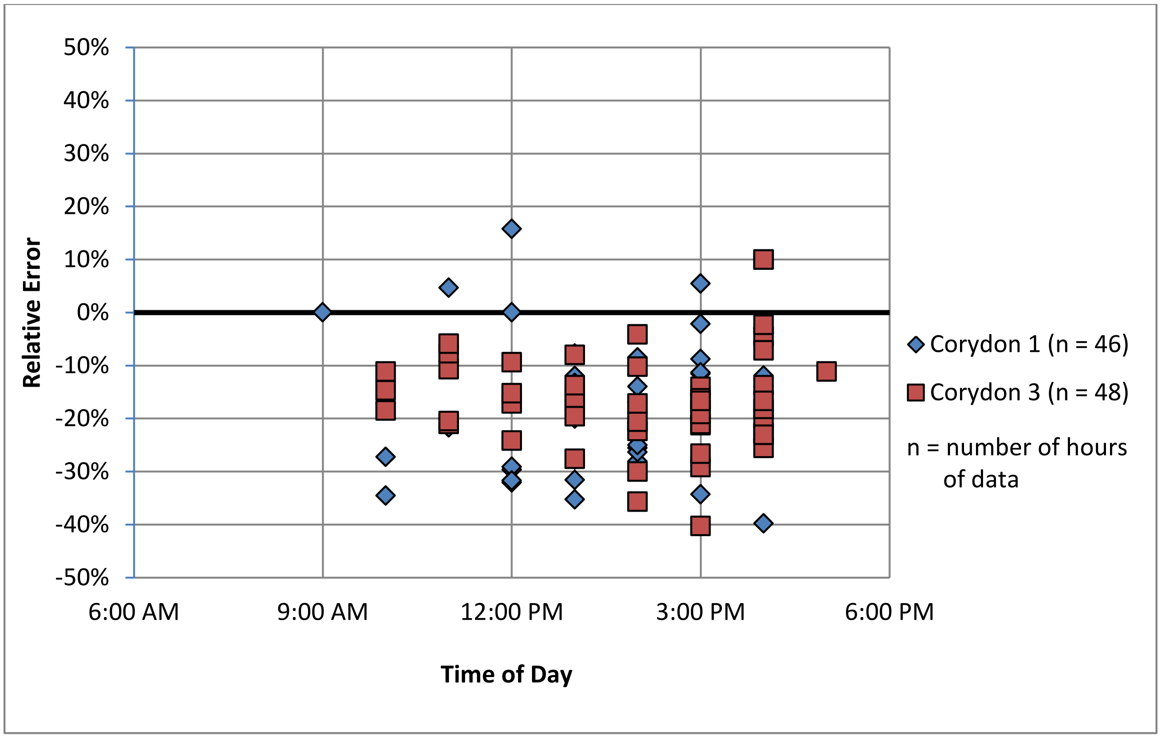


Figure 5: Relative Error of APCs throughout the Day

In addition to time of day, the APC relative error was plotted against hourly volumes to determine the effects of increased traffic on counter accuracy, as shown in Figure 6. Analysis at each count location showed that an increase in volume did not have a noticeable effect on counter accuracy, confirming the findings of Schneider, Arnold, & Ragland (2009A). The relative errors of the APCs appear to be randomly distributed, with instances of undercounting by 30% occurring at low and high pedestrian volumes, and overcounting events mixed throughout.

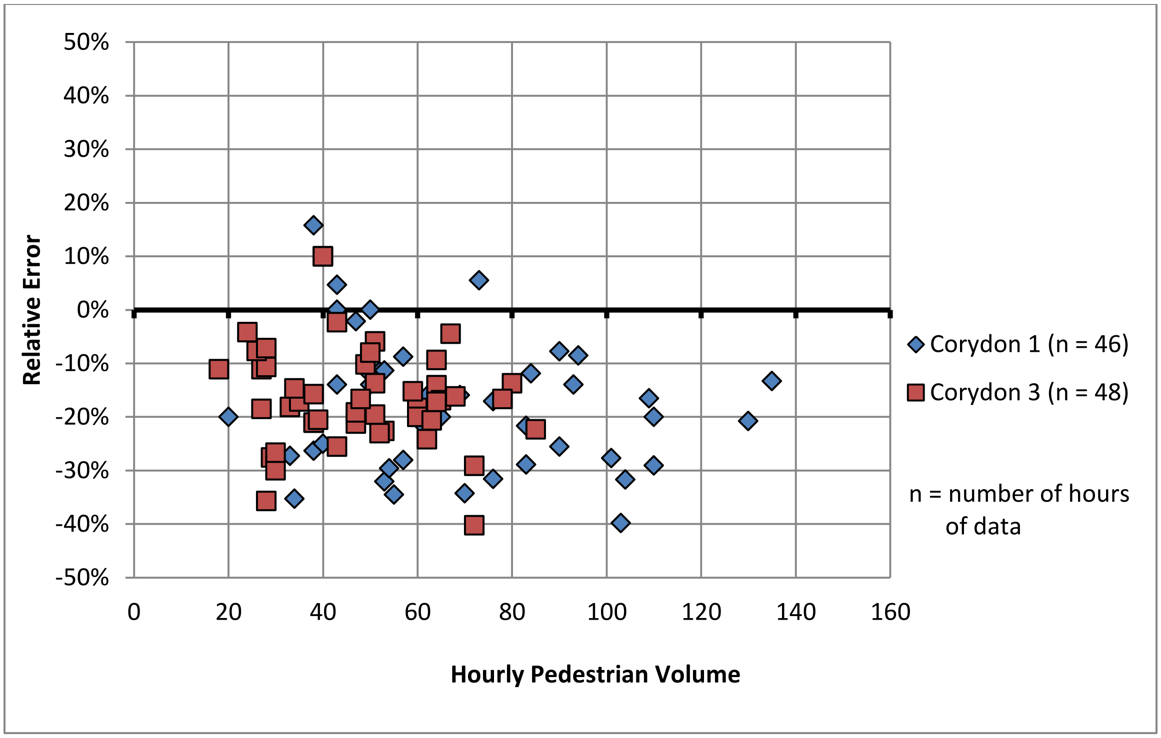


Figure 6: Relative Error of APCs at Different Volumes

The APCs at the Corydon 1 and Corydon 3 locations had a similar level of undercounting during the manual counts. The average rate of undercounting pedestrians was consistent over varying pedestrian volumes and time of day, indicating that occlusion rates are not noticeably different between the sites. The Corydon 2 and Corydon 4 APCs detected similar levels of pedestrian traffic as the Corydon 3 location, and are presumed to have similar occlusion rates as the Corydon 1 and 3 locations.

Correction factors are typically applied to counts to correct for the assumed counter error. With passive infrared counters, this error often stems from occlusion. Since the average relative error was similar between counters and across different volumes and time of day, the same correction factor would hypothetically be applied to every count in this research. As the analysis only compares pedestrian traffic characteristics between locations in the study area, correction factors would impact all of the counts proportionately and would not impact the relationships between traffic patterns and volumes. Therefore, correction factors were not developed for this research.

3.5 DATA PROCESSING

To prepare the collected data for analysis, the data had to be cleaned to remove erroneous counts, and compiled to determine average hourly counts for each day of week and month. These average values were used to replace select erroneous or missing data in the dataset during the data cleaning stage. This research followed the recommendations of the FHWA's Traffic Monitoring Guide for collecting non-motorized data in typical weather and using local judgement to decide whether to include days with inclement weather (2013).

3.5.1 Data Cleaning

The raw dataset was screened to produce a smaller and more stable dataset comprised of typical days. A typical day was considered to be a day with less than 1mm of rain, and not coinciding with a statutory holiday. As described in Chapter 2, rain has a significant effect on pedestrian activity. There are many other weather factors, besides precipitation, that affect pedestrian traffic volumes, including temperature, wind, and humidity (Miranda-Moreno & Chapman Lahti, 2013). Rain data was the only weather variable used during the data cleaning process because of its accessible data and binomial nature. Holidays were removed from the dataset due to their irregular pedestrian daily volumes and hourly traffic patterns.

3.5.1.1 Precipitation

The influence of all precipitation was analyzed over the course of the study duration. For each instance of precipitation, the daily volume was compared to the monthly average day of week pedestrian traffic (MADWPT) volume and used to calculate the change in daily volume to days with precipitation compared to days without. For example, if it rained on a Friday in June, that daily volume would be compared to the average of the other Fridays in June when it did not rain. This process was repeated for each station and then combined to form a larger dataset covering all stations.

There were 116 days with recorded precipitation over the 382 day study duration. Of the 116 days, 87 of the days had a maximum daily temperature greater than 0 °C, and the remaining 29 coincided with maximum daily temperatures of 0 °C or less. For the purposes of this research, precipitation on days with a maximum daily temperature greater than 0 °C was categorized as rain, and snow when the maximum daily temperature was 0 °C or less.

Over all the days with rain, the average deviation in daily volume from the MADWPT volume was a reduction of 8% as shown in Figure 7. High daily precipitation measurements correlated with larger reductions in daily pedestrian volumes relative to the MADWPT volumes.

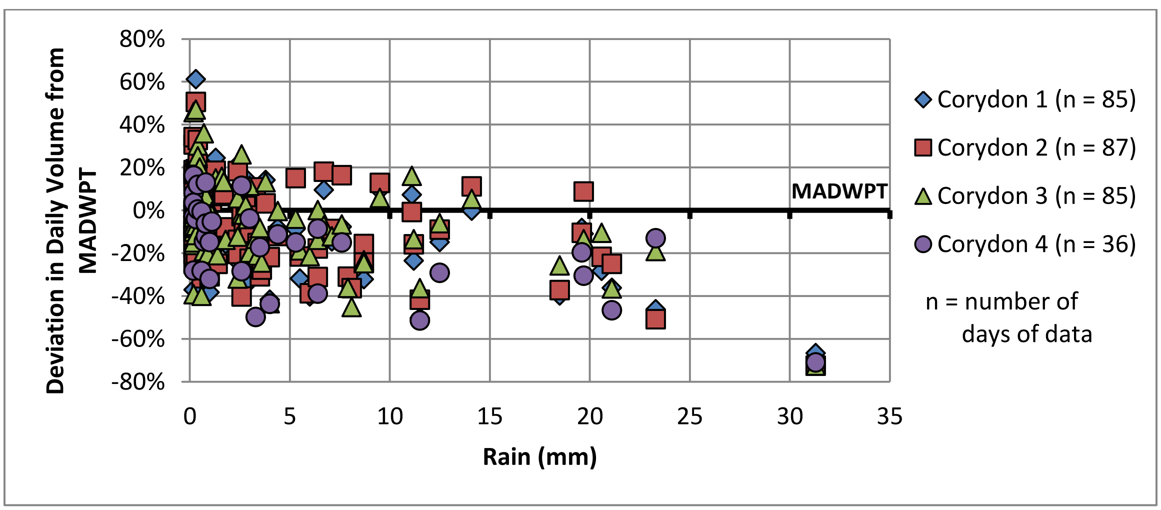


Figure 7: Effect of Rain on Daily Pedestrian Volumes

Looking at only days with less than 3 mm of rain, the average deviation in daily volume from the MADWPT volume was a reduction of only one percent. Figure 8 shows the deviation from the MADWPT for days with less than 3 mm of rain. On these days, the deviation in daily traffic from expected MADWPT ranged from a decrease of 40% to an increase of 61%. This suggests rain in small amounts does not have a consistent effect on daily pedestrian volumes, and these days could remain in the dataset for analysis.

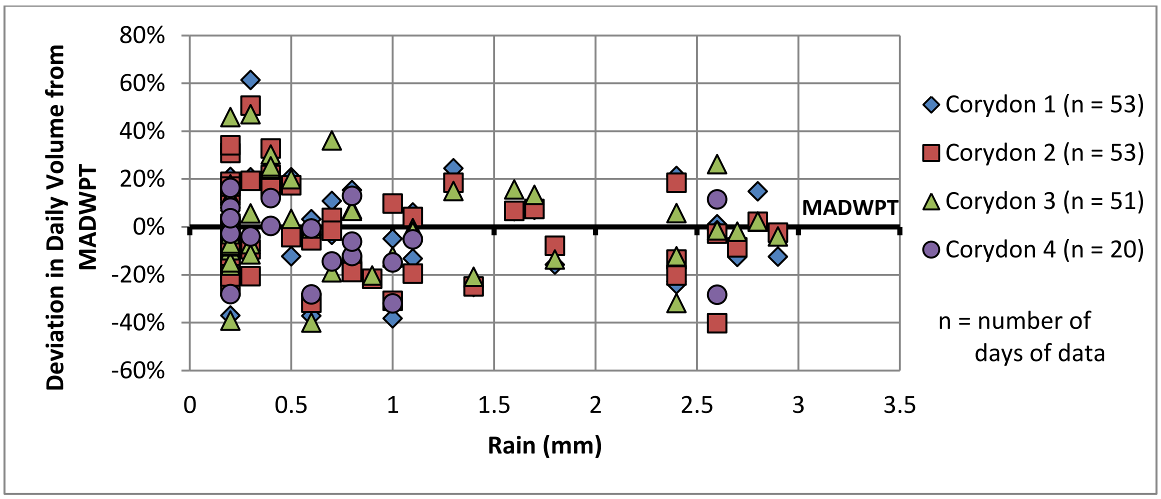


Figure 8: Effect of Less than 3 mm of Rain on Daily Pedestrian Volumes

Upon visual inspection of the hourly volumes on days with less than 3 mm of rain, larger volumes of precipitation had a noticeable effect on the hourly volume distribution of a day. For example, Thursday, April 30, 2015 saw 2.6 mm of rain in Winnipeg. Figure 9 shows the deviation in hourly traffic proportions at each of the APCs on this day compared to the average hourly traffic proportions of Thursdays in April, or the expected hourly traffic distribution. During the period of rain, from 6 p.m. to 10 p.m., there was an overall reduction in the proportion of daily traffic compared to the average hourly proportions for Thursdays in April. This deviation in hourly traffic distribution at all four sites suggests that rain may have impacted hourly traffic patterns even if daily pedestrian volumes were not reduced. Therefore, in order to avoid the effects of rain when comparing hourly traffic patterns, the cutoff threshold for maximum precipitation was reduced to a maximum of 1 mm for the research. This threshold allowed the inclusion of days with very little rain in the final dataset, effectively maintaining a large sample size while minimizing the influence of rain during analysis.

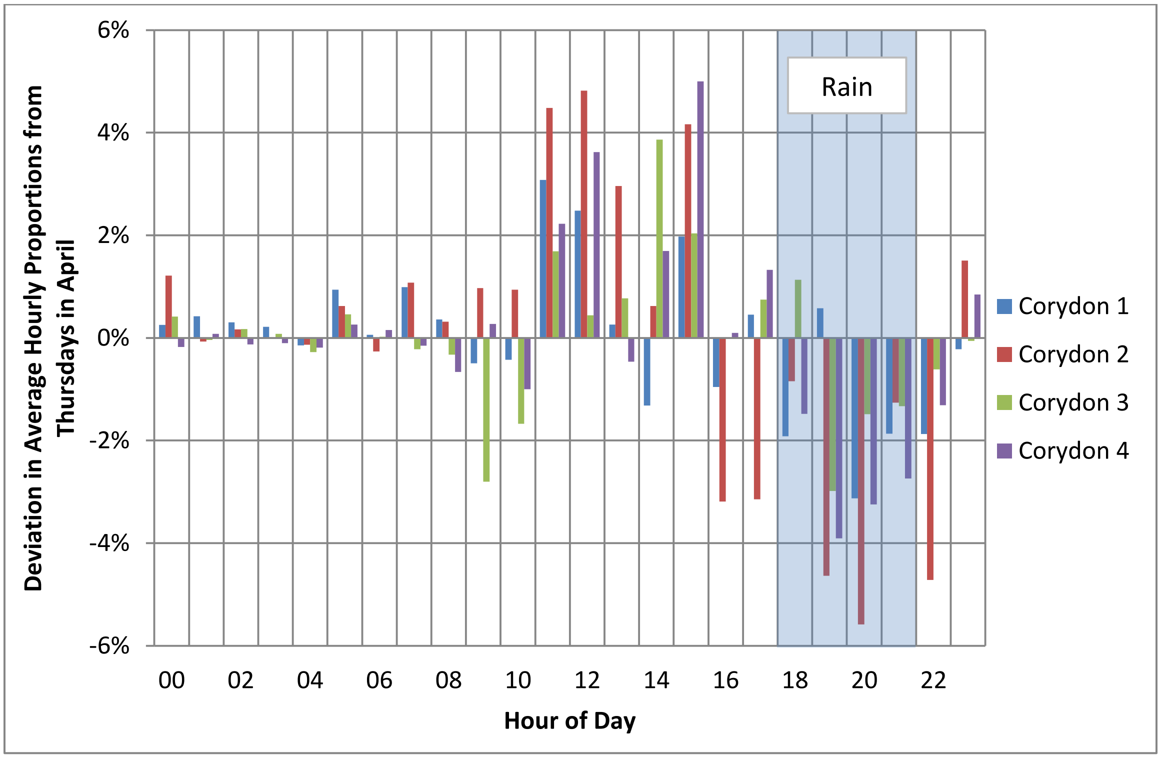


Figure 9: Impact of Rain on Hourly Traffic Distribution on April 30, 2015

A total of 51 days were removed from the dataset due to rain. There were no cases where all instances of a particular day of week were removed for a month. However, in June 2015, three of the four Saturdays had more than 1 mm of rainfall and were omitted from the final dataset, leaving a single Saturday of data in June.

Days with snow were included in the research. There was not a distinguishable trend between the amount of snow and the deviation in pedestrian volume from the MADWPT. Figure 10 shows the relationship between the amount of daily snowfall and the average deviation in daily pedestrian volume from the MADWPT. Due to 22 of the 29 days with snowfall having less than 1 cm of snow, average deviations are shown for each snow measurement and APC rather than a data point for every day with snow. The average deviation in daily pedestrian volume on days with snow across all four counting locations was a 7% reduction. Similar to rain, there was a large range in traffic deviations. The occurrence of snow did not have a heavy influence on hourly traffic, and was therefore retained in the dataset.

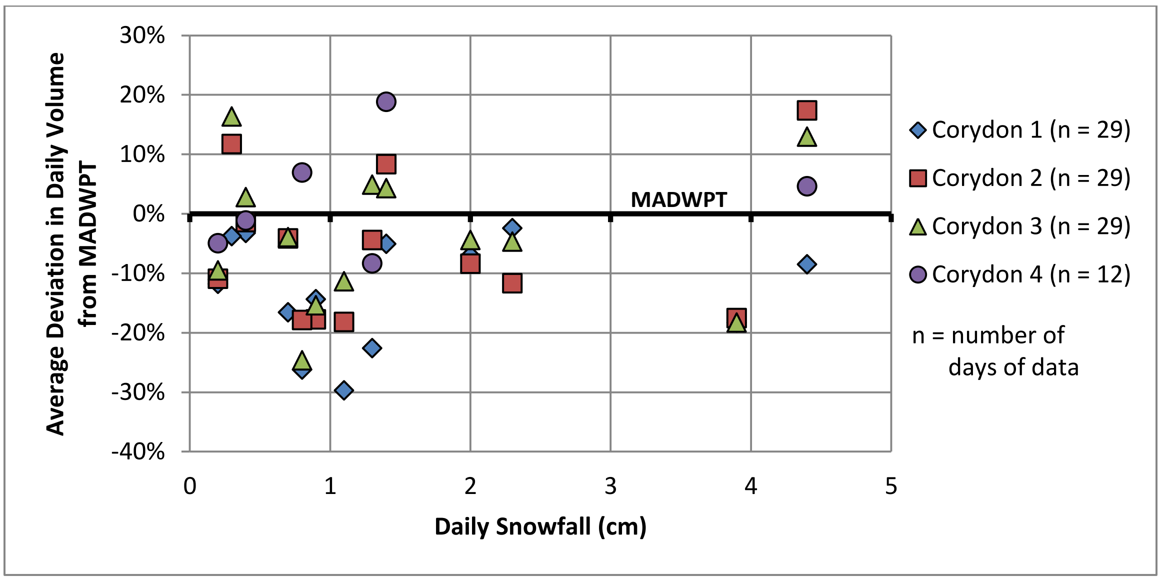


Figure 10: Effect of Snow on Daily Pedestrian Volumes

3.5.1.2 Holidays

During holidays, volumes may differ from the MADWPT volumes, and hourly traffic may differ from the expected hourly travel pattern (Aultman-Hall, Lane, & Lambert, 2009). On many holidays, businesses are closed, so there is a shift from commuting trips to other trip types. Data from holidays were removed from the study due to their expected difference from the MADWPTs. When evaluating the day of week traffic patterns, a count on a holiday could skew the proportion of weekly traffic on each day of the week, due to the increase or decrease in holiday traffic. This issue would impact the evaluation of day of week pedestrian traffic distributions from month to month. The following days from the study period were removed due to being statutory and civic holidays.

Table 2: Holidays Removed from Data Collection

Date	Holiday
Monday, August 4, 2014	Terry Fox Day
Monday, September 1, 2014	Labour Day
Monday, October 13, 2014	Thanksgiving
Thursday, December 25, 2014	Christmas Day
Thursday, January 1, 2015	New Year's Day
Monday, February 16, 2015	Louis Riel Day
Friday, April 3, 2015	Good Friday
Monday, May 18, 2015	Victoria Day
Wednesday, July 1, 2015	Canada Day

3.5.1.3 Data Replacement

The raw APC count data was exported to a spreadsheet from Eco-Visio, where the data was automatically uploaded from the APCs. The data was cleaned to eliminate hourly volumes with artificially high or low volumes. There are many factors or scenarios that could cause extreme undercounting, overcounting, or atypical pedestrian traffic. The process of cleaning the data consisted of two parts. The data was screened to highlight irregularities, and then manually checked to investigate possible explanations for flagged data. An automatic screening flagged hourly volumes that saw a sharp spike or decline in pedestrian traffic from the previous hour. Two criteria, shown in Table 3, needed to be met in order for the particular hourly volume to be flagged. An hourly volume was flagged if the volume was either more than double or less than half of the previous hour's pedestrian volume, and if the difference between consecutive hourly volumes was greater than 10.

Table 3: Flagging Criteria for Raw Data

Criterion 1	$2 * VOL_{i-1} > VOL_i > \frac{VOL_{i-1}}{2}$
Criterion 2	$\lvert VOL_i - VOL_{i-1} \rvert > 10$

The first criterion searches for large peaks or declines in hourly pedestrian volumes relative to adjacent hours. This allows expected gentle peaks in pedestrian traffic to occur without being highlighted, while still flagging larger inconsistencies.

The second criterion was used to avoid highlighting hours with very low volumes. At all study locations, hourly volumes would often decrease to less than five pedestrians per hour in the very early hours of the morning. By requiring the difference in hourly volumes to exceed 10, expected low hourly volumes were not flagged.

The second component of data cleaning consisted of manually screening the flagged data. When an hourly volume was flagged, its cell was highlighted in a spreadsheet containing hourly volumes from the entire duration of the study. The flagged data was manually checked to visually determine if it was an outlier in the context of the full day's pedestrian traffic. If the hourly volume still appeared to be an outlier, the 15 minute pedestrian volumes during that hour were examined to determine if there was a sudden spike or drop in the any of the 15 minute intervals. Often, 15 minute volumes indicated there was an incremental increase or decrease in traffic, suggesting the apparent spike or drop in pedestrian traffic was not due to a malfunction in the APC or pedestrians loitering in front of the sensor. Sudden large changes in the pedestrian volumes across

15 minute intervals were an indication that the APC malfunctioned or there was an interference with the sensor. These hourly volumes were not representative of the actual pedestrian traffic and were removed from the dataset.

Commonly flagged times were 7 a.m. and 9 a.m. on weekdays, when pedestrians are walking to work, 12 p.m. on weekdays during lunchtime traffic, and 2 a.m. on Saturdays and Sundays after bars and lounges close. Hourly volumes at these times were often flagged for their sudden changes in traffic volumes, but are easily explainable, justifying their inclusion in the dataset.

When an hourly count was deemed to be incorrect or missing, the average of the remaining hourly volumes corresponding to the same hour of day, day of week, and month was imputed for further analysis, as seen in Schneider et al. (2009A). For example, if an incorrect hourly count was identified between 1 p.m. and 2 p.m. on a Monday in June, the average of the 1 p.m. to 2 p.m. hourly volumes from the remaining Mondays in June would be used to replace the incorrect datum. Hourly data were replaced when the missing hours corresponded to less than 20% of the daily traffic, according to their MADWPT hourly patterns. If enough hours to account for 20% of average daily traffic were missing for a day, the day would be removed from further analysis. For example, on April 2, 2015, an hour of data was missing from 1 p.m. to 2 p.m. On Thursdays in April, this hour accounts for 9% of daily traffic, and met the criterion to be replaced. This criterion of the maximum number of replaced hours per day was included to maintain a minimal impact on a day's total volume and its hourly volume distribution. Substituting values for peak hours has a greater impact than replacing an hour of data during the middle of the night, and therefore the temporal placement of missing data was checked for its influence. Replacement data was visually checked to ensure the added volumes did not look out of place in the context of the full day's traffic.

While the number of replaced hours may not appear significant, many days were missing a single hour that made them ineligible for further analysis. After replacement, a total of 19 days, across all four APCs, became eligible to include in the analysis, as seen in Table 4. This resulted in a total of 1,085 days of pedestrian traffic volumes that were used in this research.

Table 4: Rejected and Replaced Hourly Data

	Corydon 1	Corydon 2	Corydon 3	Corydon 4
Hours missing or rejected	155	268	137	391
Hours replaced	11	4	2	20
Days made available for analysis through replacement	7	4	2	6
Hours of data used in this research	7,632	7,512	7,632	3,264

Three of the original APCs began malfunctioning during the study. The malfunctions were caught when either subsequent hourly volumes of zero were recorded throughout the day, or very large hourly volumes were recorded. Malfunctioning APCs were detected the following day, at the earliest, when data was available on the Eco-Visio website. When a counter malfunction was suspected, a site visit was conducted to visually check the APC for vandalism or possible causes of the erroneous counts. In the event it was decided that the problem was internal, the APC was replaced with another APC of the same model while the original APC was sent to the manufacturer for repairs.

3.5.2 Data Quality Control

Over time, the internal clock within an APC drifts and deviates from the real time.

Deviations between the internal clocks and the real time could result in pedestrian detections being assigned to the incorrect 15 minute interval. If left unsynchronized for an extended period of time, hourly distributions of pedestrian traffic could appear to be shifted either forward or backwards in time.

Deviations from real time would increase the likelihood of errors in verifying APC accuracy with manual counts. Eco-Counter provides software called Eco-Link that allows your computer or smartphone to connect to an Eco-Counter APC through a Bluetooth connection. From this program, the APC’s settings can be adjusted, and pedestrian detections can be observed in real time. Eco-Link allows the user to synchronize the logger’s clock with the time on the Bluetooth-connected computer. To reduce the effects of internal clock drifting, the internal clocks in the APCs were synchronized approximately once every two months. Each APC along the study corridor had its internal clock synchronized on the same day to reduce the impact of clock deviations between APC locations. Exceptions to this occurred when an APC malfunctioned and needed to be replaced. The replacement APC would have its internal clock synchronized upon installation.

3.5.3 Issues during Data Collection

During the study duration, streetlamps along Corydon Avenue were replaced with newer posts. The Corydon 4 APC was mounted on a streetlamp post at the time of replacements and was removed by a serviceman when the streetlamp was taken down. A total of 13 days of data were excluded from the dataset at the Corydon 4 location while the APC was missing. The time and date of the initial removal of the APC by the service crew was easy to identify by the sudden spike in detections, followed by very little recorded pedestrian activity as it sat idle in an office until it was returned. Once recovered, the APC was installed on a sign post near the original installation site, shown in Figure 11.

Figure 11: Streetlamp (and APC) Removed by City during Maintenance

At another point in the research, quality control checks indicated unusually low volumes at the Corydon 2 location. A site visit determined a bike rack had been installed in front of the APC as shown in Figure 12. The top of the bicycle rack was level with the sensors of the APC, and any bicycles locked up would further interfere with pedestrian detection. Bicycle riders are also likely to stop in front of the APC while locking up their bicycle. In this situation, the APC was moved to a nearby tree. There were no access points between the two Corydon 2 locations, so it is assumed a particular pedestrian detected at the first location would also be detected at the second location as it continues its travel.

Figure 12: Bicycle Rack Installed in Front of APC

Another issue during the data collection was snow banks. Snow pileup in the winter threatened to block the view of the counters. When sidewalks were cleared of snow, the snow was piled between the sidewalk and the street, and often between the sidewalk and the posts on which the APCs were mounted. During site visits, snow was cleared from in front of the APCs if it was nearing the height of the sensors in the APCs. There was no evidence to suggest snow was piled high enough to interfere with detection.

3.5.3.1 Quantifying affected data

When outside sources interfere with data collection, the amount of contaminated data must be quantified. The exact beginning and end of the duration of outside interference is important in order to remove the contaminated data from the dataset before beginning the analysis. It was clear when the APC at the Corydon 4 location was removed during streetlamp maintenance because count volumes dropped drastically as the APC was removed from the streetscape. However, the installation date of the bike rack in front of the Corydon 2 APC was much more difficult since the APC was still recording pedestrians. This also meant the issue was harder to detect through data alone and was only noticed during a site visit. To determine the length of time that the bike rack was installed in front of the APC, the ratios of the daily volume at Corydon 2 to the daily volumes at each other site were calculated. This proportion technique was used instead of simple daily volumes in order to reduce the effects of weather and temporal patterns. The APC was relocated away from the bike rack on June 16, 2015, but the daily volume ratios indicated the Corydon 2 location saw a drop in pedestrian volumes starting on June 3, 2015. For example, in the two weeks before June 3, 2015, the daily volumes at the Corydon 2 location were on average 54% of the daily volumes seen at Corydon 1. Between June 3, and June 15, when it is suspected the bike rack was in place in front of the APC, this proportion dipped to 39%, showing a relative decrease in pedestrian daily volume at Corydon 2 due to the bike rack interference. When the APC was relocated, the daily volumes at the Corydon 2 location rebounded to an average of 62% of the daily volumes seen at Corydon 1. This trend was also seen when comparing the Corydon 2 location to the Corydon 3 and 4 locations. Therefore, despite having recorded pedestrian volumes from June 3, 2015, to June 15, 2015, the data from those days is likely erroneous and was removed from the Corydon 2 dataset.

3.5.4 Sample Sizes from Study Locations

After cleaning and processing the data, the final dataset included 1,085 complete days of pedestrian data and 741,025 pedestrians. The breakdown of this data by counter is shown in Table 5.

Table 5: Sample Size of Days and Pedestrians in Analysis

	Corydon 1	Corydon 2	Corydon 3	Corydon 4	Total

Number of complete days	318	313	318	136	**1,085**
Number of pedestrians	286,872	194,772	172,717	86,664	**741,025**

The breakdown of the days of data collection at each counter is shown in Table 6. This table displays the number of complete days of pedestrian data for each day of week and month. Values are color formatted to show the strength in each category. Darker shaded cells indicate a greater sample size. For example, pedestrian data was recorded for seven Tuesdays in July at each of the Corydon 1, 2, and 3 count locations. The month of July has a greater sample size due to the study starting in July 2014 and ending in July 2015. The volatility of pedestrian traffic volumes amplifies the importance of a larger sample size to find a more accurate estimate of average pedestrian volumes during a particular hour of the day, or day of the week.

Table 6: Day-of-Week and Monthly Breakdown of Sample at each APC Location

Corydon 1

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
January	4	4	4	4	4	5	5
February	4	3	4	4	4	4	4
March	5	4	4	3	4	3	4
April	3	4	3	5	4	3	4
May	3	2	3	3	1	3	3
June	3	4	5	2	4	3	1
July	5	6	7	5	7	5	4
August	2	1	4	4	3	3	2
September	3	3	3	4	3	3	3
October	4	3	4	5	5	4	4
November	5	4	4	4	4	3	5
December	4	5	5	5	3	4	4

Corydon 2

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
January	4	4	4	4	4	5	5
February	4	3	4	4	4	4	4
March	5	4	4	3	4	3	4
April	3	4	3	5	4	3	4
May	4	3	4	3	1	5	4
June	1	2	4	0	2	1	1
July	5	6	7	5	7	5	4
August	2	1	4	4	3	3	2
September	3	3	3	4	3	3	3
October	4	3	4	5	5	4	4
November	5	4	4	4	4	3	5
December	4	5	5	5	3	4	4

Corydon 3

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
January	4	4	4	4	4	5	5
February	4	3	4	4	4	4	4
March	5	4	4	3	4	3	4
April	2	3	2	5	3	2	3
May	4	3	4	3	1	5	4
June	3	4	5	2	4	3	1
July	5	6	7	5	7	5	4
August	2	1	4	4	3	3	2
September	3	3	3	4	3	3	3
October	4	3	4	5	5	4	4
November	5	4	4	4	4	3	5
December	4	5	5	5	3	4	4

Corydon 4

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
January	1	1	1	1	1	2	2
February	4	3	4	4	3	3	3
March	2	2	2	2	2	2	2
April	3	4	3	5	4	3	4
May	4	3	4	3	1	5	4
June	3	4	5	2	4	3	1
July	2	3	3	1	3	3	2
August	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0

4 DATA ANALYSIS

4.1 PEDESTRIAN TRAVEL PATTERNS AT EACH BLOCK

The cleaned and processed data was analysed to determine the pedestrian traffic patterns and volumes at each of the four count locations. The analysis was done from an hour-of-day perspective, a day-of-week perspective, and a monthly perspective.

4.1.1 Monthly Variation

Only the Corydon 1, 2, and 3 locations had traffic data for all 12 months. The APC at Corydon 4 collected data for seven months, January to July, preventing it from being used in the seasonal variation of this research. To normalize the data, the monthly average daily pedestrian traffic (MADPT) was used. In this method, the mean volume for each day of the week within each month was determined, and then within each month, the mean day-of-week volumes were averaged to calculate a normalized mean daily volume for each month. This method reduced the influence of an unequal occurrence of week days in a given month.

Monthly average factors (MAFs) were developed for each of the counting locations, by dividing the MADPT by the AADPT. As seen in Figure 13, pedestrian traffic at all three sites followed a similar seasonal pattern, with higher volumes during the summer. The Corydon 1 location had the most symmetrical shape, with gentle changes between the highest volumes in the summer months and lowest in the winter months. At the Corydon 2 APC site, the MAF peaked later than the other two sites. The mean daily volume peaked in August before declining to the lowest volumes in February. At the Corydon 3 APC site, pedestrian traffic peaked earlier in the summer. After peaking in June, pedestrian volumes dropped sharply.

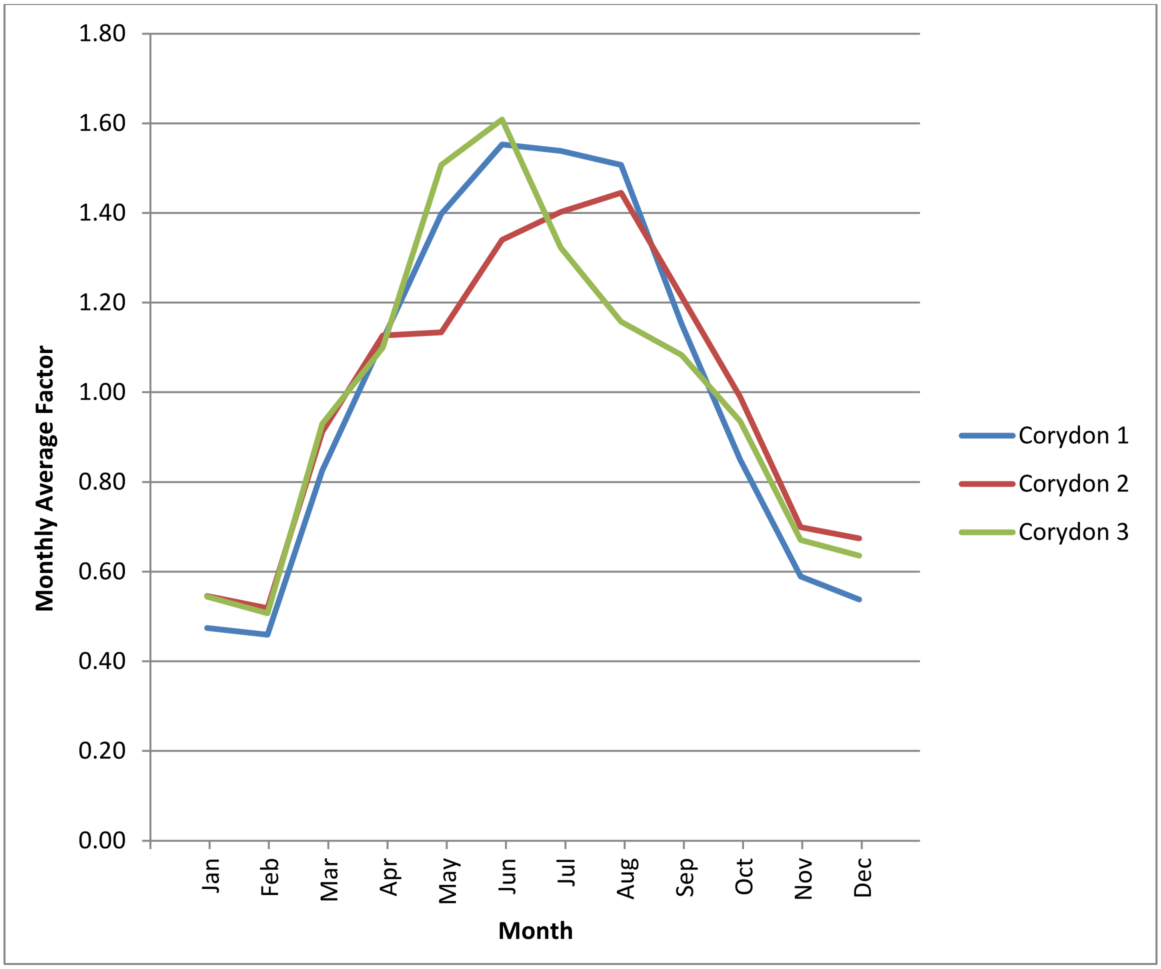


Figure 13: Monthly Average Factors for Pedestrian Traffic

The MADPTs for the four count locations are presented in Figure 14. It was found that the Corydon 1 APC experienced heavier traffic than the counters at the other locations during the summer months. The peak MADPT at Corydon 1 was 1451 pedestrians, while only 931 at Corydon 2, the second busiest location. At a distance of approximately one block, the peak MADPT at Corydon 1 was 55% greater than the highest MADPT recorded at Corydon 2. The shift in volume was not linear from block to block. While Corydon 1 was the busiest, MADPT volumes were comparable at the remaining Corydon 2, 3, and 4 locations. Factors that contribute to the varying pedestrian traffic characteristics between locations are explored and evaluated in Chapter 4.3.

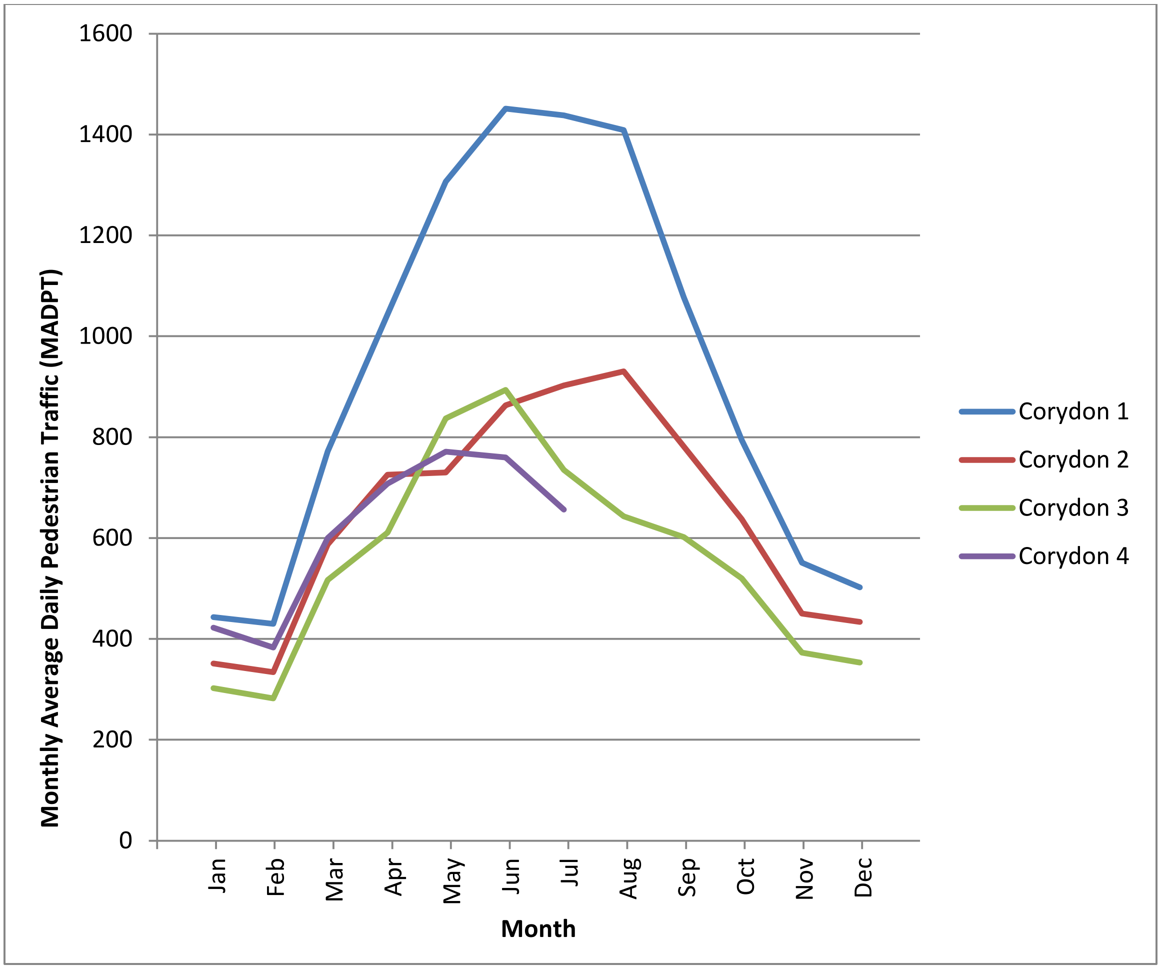


Figure 14: MADPT Volumes along Corydon Ave.

It is worth noting that the temporal trends in monthly average factors between Corydon 1, 2, and 3 are very similar from September to April. This finding suggests pedestrian traffic is reduced by a similar proportion in colder months, and despite reduced volumes, it is a better predictor of AADPT due to its consistency across count locations. Extrapolating seven day counts from any of these locations, taken between September and April, to an AADPT may be accurate while using the same monthly average factors. The variability in MADPT volumes between locations during the summer months is an indicator that despite the close proximity of the count locations and their shared corridor, they can have unique pedestrian travel patterns. The volume at one location does not mean nearby locations along the same corridor will have similar volumes or patterns.

Unlike motorized vehicle volumes, the pedestrian volume at one location cannot be extrapolated along a corridor. Site selection is important if trying to count peak pedestrian traffic in a neighbourhood.

4.1.2 Hour-of-Day Variation

Variations in hourly pedestrian traffic distributions were evident between all four study sites. The Corydon 1 location exhibited higher proportions of daily traffic during evening hours than the other three locations. The most extreme differences in hourly distributions between sites were seen during the summer months. During the winter months, the proportion of daily traffic occurring in the evening was drastically reduced. During the summer months, the hourly pedestrian traffic distribution was bimodal, with a lunchtime peak, and another much more distinct peak in the evening. The distribution remains bimodal in the winter months, but the second peak is weakened and occurs around 4 p.m.

In current practice, short term counts are often conducted between 7 a.m. and 7 p.m., since this period will usually include morning and evening commuter peaks, as well as recreational traffic (Alta Planning and Design, 2015). However, this strategy is less effective when there is heavy pedestrian traffic outside of these hours.

4.1.2.1 Seasonal influence on hour-of-day traffic

The season has an impact on the hourly distribution of pedestrian traffic in an entertainment area. In this research, the hour-of-day distribution at all four APC locations showed different traffic patterns when comparing summer months to winter months, agreeing with the pedestrian sidewalk traffic findings by Miranda-Moreno and Chapman Lahti (2013) in Montreal. Among each of the four count locations, the average proportion of daily traffic between 6 a.m. and 7 p.m. was greatest in February, and lowest in July.

Figure 15 shows the distribution of pedestrian traffic at each APC over a 168 hour week in February and July. In this figure, the days of the week are normalized to focus on the hourly distribution between days rather than the pedestrian traffic volumes between days. This temporal-based shift in traffic distribution describes a large increase in evening traffic during the summer months, due, in part, to warmer weather and longer days. The entertainment area traffic pattern seen in summer months loses its characteristically high evening volumes as school begins and the weather cools. For example, weekday traffic sees a single large peak at 8 p.m. in July, and two peaks in February, at 12 p.m. and 4 p.m. This could be due to a decrease in the popularity of going out for social activities during the winter in Winnipeg where the sun sets earlier and it can get very cold during the winter.

While milder climates in other regions may reduce the magnitude of the shifts in hour-of-day distributions over the year, this finding supports the idea that peak hours are not necessarily constant throughout the year. Summer months exhibit an entertainment area traffic pattern featuring heavy evening traffic, but that key characteristic of an entertainment pattern fades in the winter. In colder climates, further research may be required when developing a pedestrian monitoring program to account for shifts in hourly pedestrian traffic characteristics.

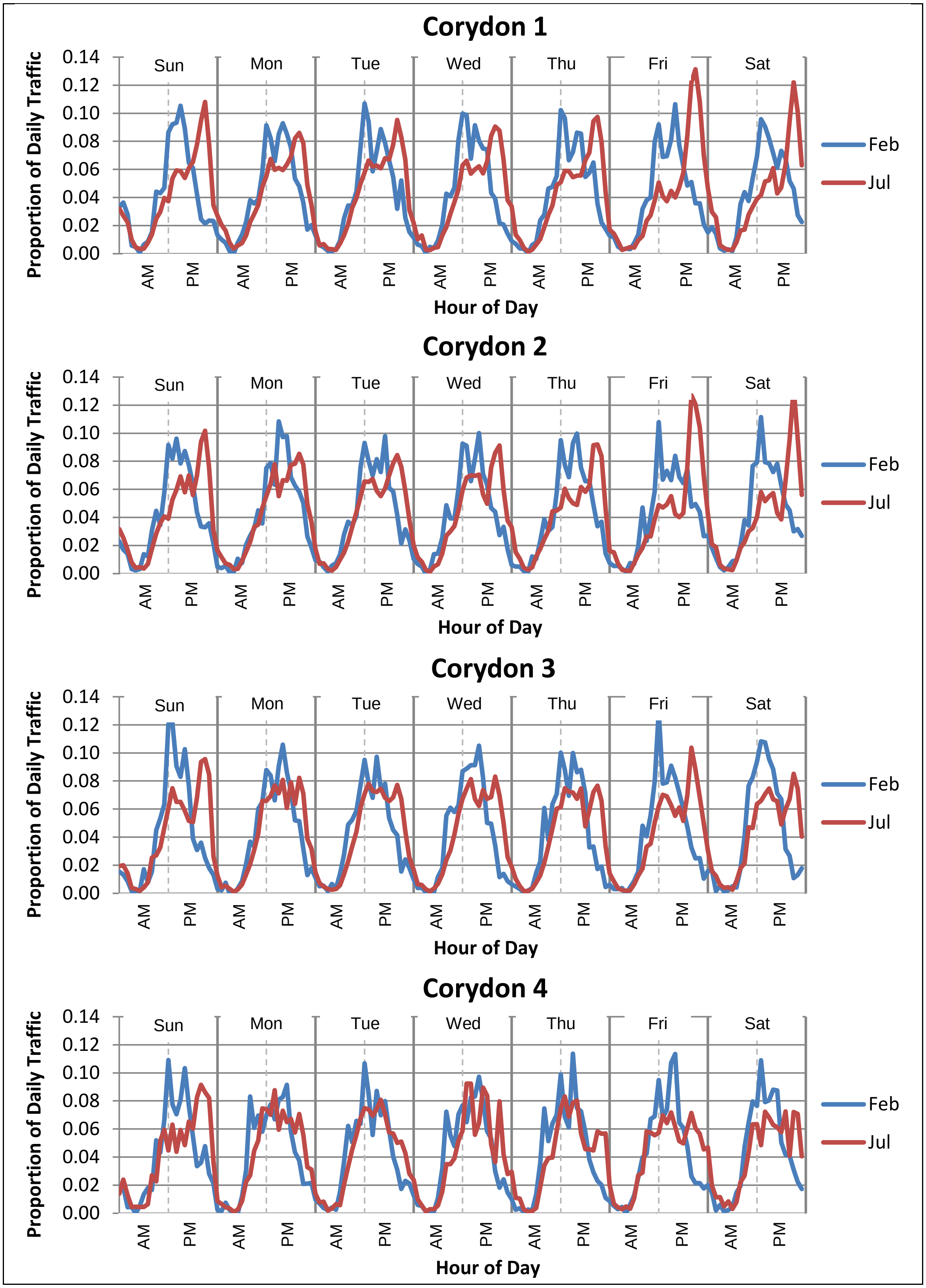


Figure 15: Seasonal Influence on Day-of-Week Pedestrian Traffic Distributions

4.1.3 Day-of-Week Variation

Day-of-week proportions were found using MADWPT volumes to determine annual and monthly DoW pedestrian traffic patterns. The calculations to determine the annual DoW proportions used the formula below. This formula is based on the AADT formula found in the Traffic Monitoring Guide (Federal Highway Administration, 2013). This formula originates from vehicle traffic monitoring and assumes DoW patterns exist from week to week. Despite the volatility in pedestrian traffic, trends in DoW pedestrian traffic proportions in this research existed on a seasonal basis.

$$Annual\ DoW\ Proportion = \frac{\frac{1}{12}\sum_{j=1}^{12}\frac{1}{n}\sum_{k=1}^{n} VOL(i)(j)(k)}{\sum_{i=1}^{7}\frac{1}{12}\sum_{j=1}^{12}\frac{1}{n}\sum_{k=1}^{n} VOL(i)(j)(k)}$$

Where:

VOL	=	daily traffic for day (k), of DoW (i), and month (j)
(i)	=	day of week
(j)	=	month of year
(k)	=	occurrence of a day of week, (i), in a month, (j). Corresponds to k=1 for the first instance of a particular day of week in a month, and k=2 for the second occurrence of that day of week in the same month.

The annual DoW proportions at each of the four study locations are shown in Figure 16. Over the course of an entire year, the Corydon 1, 2, and 3 sites averaged the highest daily pedestrian volume counts on Fridays and Saturdays, relative to the other days of the week. Due to the nature of the location and the hourly pedestrian traffic patterns, the high traffic volume on Fridays can be attributed to a combination of weekday commuter traffic and late evening traffic typically seen on nights that do not precede a business day (Friday and Saturday). The proportion of weekly traffic on Fridays and Saturdays decreases from Corydon 1 to Corydon 4. Reasoning behind this is further explained in Section 4.3, but is related to the built environment and the location of trip attractors.

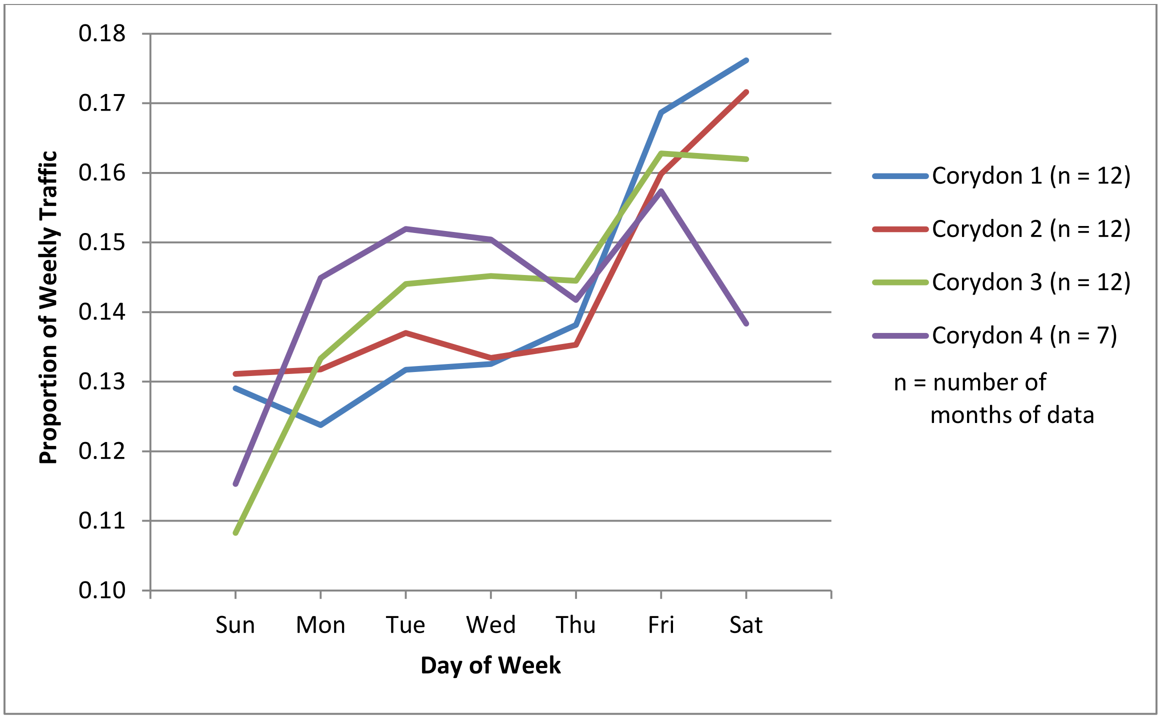


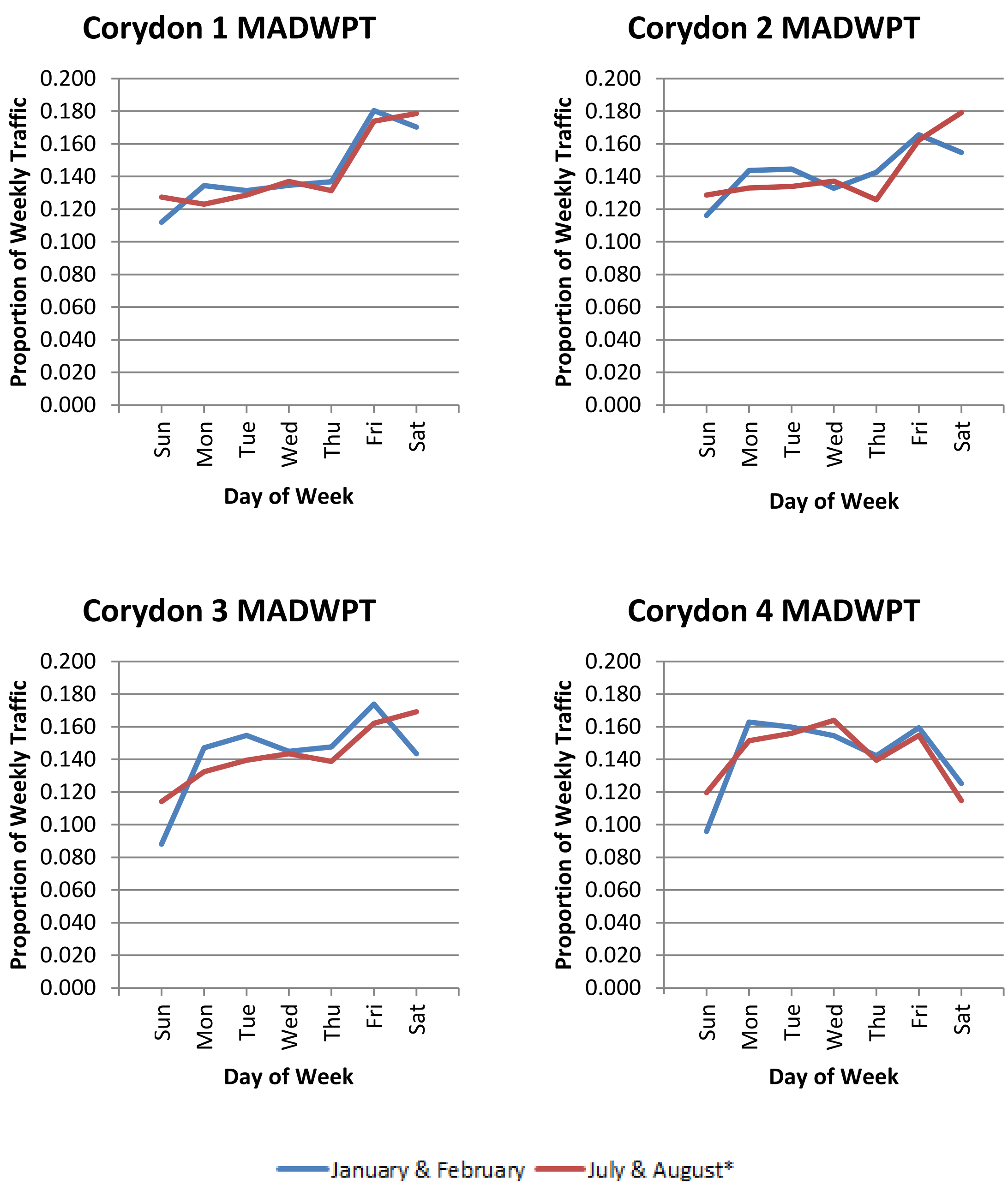
Figure 16: Annual Day-of-Week Pedestrian Traffic Proportions

The Corydon 1 location has highest pedestrian traffic on Fridays and Saturdays. The average daily pedestrian volumes from Sunday to Thursday over the year are similar, and range between 12.5% and 13.6% of the weekly traffic. Fridays and Saturdays average 16.9% and 17.6%, respectively, of the weekly traffic. The Corydon 2 location shows a similar 7-day traffic pattern as the Corydon 1 location, albeit having a slight decrease in proportion of weekly traffic occurring on Fridays and Saturdays. Corydon 3 and 4 have similar day-of-week traffic patterns. At these locations, Sundays see significantly less traffic than any of the other days of the week, and less traffic occurs on Saturdays than Fridays. The reduced traffic on weekends suggests commuter and business-related trips make up a larger percentage of total trips passing by the Corydon 3 and 4 APC locations.

4.1.3.1 Seasonal influence on day-of-week traffic

The variation in day of week traffic over time and between count locations can be compared using monthly average day of week pedestrian traffic (MADWPT) volumes or a MADWPT proportion. In this research, the MADWPT proportion is the proportion of the weekly pedestrian traffic volume that is seen on each specific day of the week, and is calculated by dividing each MADWPT by the sum of MADWPTs from the same month.

The impact of seasonal factors on DoW variation in pedestrian traffic volumes was analysed along the study area. Analysis in section 4.1.2.1 demonstrated that the month of year affects the hourly traffic trends by reducing the proportion of daily pedestrians in the late evening, particularly on Friday and Saturdays. This reduction in evening traffic can lead to shifts in day-of-week traffic patterns. The DoW proportions during the winter (January and February) and summer (July and August) were compared at each study location. Only two months for each season were used in order to present the extremes of the DoW traffic patterns at each location over the study duration. Corydon 4 did not have any data for the month of August, so only July was used in the comparison to the winter months. Figure 17 shows DoW pedestrian patterns for peak winter and summer months. At the Corydon 1, 2, and 3 count locations, the proportion of weekly traffic on Saturday and Sundays was lower in the winter months than in summer. These three locations all exhibit peak volumes on Fridays in the winter months, and Saturdays in the summer months.



* The Corydon 4 location's July & August dataset only contains days from July

Figure 17: Monthly Average Day of Week Pedestrian Traffic for Winter and Summer

The Corydon 4 APC showed a day-of-week pedestrian traffic pattern unlike the other three locations. In January and February, Mondays had, on average, the highest

MADWPT proportion. In July, Wednesdays had highest proportion of weekly pedestrian traffic. Despite a dip in pedestrian traffic on Thursdays, Saturdays and Sundays had lower traffic volumes than weekdays in both winter and summer seasons, suggesting this location is the least affected by entertainment-purpose trips among the four study sites.

In summary, the proportion of pedestrian traffic on Saturdays and Sundays declined in the winter months at the Corydon 1, 2, and 3 count locations. The Corydon 4 location did not see pedestrian traffic peak on Fridays and Saturdays in the summer like the other blocks. The analysis of hourly and DoW pedestrian patterns over the year suggest the entertainment purpose trips make up a smaller proportion of daily pedestrian traffic in the winter months. As described Chapter 4.1.2, the late evening peak period seen in summer months on Fridays and Saturdays disappears in the winter months. Since the proportion of weekly traffic seen on Saturdays also decreases in the winter, it is likely that rather than these entertainment evening trips being made earlier in the day, entertainment trips make up a reduced proportion of trips in the winter.

4.1.4 The Entertainment Pedestrian Traffic Pattern

The analysis of temporal distribution of pedestrian traffic across the four study sites identified a distinct traffic pattern outside of the conventional commuter, recreation, and mixed traffic patterns that have been observed for non-motorized traffic. The FHWA describes commuter patterns to typically have the highest peaks in the morning and evening, recreational patterns to have a single peak during the day, and mixed patterns to have varying levels of commuter and recreational trips (2013).

The entertainment traffic pattern was characterized by high levels of evening and late night traffic, and peak daily volumes occurring on Fridays and Saturdays. This pattern differentiates itself from commuter traffic patterns by exhibiting peak hours around 8 or 9 p.m., much later than afternoon commuter peak hours. On a day-of-week level, the entertainment traffic pattern has the highest traffic on Fridays and Saturdays, when people are more likely to stay out late and attend social events. This compares to commuter patterns where weekday traffic is greater than weekend traffic and consists of people travelling to and from work. The entertainment traffic pattern is unlike a recreational traffic pattern due to its unique peak hours and days. Recreational patterns tend to have highest traffic volumes in the middle of the day and on weekends when people are off work.

Based on this description, the Corydon 1 location has the strongest entertainment pedestrian traffic pattern in the summer. Each block west in the study area displayed successively weaker entertainment pattern traits, culminating in the traffic pattern observed at the Corydon 4 location, which is not that of an entertainment traffic pattern and instead sees higher weekday traffic levels and a smaller proportion of pedestrian traffic occurring in the evening. The hourly pedestrian traffic distribution at Corydon 4 is more similar to a traditional recreational traffic pattern, as hourly traffic is fairly even throughout the day and is void of large peaks.

In the winter, the entertainment traffic pattern fades at all study locations, decreasing the proportion of traffic in the evenings and weekends. In locations with warmer climates, the likelihood of the entertainment traffic pattern continuing in winter months may be greater, as recreational pedestrian trips are more heavily influenced by temperature. However, in cold climates, like that in Winnipeg, the entertainment traffic pattern applies to summer only.

4.2 ASSUMPTIONS OF DAYTIME TRAFFIC

Due to the consumption of resources needed for counting, counts less than 24 hours are often conducted and used to compare pedestrian traffic volumes. In general, there are fewer pedestrians out during the middle of the night, so most manual count methods start in the morning and end in the evening. Past studies have used pedestrian counts and estimates ranging from 12 to 17 hours to when evaluating pedestrian traffic volumes (Hankey, et al., 2012) (Alta Planning and Design, 2009). Three case studies were identified from Minneapolis, Seattle, and a collection of data from across North America (NBPD) that use count durations less than 24 hours to evaluate and compare daily traffic volumes. The greatest limitation for comparing counts less than 24 hours is the amount of traffic in the remaining hours that goes unaccounted for.

A comparison of the hourly distribution of traffic along the four sites on Corydon Avenue to the assumptions used in past research that short term counts can be representative of daily volumes was completed to determine the applicability of these assumptions for the Winnipeg study locations. The proportion of daily traffic occurring between 6 a.m. and 7 p.m. was analysed to compare to the 7 a.m. to 7 p.m. counts in Seattle, and the 6:30 am to 6:30 p.m. counts used in Minneapolis (Zegeer, Opiela, & Cynecki, 1985) (Hankey, et al., 2012). It is worth noting that this analysis compared 13 hour volumes from Corydon Ave. to 12 hour counts. The 13 hour count in this study would provide a conservative estimate of pedestrian volumes that would be observed in either of the 12 hour count periods based on past research. At each of the sites along Corydon Ave, the volume of pedestrian traffic between 6 a.m. and 7 a.m. was very low.

In this research, the volume of pedestrians detected on weekdays in September from 6 a.m. to 7 p.m. averaged to be 70% of the daily volumes at the Corydon 1 location, 71%

at Corydon 2, and 78% at Corydon 3. This is lower than the 86% found in Seattle following the same temporal conditions. The study from Seattle is 30 years old and little research has been done on this topic since then. One could expect that travel patterns have changed since then. Figure 18 shows the average proportion of daily traffic that falls within this counting period for September as well as July and February. The error bars indicate the range of this value for different days of the week. For example, the Corydon 1 location sees 53% of the daily traffic between 6 a.m. and 7 p.m. in July, but on Fridays, this value is only 43%. The low proportion of daily traffic travelling between 6 a.m. and 7 p.m. suggest 12 hour counting periods are not long enough or scheduled well enough to provide a meaningful estimate of the daily pedestrian traffic. Additionally, the variation in the proportion of daily traffic caught in that particular 12 hr interval suggests that 12 hr volumes are not appropriate metrics to use when comparing traffic volumes between sites. When sites have different hourly traffic patterns, a location with high daytime volumes and low evening volumes could be easily misinterpreted to have more pedestrian traffic than a site that has slightly less daytime volumes but significantly greater evening volumes. Therefore, 12 hr volume comparisons should only be used when the proportion of daily volume outside of the count period is known and can be accounted for.

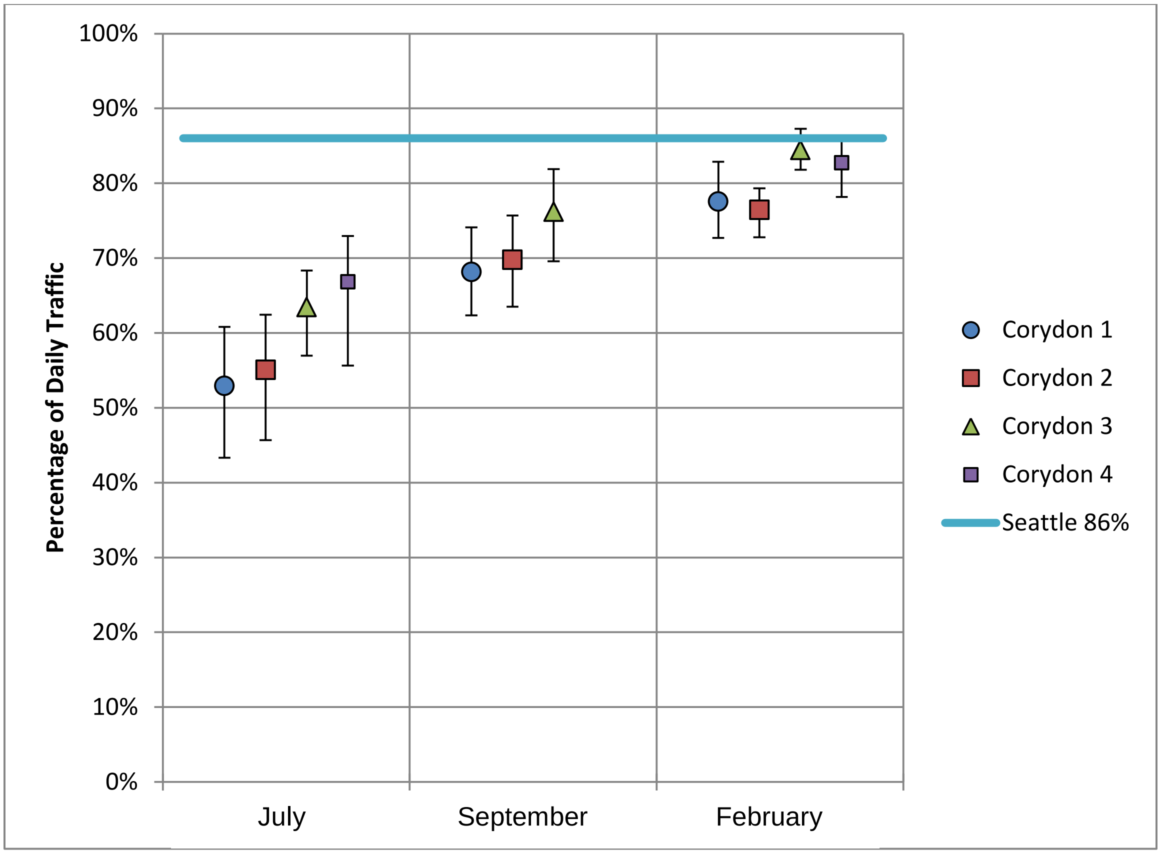


Figure 18: Proportion of Daily Traffic Occurring between 6 a.m. and 7 p.m. (DoW Average and max/min DoW)

The proportion of daily traffic found between 6 a.m. and 11 p.m. was analysed to compare to the NBPD's assumption that this period observes 95% of daily traffic (Alta Planning and Design, 2009). Data from the four APCs along the study corridor show that the percentage of the daily non-motorized traffic volume that travels between 6 a.m. and 11 p.m. varies temporally based on the time of year and day of week. Figure 19 shows the average and range of the pedestrian traffic in this time period as a proportion of daily traffic. In February, when evening traffic is lowest, the average proportion of daily traffic occurring between 6 a.m. and 11 p.m. at Corydon 1 and Corydon 2 is less than 95%. However, from Monday to Thursday, this value occasionally over 95%. In July, the proportion of daily traffic occurring between 6 a.m. and 11 p.m. is reduced.

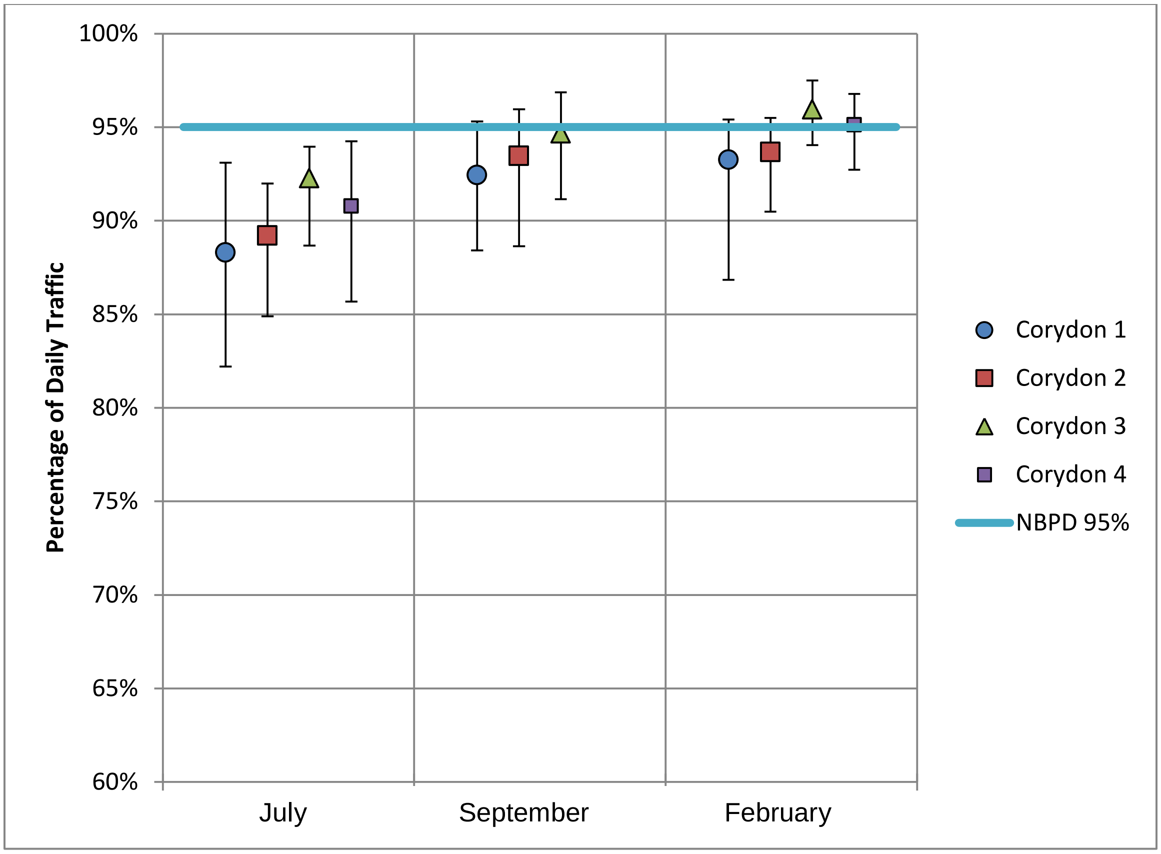


Figure 19: Proportion of Daily Traffic Occurring between 6 a.m. and 11 p.m. (DoW Average and max/min DoW)

If high volumes of pedestrians are detected during the evening hours, a 12 hr count from 6:30 a.m. to 6:30 p.m. may include less than 45% of the pedestrian traffic occurring over a full 24 hour period (Corydon 1, July), and may even exclude the peak hour. 12 hour counts should only be used if the hourly traffic pattern is known and can be used to accurately extrapolate the count to a daily estimate. The proportion of daily pedestrian traffic travelling between 6 a.m. and 11 p.m. is more consistent, but still fluctuates between the days of the week and months. During weekdays (Monday to Thursday), the assumption of 95% of daily traffic occurring during this period is more accurate and would be a reasonable estimate in most circumstances. At count locations like those within the Corydon Ave study area, the late evening traffic volumes were expected based on local experience and characteristics of the built environment. Local judgement should be used to determine the duration of counts and for counts less than 24 hours in duration, the factors used to expand them to daily volume estimates.

4.3 FACTORS INFLUENCING PEDESTRIAN TRAFFIC PATTERNS

As discussed in Chapter 2, several land uses and characteristics of the built environment impact pedestrian traffic volumes. Additionally, many of these same factors influence the temporal traffic distribution at count locations. The evening traffic peak and DoW patterns associated with entertainment areas strongly correlate with the number of commercial properties, and businesses with late business hours.

4.3.1 Performance Metrics

The performance measures used to compare the pedestrian traffic patterns at each site cover variations in hour of day, day of week patterns, and monthly patterns.

In order to easily compare the variations in hourly traffic at each site, the traffic patterns needed to be simplified to single comparable values. The study area's distinct commercial and entertainment characterization contributes to peaks in the late evening, much later than typical commuting or recreational patterns. Therefore, the evening traffic proportion was chosen as a metric to approximate a location's proximity to a theoretical all-entertainment district hourly traffic pattern, where virtually all pedestrian traffic is in the evening to and from lounges, bars, etcetera. The evening traffic proportion is the proportion of pedestrian traffic outside of the typical 6 a.m. to 7 p.m. counting period. Since it was shown in section 4.1.2.1 that season impacts the hourly traffic pattern at the study locations, the evening traffic proportion of July and February were used, as they were the highest, and lowest monthly averages at each of the four sites, respectively. These values are shown below in Table 7. The evening traffic proportion is highest at the

Corydon 1 and Corydon 2 locations, and lowest at the Corydon 3 and Corydon 4 locations during the summer and winter seasons.

Table 7: Evening traffic proportion at each counting location

Percentage of Traffic Between 7 p.m. and 6 a.m.		
	February	July
Corydon 1	22.5%	47.1%
Corydon 2	23.5%	44.9%
Corydon 3	15.6%	36.5%
Corydon 4	17.3%	33.2%

Day of week patterns are another metric used to measure the likeness of a location's traffic pattern to that of a theoretical all-entertainment area, where the majority of weekly traffic occurs on Fridays and Saturdays. Fridays and Saturdays are favourable candidates for evening activities since they do not precede conventional business days. A value referred to as the weekend weekday index (WWI) was developed in this research to quantify the difference in traffic volumes between weekends and weekdays. The WWI value is the difference between the average proportion of weekly traffic on weekends (Fridays and Saturdays) and the average proportion of weekly traffic on weekdays (Monday, Tuesday, Wednesdays, and Thursdays,) as shown below. A negative WWI indicates that average weekday volumes are greater than average weekend volumes.

$$weekend\ weekday\ index = (\frac{P_{Fri} + P_{Sat}}{2}) - (\frac{P_{Mon} + P_{Tues} + P_{Wed} + P_{Thu}}{4})$$

Where P = Proportion of weekly traffic on a particular day.

As seen in Figure 20, the ranking of sites based on WWI is fairly consistent month-to-month. The rankings follow the same order of the locations along the study corridor, with the Corydon 1 location seeing the greatest difference between weekend and weekday traffic, and Corydon 4 seeing the least.

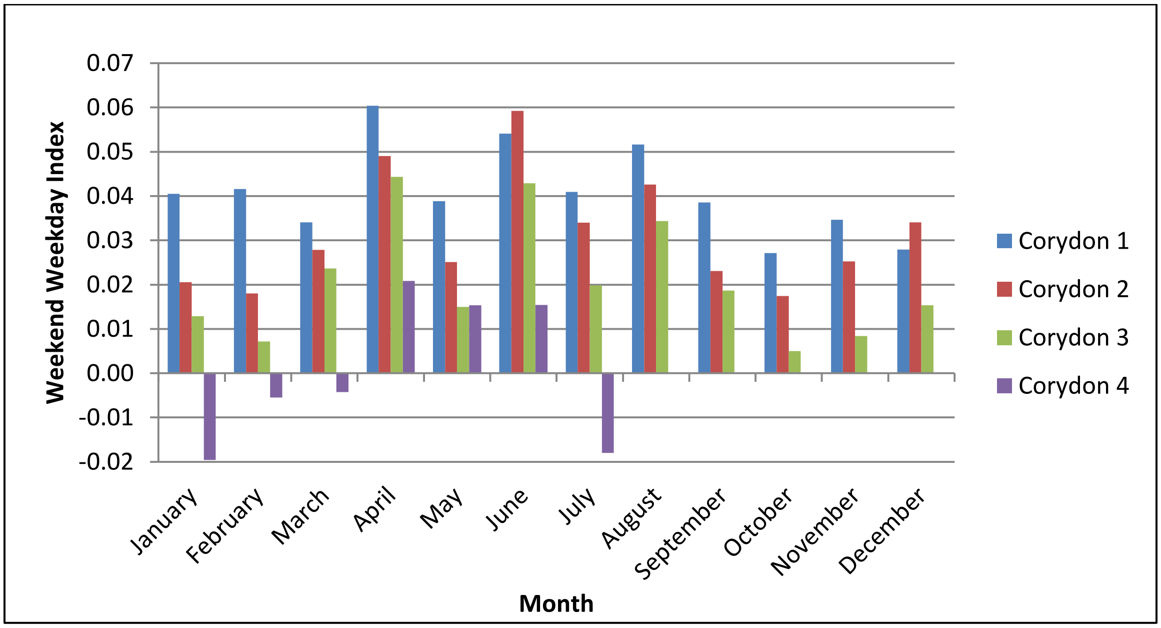


Figure 20: Weekend Weekday Index

An annual weekend weekday index was used as a metric going forward due to its simplicity in evaluating the day-of-week pedestrian traffic patterns between different locations. The weekend weekday index calculated at each site is shown in Table 8. At the Corydon 1 location, the difference between weekend and weekday pedestrian traffic levels is greatest. At the Corydon 4 location, daily traffic volumes are similar between Friday and Saturday, and Monday through Thursday.

Table 8: Annual Weekend Weekday Index at all Four Study Locations

Location	Weekend weekday index
Corydon 1	0.041
Corydon 2	0.031
Corydon 3	0.021
Corydon 4	0.001

The third metric used in the analysis compares the variation in MADPT at a particular location to another. This variation, referred to as the MADPT ratio, is the ratio of the highest MADPT at a counting location over the lowest MADPT at the same location. For locations with large seasonal variations in traffic volumes, the MADPT ratio will be greater than a site with more consistent volumes throughout the year. The MADPT ratio at each location is shown in Table 9 below. The Corydon 1 location has the highest MADPT ratio, at 3.38, while the Corydon 4 location has the lowest MADPT ratio of the four locations, at 2.01. This means that the Corydon 1 location had the greatest range of MADPT volumes, ranging from 430 daily pedestrians in February to an average of 1451 daily pedestrians in June (3.38 MADPT ratio), while the average daily pedestrian volume at Corydon 4 ranged from 383 to 771 daily pedestrians (2.01 MADPT ratio).

Table 9: MADPT Ratios at all Four Study Locations

Location	MADPT Ratio
Corydon 1	3.38
Corydon 2	2.79
Corydon 3	3.17
Corydon 4	2.01

The last metric calculated focuses on pedestrian traffic volumes rather than temporal patterns among the study sites. The highest and lowest MADPT values at each study location are used to represent the extreme monthly average daily traffic volumes.

Table 10: Extreme MADPT Volumes at all Four Study Locations

Location	Highest MADPT	Lowest MADPT
Corydon 1	1451	430
Corydon 2	931	334
Corydon 3	894	282
Corydon 4	771	383

Site characteristics were compared side-by-side with the metrics described in this section to identify trends and patterns over the four study sites.

4.3.2 Commercial Businesses

Past research has shown the link between pedestrian traffic volumes and the surrounding land use. However, there has been an identified need to further characterize counting locations beyond simply their commercial and residential makeup (Poapst, 2015). This analysis investigates the impact of different types of commercial properties, particularly those that would assist in an entertainment identity. This analysis evaluates the impact of commercial businesses on the same block (BLK) as an APC and in a three-block segment (SEG) centered on each APC.

4.3.2.1 Restaurants

The total number of restaurants on the same block as the APCs (BLK_R) and the total number of restaurants on three-block segments (SEG_R) are shown in Figure 21. The Corydon 1 block has the most restaurants, with six between Cockburn St. and Arbuthnot St. The two middle blocks each have a single restaurant, and the fourth block, with the Corydon 4 APC, had three restaurants. While looking only at restaurants on a single block, there are many missed nearby trip attractors that could attract traffic past the APC. Opening the analysis to restaurants on three-block segments centered on each APC allowed the analysis to include nearby trip destinations that could attract pedestrian traffic past an APC. When including segments, there was overlap, as a restaurant on the same block as the Corydon 2 APC now counted as a restaurant in the Corydon 1 SEG_R and Corydon 3 SEG_R totals. The Corydon 1 segment had a total of 12 restaurants on its segment (five from the eastern adjacent block, one from the western adjacent block, and six from the block with the Corydon 1 APC).

Comparing the number of restaurants on a single block to temporal trends and traffic volume levels does not show a strong correlation. However, when assuming restaurants on adjacent blocks impact pedestrian travel at a given location, the segment restaurant (SEG_R) data shows a much stronger correlation to temporal and volume trends at the four APCs. The hourly and day-of-week traffic patterns at an APC appear to correlate with the number of restaurants on a three-block segment. The data suggests a greater percent of traffic occurring in the evening and on weekends is linked to greater numbers of restaurants on a segment. The three-block segment centred on the Corydon 1 APC has the most restaurants, and the highest percentage of pedestrian traffic occurring in the evening. The Corydon 1 APC registered the greatest difference in day of week traffic proportions between weekdays and weekends. The MADPT volumes of warmer months appear to correlate with the number of nearby restaurants, but during the colder months with lower MADPTs, there is less of a relationship with restaurants.

	Restaurants on block	Restaurants on segment
Location	BLK_R	SEG_R
	5	-
Corydon 1	6	12
Corydon 2	1	8
Corydon 3	1	5
Corydon 4	3	5
	1	-

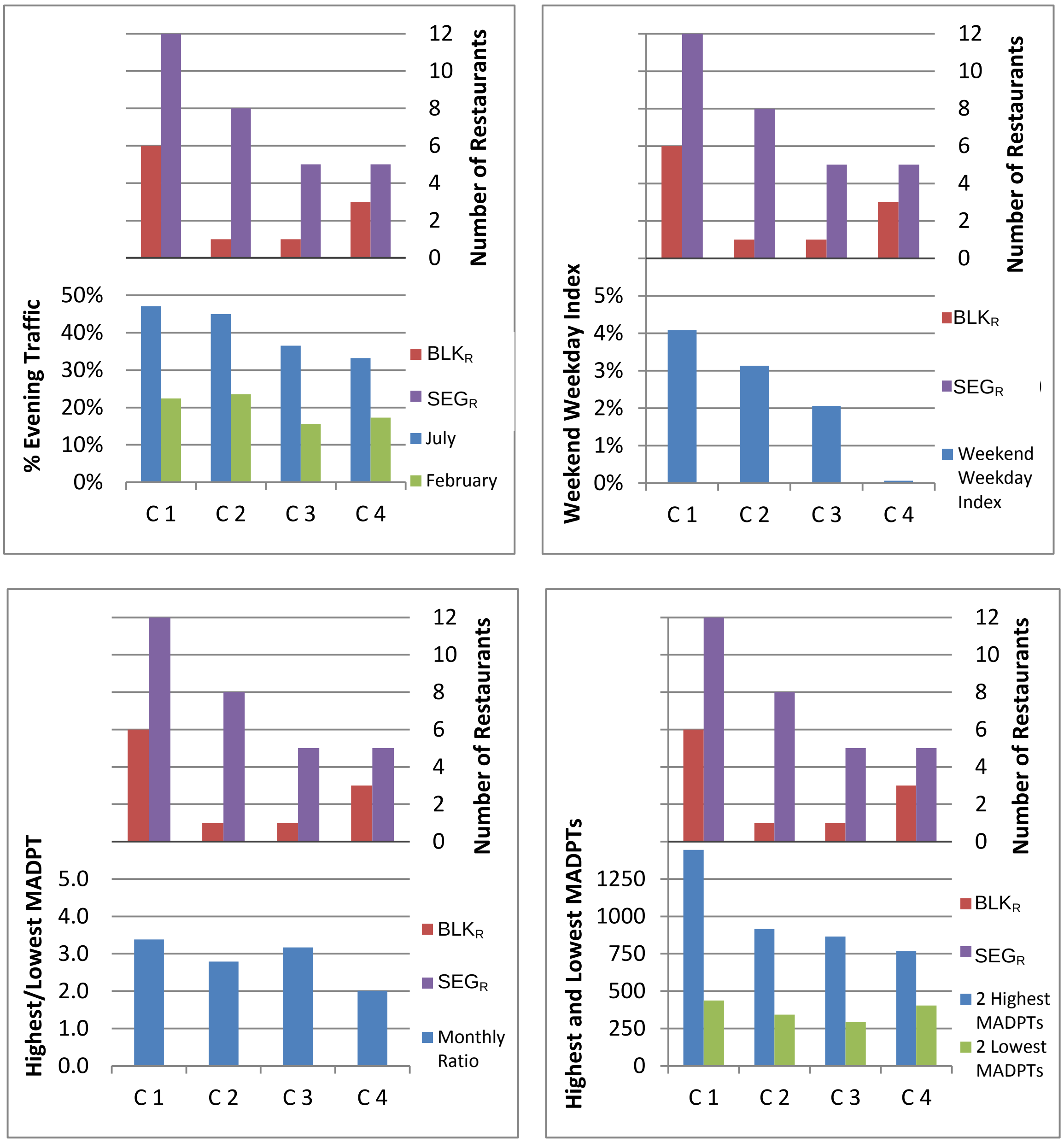


Figure 21: Number of Restaurants and Pedestrian Traffic Characteristics

4.3.2.2 Licensed restaurants

The effect of restaurants was investigated further by focusing on commercial properties that are licenced to serve alcohol, such as restaurants, lounges, or bars. This focus narrows the broad classification of restaurants to establishments more likely to attract patrons in the evening for socializing as well as eating or drinking. This analysis excluded some businesses in the study area, such as fast food restaurants or coffee shops. The Corydon 1 block had the most licenced restaurants with two. The Corydon 2 and Corydon 4 blocks each had a single licenced restaurant, while the Corydon 3 block did not have any. Interestingly, the block directly east of the study area had three licenced restaurants. When considering licenced restaurants on the east and west adjacent blocks, the Corydon 1 segment had six licenced restaurants. The numbers of licenced restaurants at the Corydon 2, Corydon 3, and Corydon 4 segments were three, two, and one, respectively.

The total number of licenced restaurants on the same block as the APCs (BLK_{LR}) and the total number of licenced restaurants on the same block and the adjacent blocks (SEG_{LR}) are shown in Figure 22. On a single block basis, there was no clear correlation between the number of licenced restaurants on the same block as an APC and the temporal pedestrian traffic patterns and volumes. This could be the result of the very short study area, and the idea that pedestrian traffic is affected by factors outside of its one block.

When including licenced restaurants in a three-block segment, there was a strong correlation with the percent evening traffic, weekend weekday index, and maximum MADPTs. As the number of licenced restaurants increases, the percent of pedestrian traffic in the evening increases during warmer months, the proportion of weekly traffic seen on Fridays and Saturdays increases compared to weekdays, and pedestrian traffic volumes increase in the warmer months. During the winter months, there does not appear to be a correlation with the percent evening traffic, or the MADPT volumes.

Location	Licenced restaurants on block	Licenced restaurants on segment
	BLK_{LR}	SEG_{LR}
	3	-
Corydon 1	2	6
Corydon 2	1	3
Corydon 3	0	2
Corydon 4	1	1
	0	-

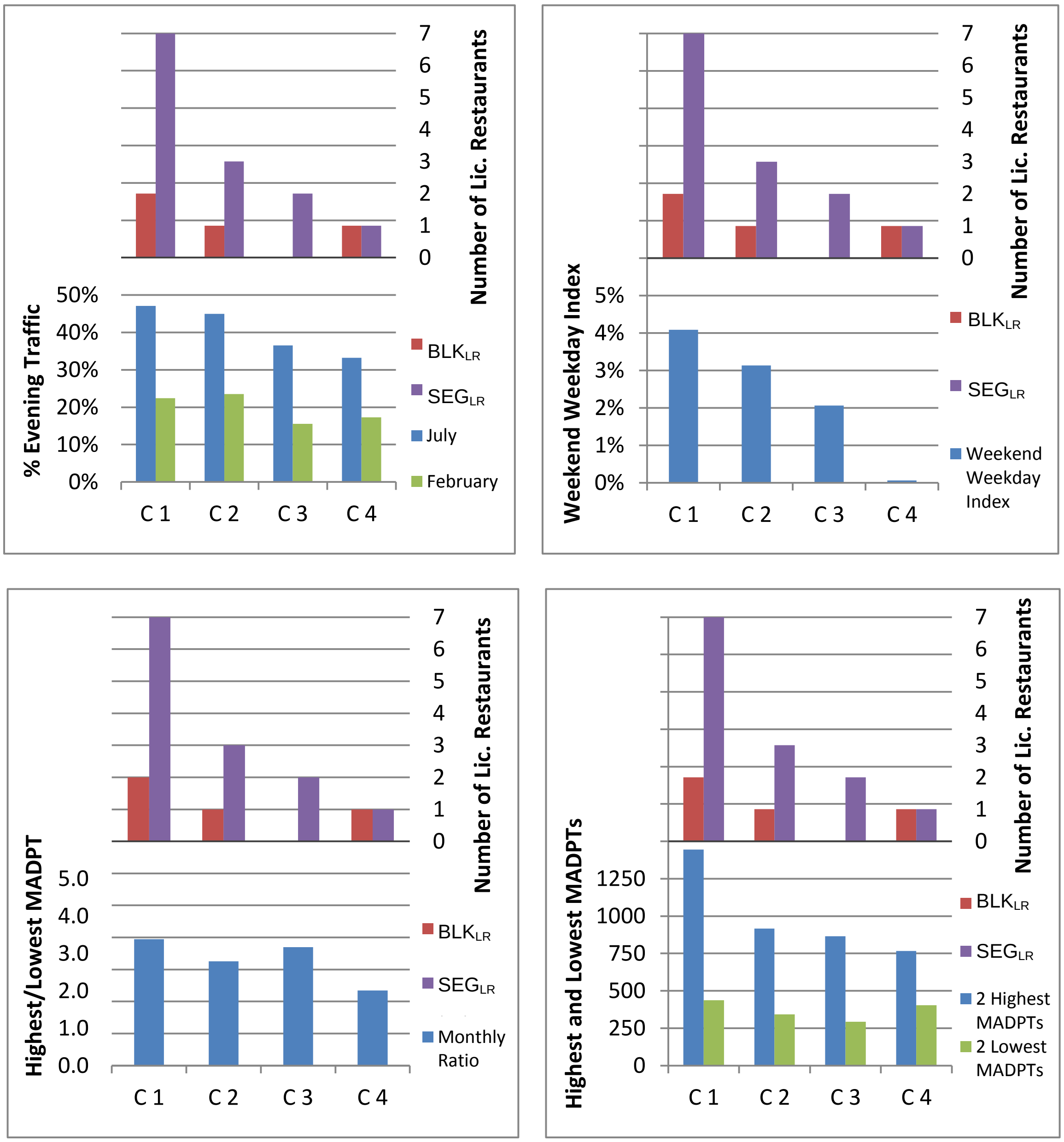


Figure 22: Licenced Restaurants and Pedestrian Traffic Characteristics

4.3.2.3 Restaurant frontage

In addition to the number of restaurants in the study area, the combined frontage length of the restaurants near each APC was calculated as a percentage of block or segment length. The frontage value was determined using Google Earth to measure the length of curbside property along Corydon Ave. Frontage values were included as a variable in this analysis to take into account the size of restaurants when evaluating their impact on pedestrian traffic patterns and volumes. It is likely a large restaurant with more tables would have a larger effect on pedestrian traffic than a small restaurant with a smaller seating capacity.

The frontages of restaurant properties in the study area ranged from approximately 5 m to 15 m. Restaurant frontages on a block ($BLK_{R\text{-}F}$) and segment ($SEG_{R\text{-}F}$) are compared to pedestrian traffic in Figure 23. The results suggest a single block is too small of a study area to evaluate the impact of commercial property frontage on pedestrian traffic. A block without a single restaurant may be between blocks that are each home to multiple restaurants. It is unreasonable to assume the block without restaurants will be void of all foot traffic related to the nearby restaurants. While isolating single blocks, there was not a correlation with pedestrian traffic patterns or volumes along that block and the sum of the block's restaurants' frontage. Expanding the analysis to include the frontage of restaurants on the three-block segment ($SEG_{R\text{-}F}$) drew a stronger correlation. An increase in restaurant frontage along a segment correlates with an increase in the proportion of evening and weekend traffic during summers, as well as higher pedestrian volumes in the summer. The similarities are greatest when comparing the frontage of restaurant properties along a segment and the highest MADPTs at the APC at the center of each segment. The Corydon 1 segment had the highest MADPT of the four sites and had the highest proportion of restaurant frontage among the study sites. The Corydon 2, 3, and 4 segments had much more similar summer MADPTs and restaurant frontage values.

Location	Frontage of restaurants as a percentage of block length $BLK_{R\text{-}F}$	Frontage of restaurants as a percentage of segment length $SEG_{R\text{-}F}$
	57%	-
Corydon 1	40%	36%
Corydon 2	10%	23%
Corydon 3	20%	20%
Corydon 4	30%	20%
	10%	-

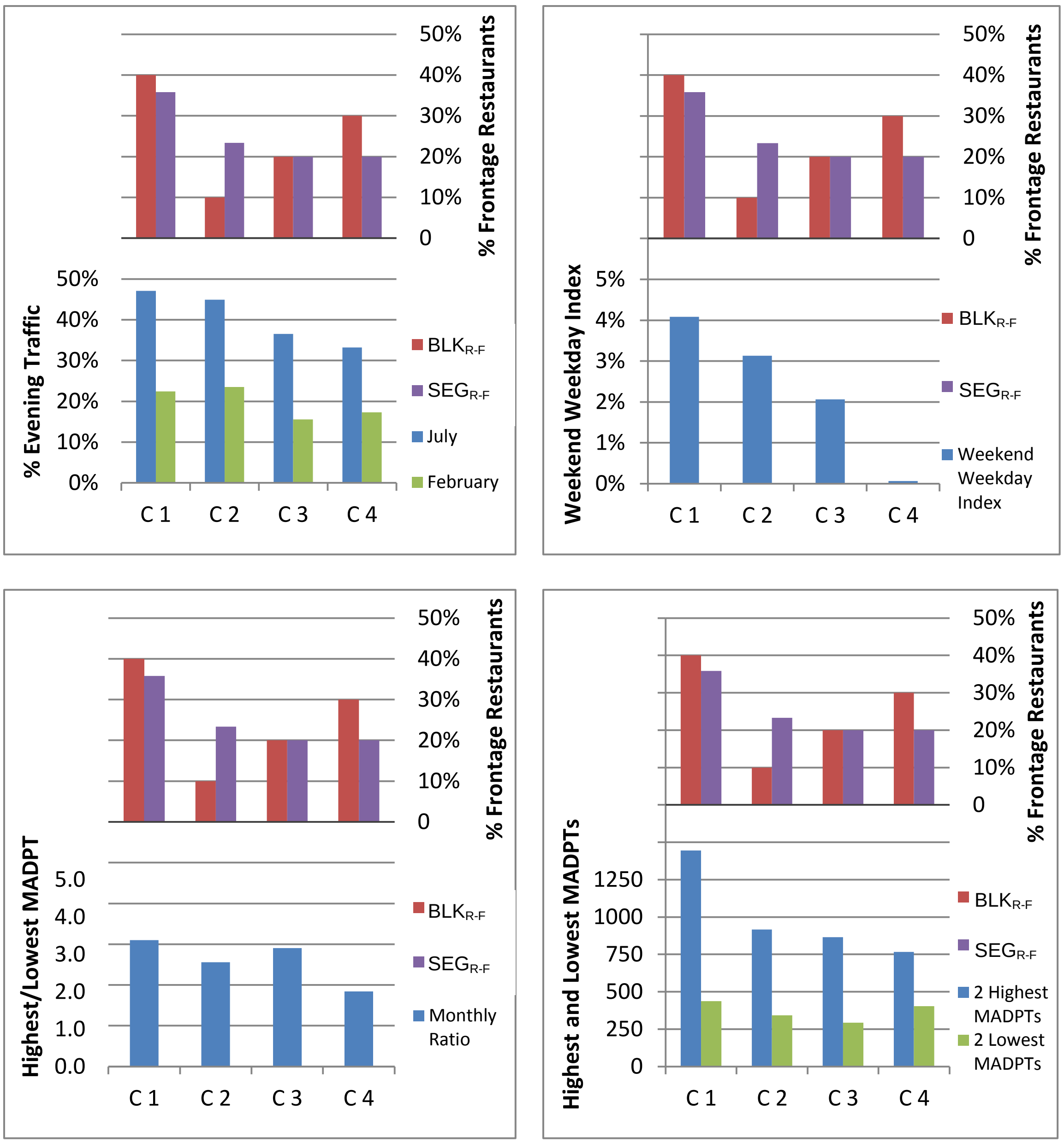


Figure 23: Frontage of Restaurants as a % of Block Length and Pedestrian Traffic Characteristics

4.3.2.4 Licensed restaurant frontage

The sum of the frontage value of licensed restaurant properties was calculated as a percentage of the block length (BLK_{LR-F}) and segment length (SEG_{LR-F}). The frontage values of all licensed restaurants in the study area were approx. 15 m, with the exception of some slightly larger properties on the block east of Cockburn St. and the study area. This consistency leads the distribution in licensed restaurant frontage values to be very similar to the distribution of licensed restaurants across the study area. Analysing individual blocks (BLK_{LR-F}) did not reveal a strong correlation between licensed restaurant frontage and temporal pedestrian traffic patterns or volumes. However, when focusing on a three-block span (SEG_{LR-F}), there were clear similarities. The increase in licensed restaurant frontage from the Corydon 4 segment to the Corydon 1 segment correlates with an increased proportion of traffic during the evening (in the summer), on weekends, and MADPT in warmer months.

There does not appear to be a correlation between the licensed restaurant frontage and the hourly traffic patterns in the winter months or MADPT volumes in the winter, suggesting trip purpose in the winter differs from that seen in the summer months.

Location	Frontage of licensed restaurants as a percentage of block length $BLK_{LR\text{-}F}$	Frontage of licensed restaurants as a percentage of segment length $SEG_{LR\text{-}F}$
	53%	-
Corydon 1	20%	28%
Corydon 2	10%	10%
Corydon 3	0%	7%
Corydon 4	10%	3%
	0%	-

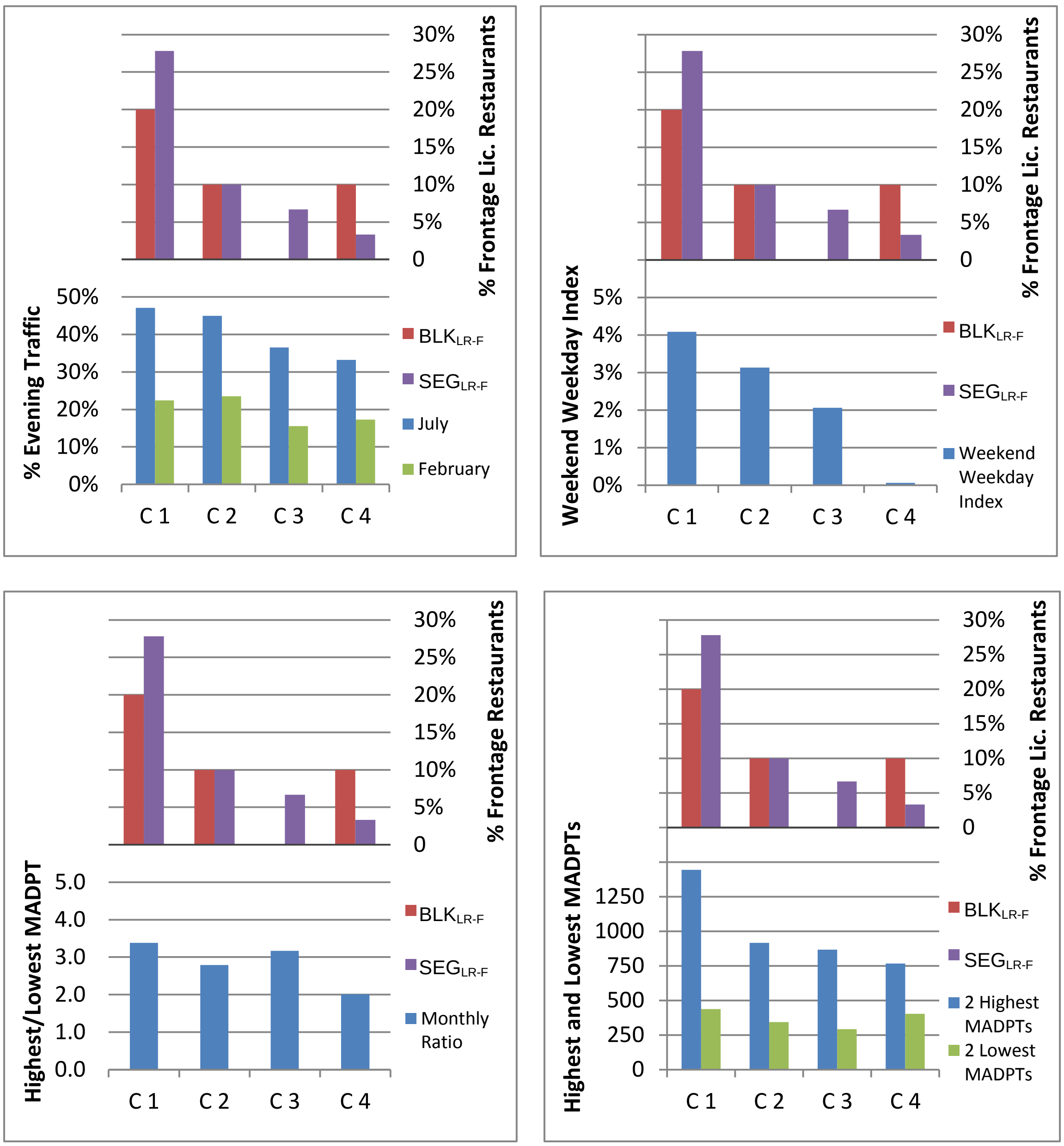


Figure 24: Frontage of Licensed Restaurants as a Percentage of Block Length and Pedestrian Traffic Characteristics

4.3.3 Multi-modal Connections

Corydon Ave is a busy arterial street with on-street parking available for the majority of the study area in each direction. A total of 56% of the westbound direction curb has available on-street parking and 52% in the eastbound direction, combining to measure a total percentage of block length available for on-street parking to be 108%. The availability of on-street parking can affect the distance that pedestrians walk from their vehicle to their intended destination. In addition, buses run along Corydon Ave and the location of bus stops can influence the volume of pedestrians during certain times. Although transit riders and vehicle drivers may not be predominantly thought of as pedestrians, each is a pedestrian when walking from their trip origin to the bus or car, or from their bus or car to their final trip destination. For these reasons, parking availability and bus stops were measured to determine their impact on pedestrian traffic characteristics.

4.3.3.1 On-street parking

The amount of on-street parking on each block was quantified to help compare the differences in built environment and the likelihood of pedestrians originating from on-street parking. The measured on-street parking includes daytime and evening-only on-street parking, meaning this analysis included portions of the street where parking is permitted throughout the day, as well as portions where parking during the certain hours of the day is prohibited, but becomes available in the evening. This is to capture the parking environment during evening pedestrian traffic peaks that are unique to the study area. The on-street parking on both sides of the road was measured and can be seen in Figure 25. The four blocks with APCs had between 80% and 136% on-street parking. A theoretical maximum of 200% parking would indicate on-street parking was available in both directions for the entire length of the block. The block between Cockburn St and

Arbuthnot St had the lowest rate of on-street parking at 80%, meaning there is a combined 122 m of on-street parking along the 152 m segment of Corydon Ave. The most obvious explanation of the differences in on-street parking is the amount of access points to service stations, vehicle repair shops, and small parking lots along a block.

The percentage of on-street parking is shown in Figure 25 along with each of the metrics used for temporal patterns and volumes at each of the counting stations. When the measure of parking was extended from a single block (BLK_P) to include parking along a three-block segment (SEG_P), the ranking of the four study sites remained in the same order. The peak in on-street parking, seen at the Corydon 3 block and segment, does not appear to have a significant effect on the pedestrian traffic behaviour or volumes at the given location. There does not appear to be a correlation between the amount of on-street parking and pedestrian traffic patterns. Even in winter weather, when colder temperatures can entice people to drive instead of walk (King & Badoe, 2007), a greater amount of on-street parking does not correlate with greater pedestrian traffic volumes on the same block. The parking utilization was not within the scope of the research, but it is possible the use of parking spaces could be tied to pedestrian traffic, as high-traffic areas could see their limited parking near capacity and less-busy locations may have plenty of unused parking spaces available.

	Amount of parking		Percentage of block length available as on-street parking	Percentage of segment length available as on-street parking
Location	West-bound (m)	East-bound (m)	(BLK_P)	(SEG_P)
	90	101	125%	-
Corydon 1	47.5	65	80%	102%
Corydon 2	69.5	84	101%	106%
Corydon 3	95	112.5	136%	117%
Corydon 4	119.5	54	114%	115%
	35	0	94%	-

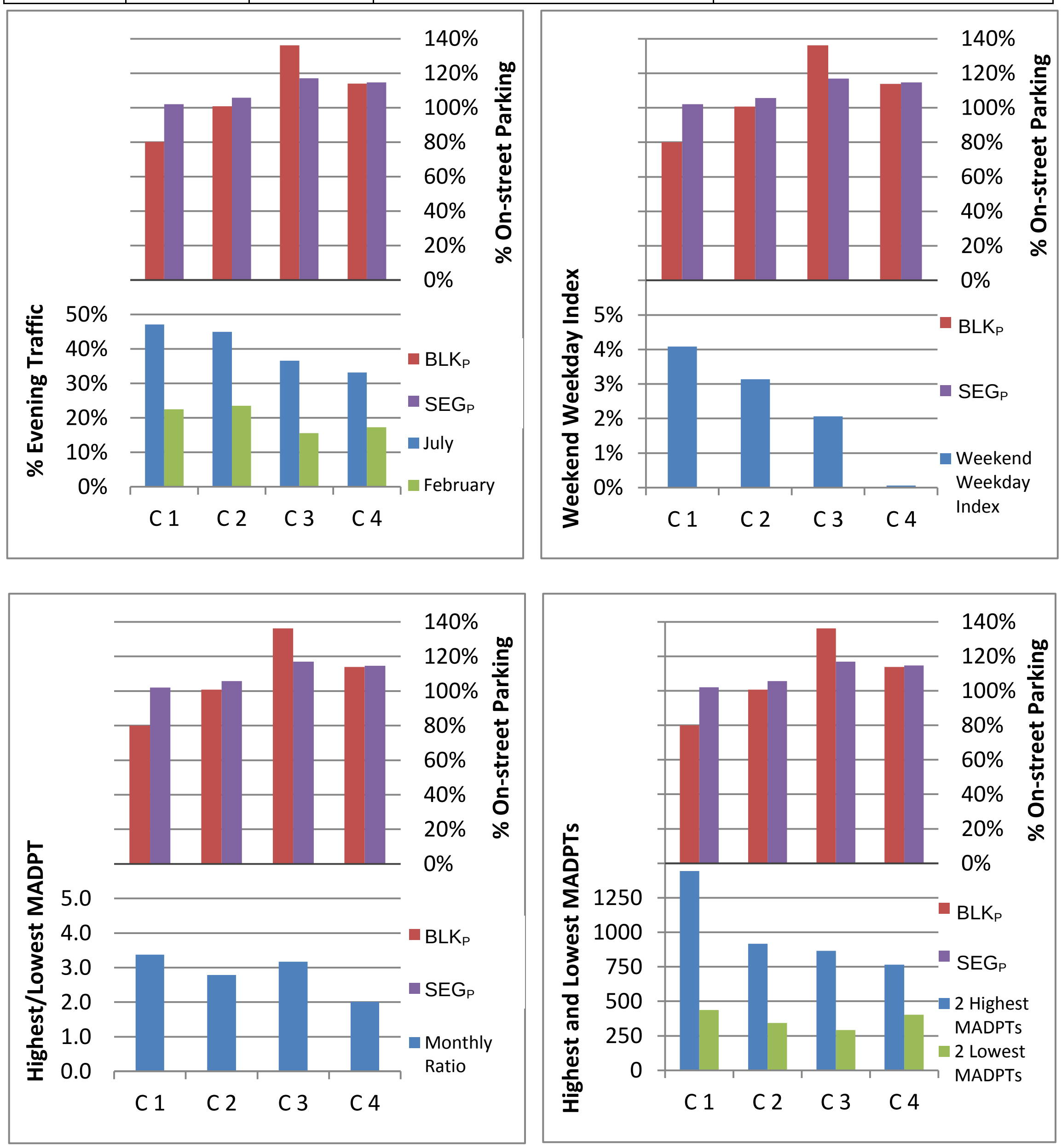


Figure 25: On-street Parking and Pedestrian Traffic Characteristics

4.3.3.2 Bus stops

Bus stops in the study area were identified to evaluate the effect of bus stop location, bus frequency, and different bus routes. A bus stop with more buses and routes is likely to attract more pedestrian traffic. However, the only bus route with stops along any of the four study blocks was Route 18. This route was frequently run during weekdays and weekends, and ran along Corydon Avenue, through downtown Winnipeg, and along Main Street. As shown in Figure 26, the route had five stops within the four block study area, at fairly equal spacing. The high frequency of stops and the fact all the stops were served by the same bus route minimized the impact of bus stops on the collected APC data. Longer gaps between stops and variations in routes would likely affect counter volumes by increasing the transit user's trip length along Corydon to or from the bus stop. The existing transit service did not require a rider to walk more than a single block along Corydon to reach a stop. Due to the proximity of bus stops to each of the APCs and the consistency in service, the bus service was not analysed further.

Figure 26: Winnipeg Transit's Route 18 along Corydon Avenue

4.4 IMPLICATIONS FOR PEDESTRIAN COUNTING

The results of this research improve pedestrian traffic monitoring by contributing to the knowledge base surrounding APC site selection, shifts in pedestrian travel characteristics along a corridor, pedestrian traffic pattern assignment, and APC troubleshooting.

This research assists transportation engineers and professionals by contributing guidance for site selection during a pedestrian traffic monitoring program. This study's analysis of traffic patterns and the built environment on consecutive blocks of a corridor can help transportation professionals better understand the importance and impact of a count's location along a corridor. These correlations between the built environment and pedestrian traffic characteristics can lead to more accurate estimates of pedestrian traffic patterns when comparing sites along a corridor. Using the findings from this research, pedestrian traffic monitoring programs can better identify locations along a corridor with higher daily pedestrian volumes and estimate shifts in temporal traffic patterns. For jurisdictions with pedestrian traffic monitoring programs that rely on count durations of less than 24 hours, this research will assist with scheduling counts in order to record peak traffic periods.

This research will benefit the pedestrian traffic monitoring community by demonstrating the volatility in pedestrian volumes over short distances, and the underlying uncertainties when extrapolating a pedestrian traffic volume to other locations along the corridor. By analysing pedestrian count data from four consecutive blocks along a corridor, this research has shown that despite count sites being located along the same facility and only 160 m apart, average daily pedestrian volumes can fluctuate by over 75% between sites. This provides justification to conduct a pedestrian traffic count at a previously uncounted location rather than assume traffic volumes based on nearby counts. More accurate traffic estimates will lead to better inputs for decision-making.

The identification of an entertainment pedestrian traffic pattern contributes to current practice by presenting an urban pedestrian traffic pattern distinctive to entertainment districts with many restaurants and bars. Until this research, there has been minimal research to identify pedestrian traffic patterns on sidewalks. When setting up a pedestrian traffic monitoring program, jurisdictions will be aware of an additional traffic pattern that would require its own set of factors to expand short term counts.

Lastly, this research identifies issues that can disrupt automated pedestrian counting data collection. By documenting challenges that arose in data collection, non-motorized traffic monitoring programs can anticipate similar issues and prepare to prevent or minimize interference or poor data in the data collection process. Clearer owner identification on APC devices, regularly scheduled site visits, and regular data checks, among others, can increase efficiency by ensuring counting programs minimize the quantity of lost or poor data.

5 CONCLUSION

This chapter discusses the research findings and identifies opportunities for future research. The purpose of this research was to analyze pedestrian traffic patterns and volumes along a corridor and identify factors in the built environment that led to these patterns. This research analysed 12 months of hourly pedestrian volumes at three locations equipped with automated counters on consecutive blocks along a corridor in Winnipeg, Manitoba, Canada. A fourth counter was installed on an adjacent block along the same corridor and collected hourly pedestrian traffic data for seven months. The data along the four blocks of Corydon Ave exhibit varying volumes and temporal patterns of pedestrian traffic, demonstrating the possible error in extrapolating pedestrian traffic from one location over a span of multiple blocks.

5.1 ENTERTAINMENT TRAFFIC PATTERN

This research identified a traffic pattern in the study area unique to previously documented pedestrian traffic patterns. This *entertainment traffic pattern* has hourly peaks in the late evening, and has the highest volumes of pedestrian traffic on Fridays and Saturdays. The observed traffic pattern differed from the conventional commuter patterns by the position of hourly traffic peaks during the day. Commuter patterns are known for morning and afternoon peaks centered around a 9-5 workday, and less traffic on weekends. Recreational traffic patterns are known for high afternoon traffic levels, and high weekend volumes compared to week days.

- This research identified heavy evening traffic as a key characteristic of an entertainment traffic pattern. Locations with an entertainment pedestrian traffic pattern exhibited a bimodal hourly pedestrian traffic distribution with a small peak at noon and another, larger, peak around 8 p.m. Fridays and Saturdays saw very large peaks in the evening, around 8 or 9 p.m. During the winter months, the presence of the entertainment pedestrian traffic pattern's hourly characteristics subsided. Evening traffic decreased enough to eliminate the evening traffic peak, and instead exhibited similar peaks at noon and 4 p.m.

- The entertainment traffic pattern exhibited the greatest daily pedestrian volumes on Fridays and Saturdays, averaging 16.9 and 17.6% of the weekly pedestrian volume, respectively, at the Corydon 1 APC location. During the winter months, locations that exhibited strong entertainment traffic patterns in the summer saw decreases in the proportion of weekly traffic seen on Saturdays. This shift in day-of-week pedestrian traffic distribution leads to peak volumes occurring on Fridays instead of Saturdays.

- All four APC locations in the study area saw large increases in pedestrian traffic in the summer months compared to the winter. Each location saw the lowest volumes of pedestrian traffic in February. At the three locations with 12 months of data, the months November to February exhibited the lowest volumes, before there was a large increase in pedestrian volumes in March. The summer traffic volumes between sites lacked the same consistency seen during the winter months, supporting the idea that pedestrian traffic in Winnipeg converges to a more general traffic pattern in the winter months across different locations.

- Peak hours for pedestrian traffic volumes can vary seasonally. At multiple count locations in this research, the peak hour for pedestrian traffic occurred at 8 p.m. during summer months. In winter months, peaks in hourly pedestrian traffic were seen at 12 p.m. and 4 p.m. This is an indication that a count location may exhibit multiple traffic patterns over the course of a year.

5.2 SHIFTS IN TRAFFIC PATTERNS AND VOLUMES ALONG A CORRIDOR

Pedestrian traffic patterns are volatile, and even within close spatial proximity, the temporal traffic patterns can have large shifts. The representative area of a single APC location has been shown to be as small as a single city block, indicating the importance of counter placement.

- Over the study area, the Corydon 1 APC location exhibited the strongest entertainment pedestrian traffic pattern. The three other APC locations showed a gradually weaker entertainment traffic pattern the further west they were located, indicating gradual transitions occur between locations with different pedestrian traffic patterns.

- Pedestrian volumes varied significantly between sites. The Corydon 1 block had a peak MADPT of 1451 daily pedestrians in June. Meanwhile, the Corydon 2 location, one block west along the same corridor, had a peak MADPT in August of 931 pedestrians. This finding indicates that locations along the same corridor and within close proximity to one another can have much different levels of pedestrian traffic.

- The observed shift in hourly, day of week, and seasonal pedestrian traffic patterns over a four block span indicates that extreme due diligence must be taken when comparing short term pedestrian counts between locations. Without known temporal traffic patterns, short term counts less than 7 days are not reliable measures for comparing pedestrian volumes between sites.

- Assumptions that a particular short term count will contain a constant proportion of daily traffic cannot be applied at all sites. Short term counts are often conducted during the day, and are susceptible to missing a large portion of pedestrians if the count location is home to heavy evening pedestrian traffic. The entertainment traffic pattern identified in this research has peak pedestrian hourly traffic at 8 p.m. and it would therefore be inappropriate to miss the peak pedestrian periods when scheduling counts.

- When sites have different hourly traffic patterns, a location with high daytime volumes and low evening volumes could be easily misinterpreted to have more pedestrian traffic than a site that has slightly less daytime volumes but significantly greater evening volumes.

- Pedestrian traffic in colder months has the lowest monthly average factors, but despite reduced volumes, it is a better predictor of AADPT due to its consistency across count locations.

5.3 FACTORS INFLUENCING TRAFFIC PATTERNS AND VOLUMES

This research analysed characteristics of the built environment to determine factors that influence temporal pedestrian traffic patterns and volumes at a count location. The APCs were placed on consecutive blocks along a corridor, providing constant motorized traffic volumes and population density between the sites. The correlation between measures of the entertainment traffic pattern and variables such as restaurants, restaurants licensed to serve alcohol, and on-street parking were studied to understand the effect of site selection of APCs.

- Analysing built environment characteristics on a three-block segment often showed a stronger correlation with pedestrian traffic characteristics than only analysing a single block's built environment. Longer segments would lead to more overlap, and less variation, in built environment features. This indicates that although three-block segments are beneficial, extending segments lengths beyond three blocks would quickly dilute the differences in the built environment between nearby count locations and draw weaker conclusions.

- There is no correlation between the frequency or total property frontage of restaurants or licensed restaurants on a single block and the pedestrian traffic on that block. This is evidence that trip attractors or producers on adjacent blocks are responsible for a significant proportion of pedestrian traffic at any particular location.

- The number of restaurants on a three-block span centered around a count location has a strong positive correlation with the percentage of pedestrian traffic occurring on summer evenings, the increase in daily pedestrian traffic on Fridays and Saturdays over Monday to Thursday traffic, and MADPT volumes in the summer. There was not a correlation with winter evening traffic, the variance in MADPT, or winter MADPTs.

- The number of restaurants licensed to serve alcohol on the same block and within one adjacent block has a strong positive correlation with the percentage of pedestrian traffic occurring on summer evenings, the increase in daily pedestrian traffic on Fridays and Saturdays over Monday to Thursday traffic, and MADPT volumes in the summer. There was not a correlation with winter evening traffic, the variance in MADPT, or winter MADPTs.

- The sum of property frontage for restaurants along Corydon Ave. on a three-block span centered around a count location has a strong positive correlation with the percentage of traffic occurring on summer evenings, the increase in daily pedestrian traffic on Fridays and Saturdays over Monday to Thursday traffic, and MADPT volumes in the summer. There was not a correlation with winter evening traffic, the variance in MADPT, or winter MADPTs. This means that the size of the restaurants in the study area can be measured to help estimate relative traffic patterns and volumes along a corridor. However, the restaurant frontage values did not provide a noticeable improvement over analysing the number of restaurants.

- The sum of the property frontage for licensed restaurants along Corydon Ave. on the same block and a three-block segment has a medium strength positive correlation with the percentage of traffic occurring on summer evenings, the increase in daily pedestrian traffic on Fridays and Saturdays over Monday to Thursday traffic, and MADPT volumes in the summer. There was not a correlation with winter evening traffic, the variance in MADPT, or winter MADPTs. This means that the size of the licensed restaurants in the study area can be measured to help estimate relative traffic patterns and volumes along a corridor. However, the restaurant frontage values did not provide an improvement over easier analysis of the number of licensed restaurants.

- The percentage of a block with available on-street parking displayed a weak negative correlation with the proportion of daily traffic occurring in the evening, the increase in daily pedestrian traffic on Fridays and Saturdays over Monday to Thursday traffic, and summer MADPTs. The quantity of on-street parking did not vary significantly over the study area, limiting the strength of any conclusions involving on-street parking.

- The likelihood of the presence of an entertainment pedestrian traffic pattern defined by high levels of evening traffic, heavier traffic on Fridays and Saturdays, and overall daily volumes can be compared between locations along the same corridor by evaluating the number of restaurants and licensed restaurants surrounding each location.

5.4 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Limitations to this research include the placement of APCs, the number of available APCs, and equipment maintenance. As explained in Section 3.2, site selection was limited to locations that facilitated the installation of APCs. This requirement influenced what blocks could be included in the study, and eliminated potential counting locations that may have offered stronger examples of an entertainment pedestrian traffic patterns. The availability of APCs restricted the research from evaluating more count locations and corridors. With only three locations with a full year of data, and a fourth with seven months, there is uncertainty whether the results would be replicated along another corridor with similar characteristics. Monitoring pedestrian traffic at other similar corridors would improve the validity of the study results by determining the applicability of the findings from this study area to other entertainment districts within Winnipeg. It was expected when the study area was selected that the resulting pedestrian traffic patterns would differ from those that have been identified in past research across North America. It is therefore possible that there are many other unique traffic patterns present in a city that have not been identified in past research, and local experience and judgement are valuable in developing pedestrian traffic monitoring programs.

Another limitation to the study is the large number of days of erroneous or missing data. A setback to using Eco-Counter Pyro box APCs is not being able to diagnose a dying battery until it stops working. Each time a battery died (three occurrences), a new battery had to be ordered from outside the province and several days of data collection were missed. As the APCs were under warranty, the APC battery needed to be completely dead before replacement battery was shipped. Having replacement batteries for the APCs on hand would reduce the replacement time, and the counters could be functioning again almost immediately.

This research provides new opportunities for research in pedestrian traffic monitoring.

- Stronger or different entertainment pedestrian patterns likely exist outside of the study area. The easternmost APC in the study area showed the strongest entertainment pedestrian traffic pattern. Based on local experience and the built environment, it is likely that one block further east would have exhibited greater proportions of traffic in the evenings and on weekends. Additional research is needed to strengthen the classification of an entertainment pedestrian traffic pattern through the analysis of other locations that have traffic peaks at different times of the day or days of the week.

- This research showed correlations between characteristics of the built environment and pedestrian traffic patterns and volumes. There are many features of the built environment not present in the study area that could contribute to an evening pedestrian pattern. Businesses such as movie theatres, night clubs, concert venues, and bowling alleys, among others, could contribute to an entertainment traffic pattern, but were not present in the study area to be analysed.

- Pedestrian traffic patterns in the study area changed over the course of the year. In the winter, the entertainment traffic pattern that was present in the summer shifted to more of a commuter pattern. The proportion of traffic in the evening dropped, and the proportion of weekly traffic on Saturdays decreased. Future research can determine whether this phenomenon is specific to this study area or if all locations and summer traffic patterns are affected equally.

- Lastly, this research lays the groundwork for future research on the shifts in traffic patterns and volumes over a grid network, compared to a single corridor. It is still unknown if traffic along a corridor correlates with traffic along intersecting streets, or parallel streets.

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APPENDIX A – PEDESTRIAN TRAFFIC DATA

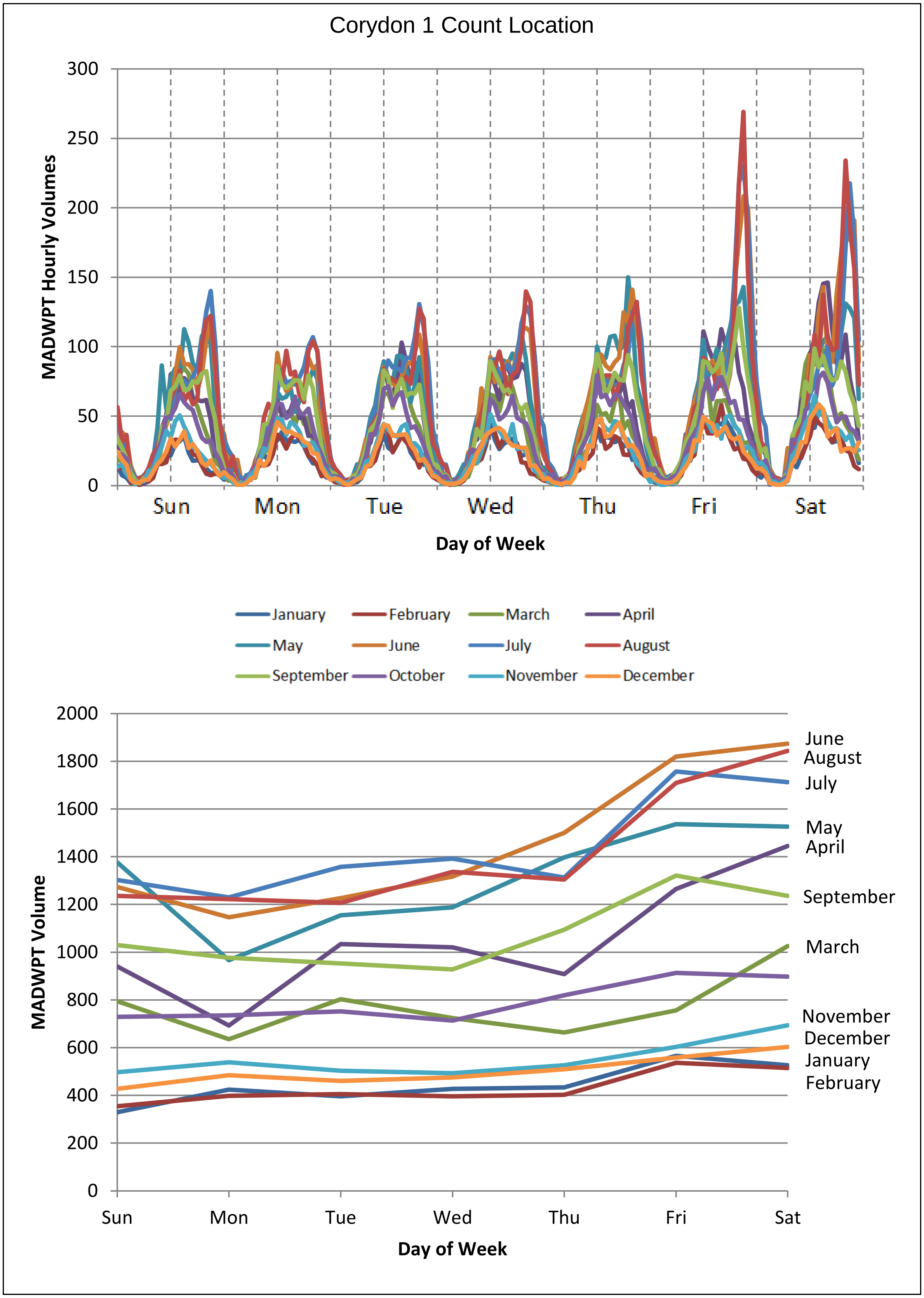

Figure 27: Pedestrian traffic at the Corydon 1 count location

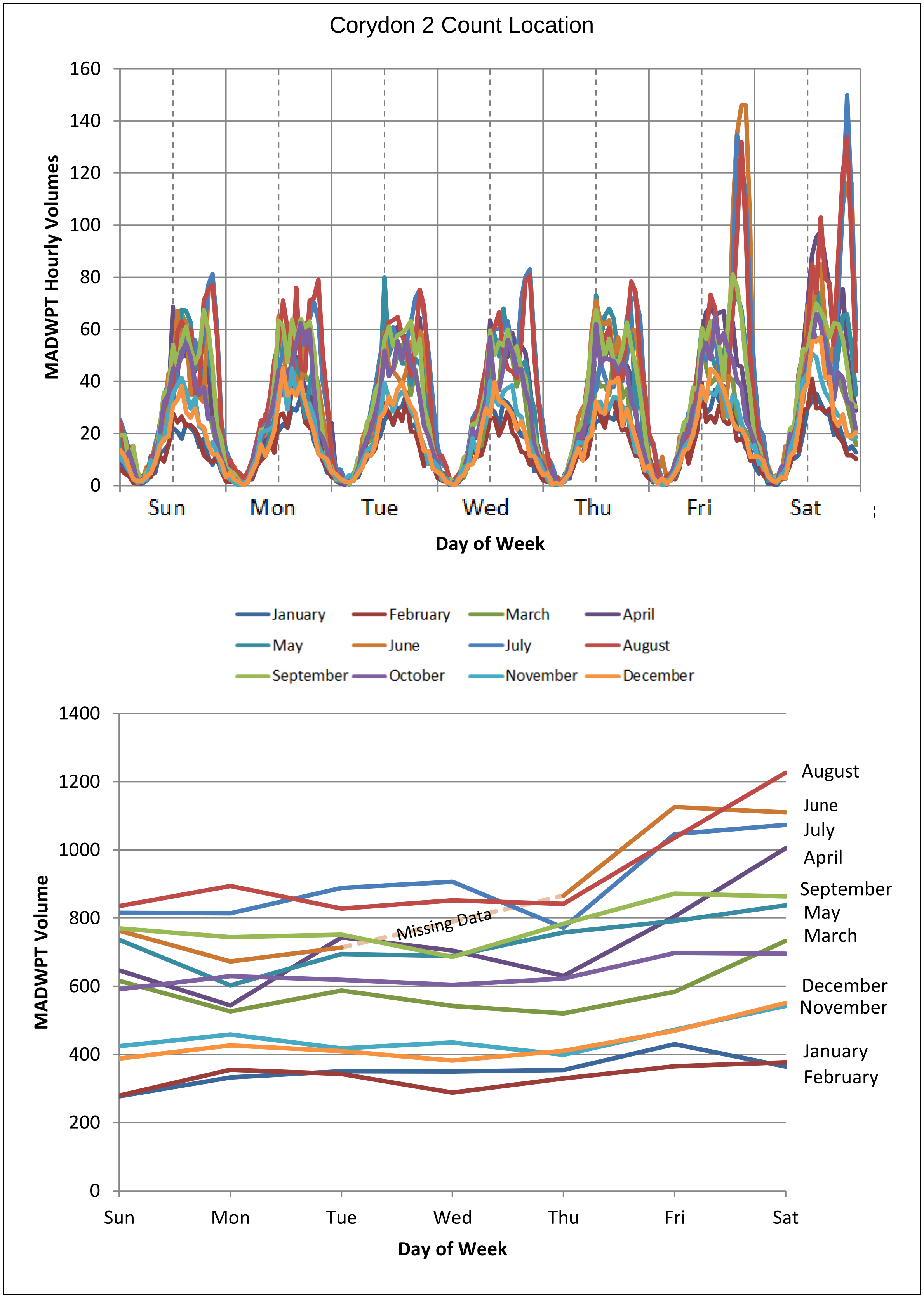

Figure 28: Pedestrian traffic at the Corydon 2 count location

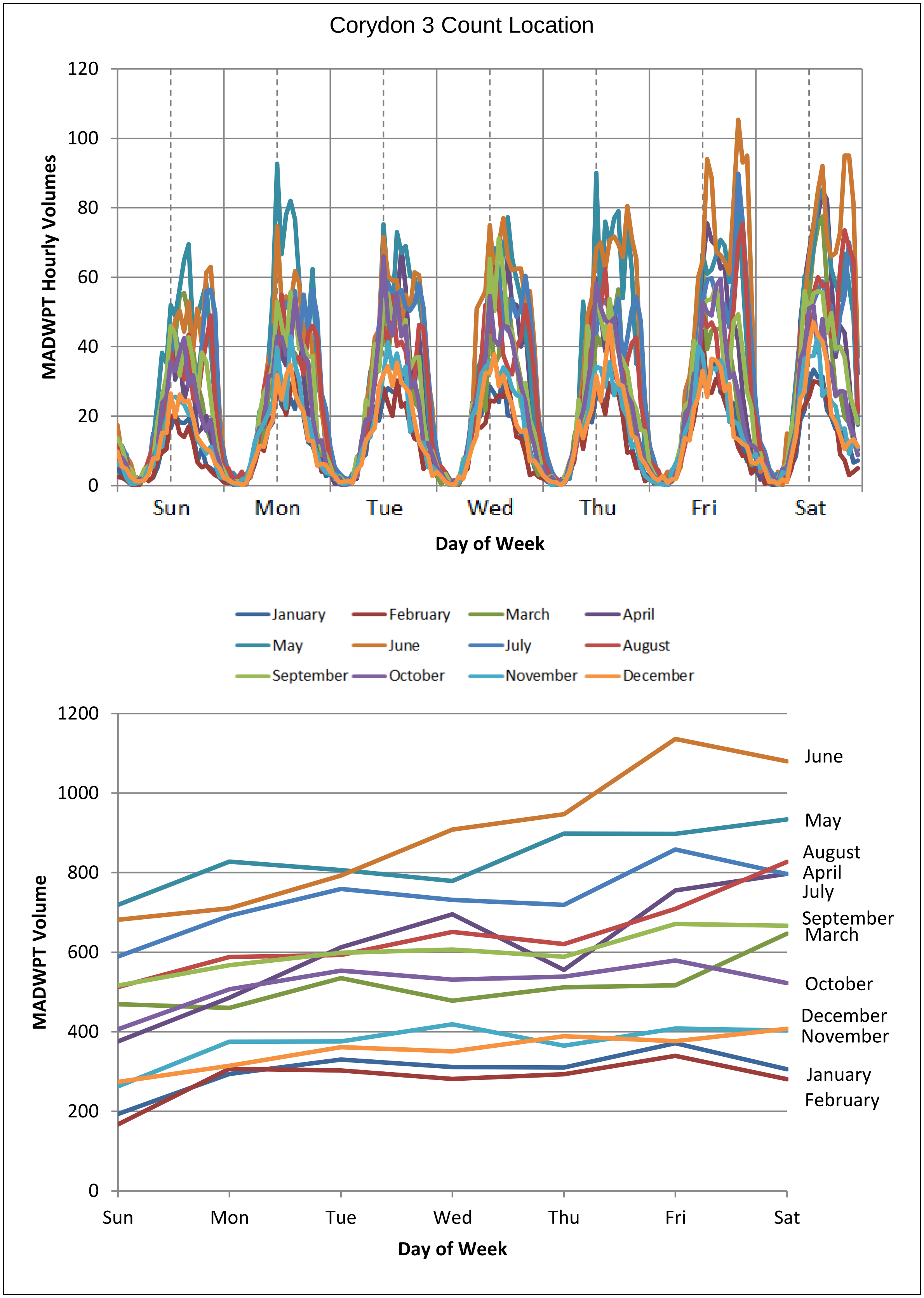

Figure 29: Pedestrian traffic at the Corydon 3 count location

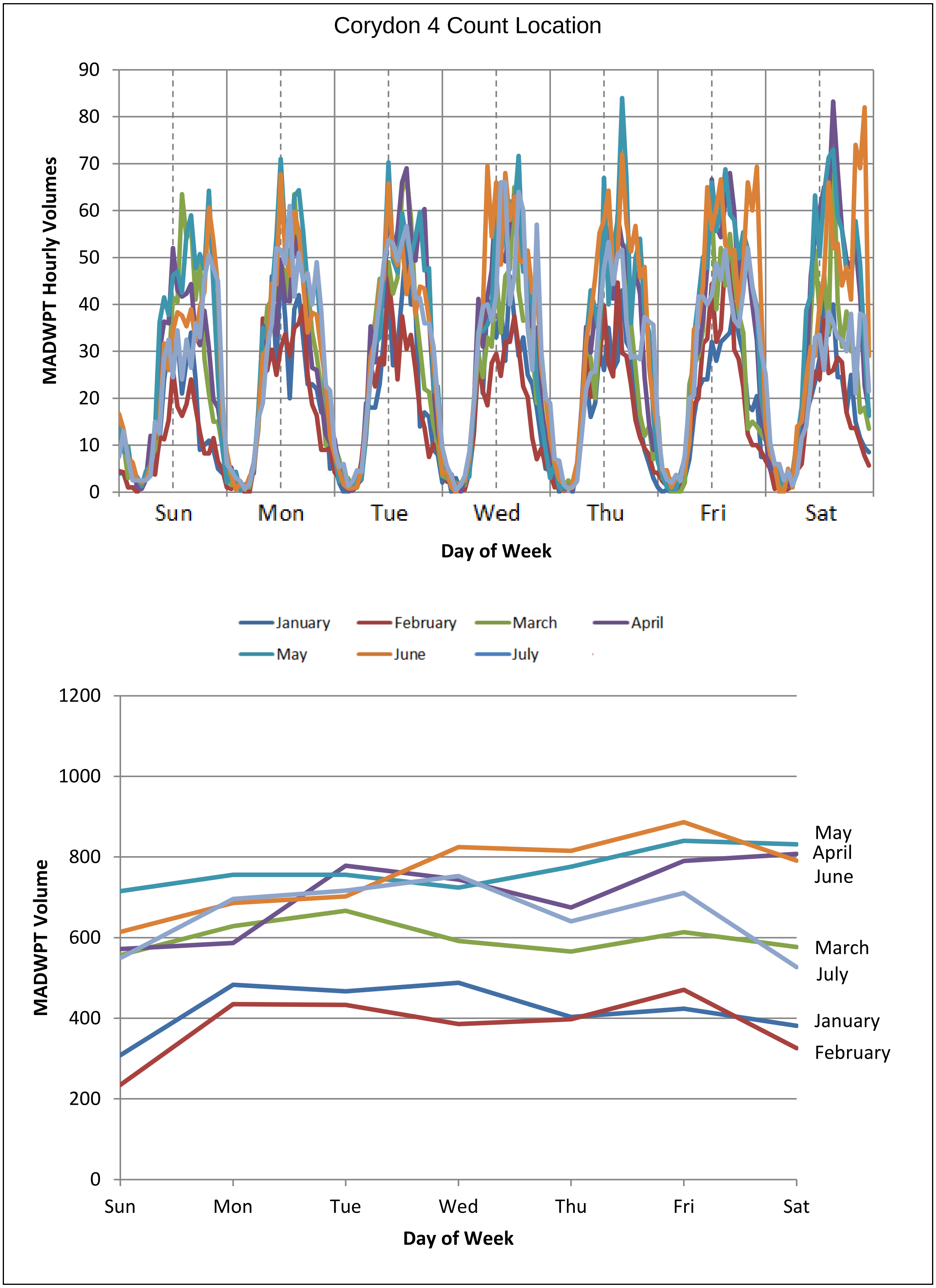

Figure 30: Pedestrian traffic at the Corydon 4 count location